Sunrise Wind Farm Project

Underwater Noise and Exposure Modeling

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Sunrise Wind LLC

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This report supports both BOEM and NOAA Fisheries/MMPA permit processes. Results presented here are preliminary and have not been subject to NOAA Fisheries OPR review as part of the MMPA process. NOAA Fisheries OPR may request changes that lead to revised results. A final report will be provided to BOEM upon completion of the NOAA Fisheries review process and in advance of publication of the Draft EIS.

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Acronyms and Abbreviations

ANSI	American National Standards Institute
APE	American Piledriving Equipment
BMP	best management practice
BOEM	Bureau of Ocean Energy Management
BRAHSS	Behavioral Response of Australian Humpback whales (Megaptera novaeangliae) to Seismic Surveys
CPA	closest point of approach
COP	Construction and Operations Plan
dB	decibels
DC	direct current
DP	dynamic positioning
EEZ	Exclusive Economic Zone
$ER_{95\%}$	95% exposure range
ESA	Endangered Species Act
FM	frequency-modulated
FWRAM	Full Wave Range Dependent Acoustic Model
GDEM	Generalized Digital Environmental Model
h	hour
HDD	horizontal directional drilling
HF	high frequency (cetacean hearing group)
HRG	high resolution geophysical (survey)
Hz	hertz
IAC	Inter-Array Cables
JASCO	JASCO Applied Sciences
JASMINE	JASCO Animal Simulation Model Including Noise Exposure
kg	kilogram
kHz	kilohertz
kJ	kilojoule
km	kilometer
LF	low frequency (cetacean hearing group)
m	meter
mm	millimeter
m/s	meters per second
MA	Massachusetts State
MF	mid-frequency (cetacean hearing group)
MMPA	Marine Mammal Protection Act
MONM	Marine Operations Noise Model
NARW	North Atlantic right whale
NAS	noise abatement system
nm	nautical mile
NMFS	National Marine Fisheries Service (also known as NOAA Fisheries)
NMS	noise mitigation system
NOAA	National Oceanic and Atmospheric Administration
NODE	Navy Operating Area Density Estimate
NY	New York
OCS	Outer Continental Shelf
OCS–DC	Offshore Converter Station
OSP	Optimum Sustainable Population
PDSM	Pile Driving Source Model
PE	parabolic equation
PK	zero-to-peak sound pressure level
PPW	phocid (pinniped) in water (hearing group)
Project	Sunrise Wind Farm Project
PTS	permanent (hearing) threshold shift
PW	phocid (seal) in water (hearing group)
RAM	Range-dependent Acoustic Model
RI	Rhode Island State
rms	root mean square
SC	species of concern
SEL	sound exposure level
SELcum	cumulative sound exposure level
SERDP-SDSS	Strategic Environmental Research and Development Program Spatial Decision Support System
SGCN	Species of greatest conservation need
SL	source level
SPL	root-mean-square sound pressure level
SRTM	Shuttle Radar Topography Mission
SRWEC	Sunrise Wind Export Cable
SRWF	Sunrise Wind Farm
TL	transmission loss
TTS	temporary (hearing) threshold shift
TU	sea turtles in water (hearing group)
WEA	Wind Energy Area
WTG	wind turbine generator
μPa	micropascal

Executive Summary

Sunrise Wind LLC (Sunrise Wind), a 50/50 joint venture between Orsted North America Inc. and Eversource Investment LLC, proposes to construct, own, and operate the Sunrise Wind Farm Project in the designated Bureau of Ocean Energy Management Renewable Energy Lease Area OCS-A 0487. The Sunrise Wind Farm includes up to 95 foundations consisting of wind turbine generators (WTGs) and an Offshore Converter Station (OCS–DC), as well as Inter-Array Cables connecting the WTGs and OCS–DC. The Sunrise Wind Export Cable includes one submarine export cable bundle comprised of two cables located within an up to 104.7-mi (168.5-km)-long. The WTGs will each be supported by a tapered monopile foundation (7 meter [m] top diameter, 12 m bottom diameter). The OCS–DC will be supported by a four-legged jacket foundation. The Project will also require casing pipe installation and pile driving of sheet piles (referred to as goal posts) to support horizontal directional drilling (HDD) activities in New York state waters.

Underwater noise associated with the construction of offshore components of the Sunrise Wind Farm will predominantly result from impact pile driving for the monopile and jacket foundations. Underwater noise associated with the construction of the Sunrise Wind Export Cable will primarily result from impact pile driving for the casing pipe and vibratory pile driving of the goal posts needed for the Landfall HDD construction. A quantitative assessment of the sounds produced by pile driving was undertaken in this study.

WTG monopile foundations consisting of a single pile, tapered from 7 to 12 m in diameter, were modeled at two representative locations in the lease area. A four-legged OCS-DC jacket foundation consisting of 8 pin piles (2 pin piles per jacket leg), each 4 m in diameter, was modelled at one representative location in the lease area. Installation of 1.2 m casing pipes and goal posts were modeled at one representative location. Forcing functions for impact pile driving (for the monopiles, jacket piles, and casing pipes) were computed for each pile type using GRLWEAP (GRLWEAP, Pile Dynamics 2010). The resulting forcing functions were used as inputs to JASCO's impact pile driving source model (PDSM) to characterize the sounds generated by the piles, and acoustic sound fields were computed using JASCO's Full-Wave, Range-Dependent Acoustic Model. To account for the likely minimum sound reduction resulting from noise abatement systems (NAS), such as bubble curtains, the modeling study included hypothetical broadband attenuation levels of 0, 6, 10, and 15 dB for monopile and jacket pile acoustic modeling results. Based on a recent analysis of NAS (Bellmann et al. 2020b), the 10 dB level was conservatively chosen as an achievable sound reduction level when one NAS is in use during pile driving, and is highlighted in this analysis. Sound fields for vibratory pile driving of the goal posts were modeled by propagating measured sound spectra using a range-dependent acoustic model. No NAS was considered for vibratory driving.

For installation of monopile and jacket foundations, the number of individual animals that may be affected and the associated monitoring distances (exposure and acoustic ranges) for mitigation purposes were determined using JASCO's animal movement modeling software (JASMINE). JASMINE integrates the computed sound fields with species-typical movement (e.g., dive patterns) to estimate received sound levels for modeled marine mammals and sea turtles that may occur near the construction area. Using the time history of the received levels, exposure ranges accounting for 95% of exposures above injury and behavioral disruption thresholds (NMFS 2018, McCauley et al. 2000b, Finneran et al. 2017) were calculated.

Exposure estimates and exposure ranges for monopile and jacket foundation installation were calculated for five different construction schedules. Construction schedules 1 and 2 represent traditional, sequential operations with one pile driving vessel (operating one hammer). Construction schedule 1 assumes two monopiles are driven each day and construction schedule 2 assumes three monopiles are driven each day. Construction schedules 3, 4, and 5 represent potential concurrent operation of two pile driving vessels (each vessel operating one hammer). Construction schedule 3 assumes two concurrently operating monopile installation vessels, each installing two piles per day, and that they are operating near each other. Construction schedule 4 is the same as 3 except that the vessels are operating a greater distance from each other. Construction schedule 5 assumes installation of a jacket foundation while a separate vessel is concurrently installing monopile foundations, and that they are operating near each other. It was found that concurrent operations may (marginally) increase the overall number of injuries because more piles are installed per day. It was also found that concurrent operations could reduce the number of behavioral disruptions because the Project would be completed faster.

Fish were considered static receivers, so only the acoustic range to their regulatory thresholds (GARFO 2019) were calculated. Exposure ranges (for marine mammals and sea turtles) and acoustic ranges (fish) are reported for various levels (0, 6, 10, and 15 dB) of broadband attenuation that could be expected from the use of mitigation systems such as a bubble curtain. Acoustic ranges for casing pipe and goal post installation without attenuation were calculated for marine mammals, sea turtles, and fish.

1. Introduction

1.1. Project Background and Overview of Assessed Activity

Sunrise Wind LLC (Sunrise Wind), a 50/50 joint venture between Orsted North America Inc. and Eversource Investment LLC, proposes to construct, own, and operate the Sunrise Wind Farm Project (the Project). The Sunrise Wind Farm (SRWF) will be located on the Outer Continental Shelf (OCS) in the designated Bureau of Ocean Energy Management (BOEM) Renewable Energy Lease Area OCS-A 0487[1] (Lease Area). The Lease Area is approximately 16.4 nautical miles (nm) (30.4 kilometers [km]) south of Martha's Vineyard, Massachusetts, approximately 26.1 nm (48.2 km) east of Montauk, New York (NY), and 14.5 nm (26.8 km) from Block Island, Rhode Island. The Lease Area contains portions of areas that were originally awarded through the BOEM competitive renewable energy lease auctions of the Wind Energy Areas (WEAs) off the shores of Rhode Island and Massachusetts. Other components of the Project will be located in federal waters on the OCS, in state waters of New York, and onshore in the Town of Brookhaven, Long Island, NY. The proposed interconnection location for the Project is the Holbrook Substation, which is owned and operated by Long Island Power Authority. Sunrise Wind executed a contract with the New York State Energy Research and Development Authority for a 25-year Offshore Wind Renewable Energy Certificate Agreement in October 2019.

The Project will be comprised of the following offshore infrastructure, collectively referred to as the SRWF and Sunrise Wind Export Cable (SRWEC) (Figure 1.1-1):

- Up to 94 wind turbine generators (WTGs) at 102 potential locations;
- One Offshore Converter Station with direct current electrical technology (OCS–DC);
- Up to 95 foundations (for WTGs and the OCS–DC);
- Up to 290 km of Inter-Array Cables (IAC); and
- One SRWEC comprised of two cables located within an up to 168.5 km-long corridor with a horizontal directional drill (HDD) exit pit in NY state waters.

A range of offshore Project designs are being considered to allow for assessment of proposed activities and the flexibility to make development decisions prior to construction. The Project Design Envelope involves several scenarios with potential underwater noise impacts that are associated with offshore construction activities. This Underwater Noise and Exposure Modeling assessment considers the information available at this time; the precise locations, noise sources, and schedule of the construction and operation scenarios may be subject to change as the engineering design progresses.

As it pertains to underwater noise, the primary sources associated with the Project construction are impact (impulsive) pile driving during offshore WTG and OCS–DC foundation and nearshore casing pipe installation, and vibratory (non-impulsive) pile driving of supportive HDD sheet piles (hereafter referred to as goal posts). Secondary sound sources also contribute to overall Project noise and are associated with other construction and operational activities. These secondary sources are non-impulsive (dredging, drilling, dynamic positioning [DP] thrusters) and continuous (vessel propulsion, turbine operation) sound to the environment.

[1] A portion of Lease Area OCS-A 0500 (Bay State Wind LLC) and the entirety of Lease Area OCS-A 0487 (formerly Deepwater Wind New England LLC) were assigned to Sunrise Wind LLC on September 3, 2020, and the two areas were merged and a revised Lease OCS-A 0487 was issued on March 15, 2021. Thus, when using the term "Lease Area" within this report, the term refers to the new merged Lease Area OCS-A 0487.

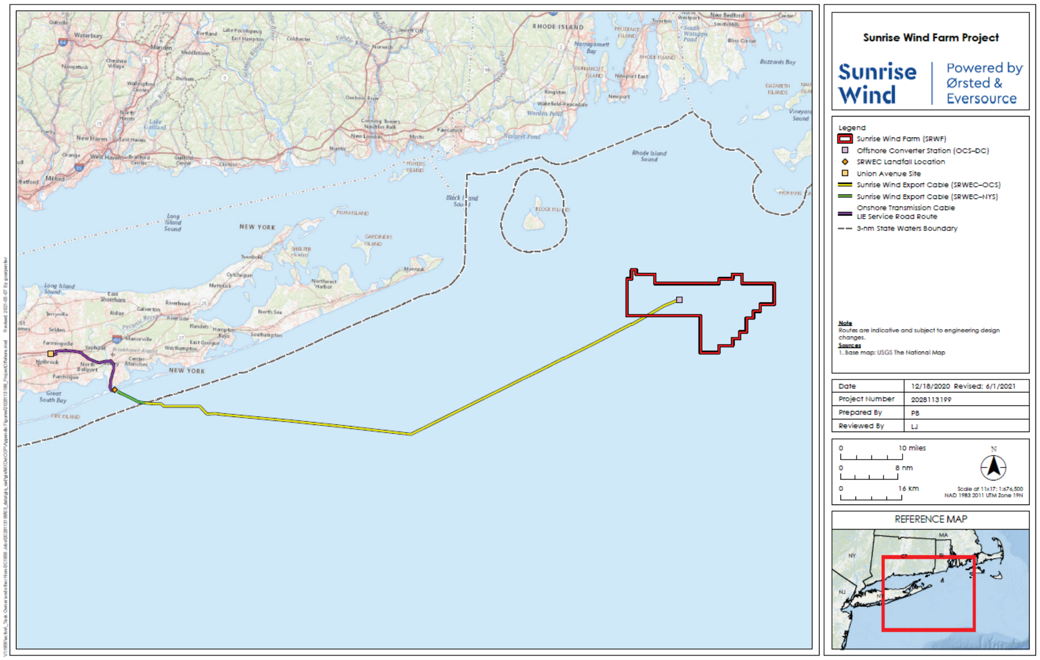

Figure 1.1-1. Sunrise Wind Farm (SRWF) and Sunrise Wind Export Cable (SRWEC) locations.

1.2. Modeling Scope and Assumptions

The objective of this underwater noise assessment is to estimate the number of marine mammals and sea turtles predicted to experience sound levels exceeding regulatory thresholds and to calculate exposure ranges for foundation installation and acoustic ranges for all pile driving (foundation, casing pipe and goal post installation). For fish, acoustic ranges to their regulatory acoustic thresholds predicting injury and behavioral disturbance were calculated.

JASCO Applied Sciences (JASCO), modeled the potential underwater acoustic impacts resulting from the installation of the following:

- Tapered monopiles that have a 7 meter [m] diameter at the expected waterline and 12 m diameter at the mudline (7/12 m monopile);
- Pin piles 4 m in diameter for jacket foundations;
- Casing pipes up to 137.16 m long and 1.2 m in diameter; and
- Goal posts made up of sheet piles, with each pile up to 30 m in length and 600 mm wide.

Sections 1.2.1 and 1.2.2 describe the pile driving hammer energy settings and number of strikes/duration for the expected (weekly) impact and vibratory hammering, respectively. Section 1.2.3 describes the construction schedule assumptions used in predicting the number of exposures for each species. The results in this report are presented as zero-to-peak sound pressure levels (PK), single-strike (i.e., per-pulse) and accumulated sound exposure levels (SEL), and sound pressure levels (SPL). Section 2 explains the metrics used to represent underwater acoustic fields, the impact criteria considered, and the approaches used for acoustic and animal movement modeling. Section 3 considers potential impacts to representative marine species, Section 4 provides results of the modeling, and Section 4.5.2.2 provides a summary.

Although up to 94 WTGs are expected to be installed, Sunrise Wind has accounted for up to 8 potential locations where WTG installation is unable to be completed due to environmental or engineering constraints (i.e., only 94 WTGs will be installed, but the Project Design Envelope includes seafloor preparation and foundation installation activities at 102 potential locations).

1.2.1. Impact Pile Driving

1.2.1.1. Monopile Foundation

A monopile used as a foundation in a wind farm is a single hollow cylinder fabricated from steel that is installed by driving (hammering) it into the seabed. The 7/12 m monopiles proposed for the SRWF represent the expected maximum size of a monopile that will be installed within the Project Design Envelope as WTG foundations. The 7/12 m monopiles include a tapered section near the water line (nominal dimensions shown in Table 1.2-1). Sound fields from the 7/12 m monopiles were modeled at two representative locations in the SRWF: ID-97 and ID-259 in order to sample the water depth variation within the Project Area (Figure 1.2-1, Table 1.2-2). The 7/12 m monopiles were assumed to be vertical and driven to a maximum expected penetration depth of 50 m.

Table 1.2-1. Nominal dimensions of the 7/12 m tapered monopile foundation.

Section length (m)	Outside diameter top (m)	Outside diameter bottom (m)	Section length (m)	Outside diameter top (m)	Outside diameter bottom (m)
0.24	7	7	4	12	12
3.936	7	7	4	12	12
4.44	7	7	4	12	12
4.2	7	7	4	12	12
4.2	7	7	7.5	12	12
4.2	7	7	4.2	12	12
4.2	7	7	4.2	12	12
4.2	7	7	4.2	12	12
4	7	7.625	4.2	12	12
4	7.625	8.25	4.2	12	12
4	8.25	8.875	4.2	12	12
4	8.875	9.5	4.2	12	12
4	9.5	10.125	4.2	12	12
4	10.125	10.75	4.142	12	12
4	10.75	11.375	4.322	12	12
4	11.375	12	2.5	12	12

Table 1.2-2. Locations for acoustic modeling of installations of 7/12 m tapered monopile foundations.

Foundation/ pile name	Location (UTM Zone 19N)		Water depth (m)	Source	Source type
	Easting	Northing			
ID-97	308675.1	4544338.1	44.9	Monopile	Impulsive
ID-259	334392.4	4527962.0	56.6		

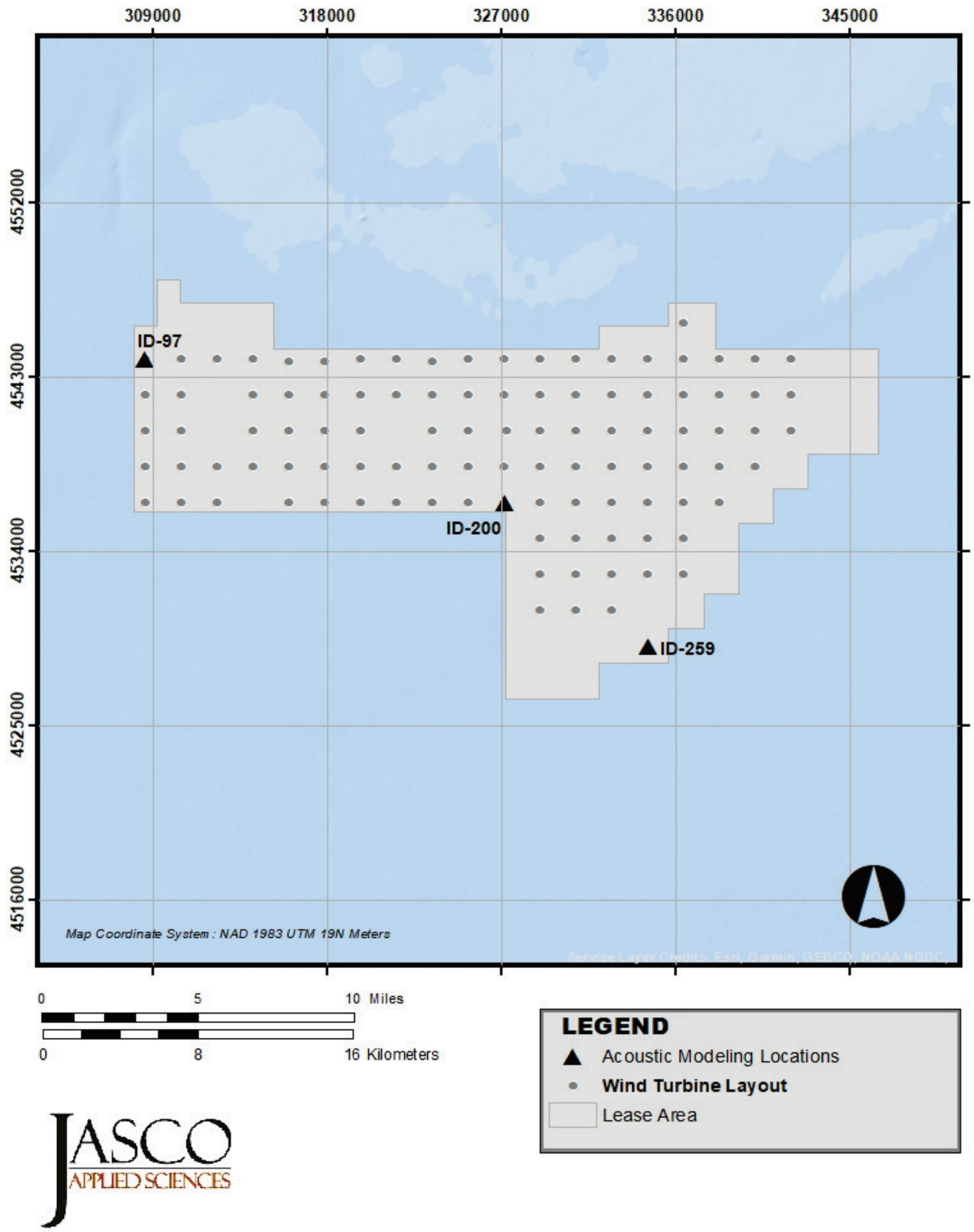

Figure 1.2-1. Sunrise Wind Farm 7/12 m monopile and jacket foundation locations used for acoustic propagation.

The amount of sound generated during pile driving varies with the energy required to drive piles to a desired depth and depends on the sediment resistance encountered. Sediment types with greater resistance require hammers that deliver higher energy strikes and/or an increased number of strikes relative to installations in softer sediment.

Maximum sound levels usually occur during the last stage of impact pile driving where the greatest resistance is encountered (Betke 2008). The make and model of impact hammer (IHC S-4000) and the representative hammering schedule used in the acoustic modeling effort were provided by Sunrise Wind and in coordination with potential hammer suppliers. Key modeling assumptions for the 7/12 m monopiles are listed in Table 1.2-3, and a representative hammering schedule is shown in Table 1.2-4. Additional modeling details and input parameters are provided in Appendix A.1.

Table 1.2-3. Major pilling assumptions used in underwater acoustic modeling of the 7/12 m monopiles.

Parameter	Value
Hammer	IHC S-4000 (impact)
Modeled maximum impact hammer energy	4000 kJ
Pile length	129.68 m
Pile diameter	7 to 12 m
Pile wall thickness	8.1–13.5 mm
Seabed penetration	50 m

Table 1.2-4. Hammer energy schedule and number of strikes for the installation of a 7/12 m monopile with an IHC S-4000 hammer.

Hammer energy level (kJ)	Strike count	Pile penetration range (m)
1000	3015	0–14
1500	2140	14–24
2,000	2084	24–34
2500	1843	34–43
3200	1316	43–50
Total	**10,398**	**50**
Strike rate (strikes/min)	50	

Though not included in the hammering schedule (and not used in the exposure analysis), the 7/12 m monopile was additionally modeled at the highest hammer energy of 4,000 kJ, by considering just one strike at the maximum seabed penetration depth (50 m), and a penetration rate similar to that of the 3,200 kJ energy level, implying penetration to refusal. Results for the 4,000 kJ energy level are presented in Appendices G.1, G.2, and G.3 for single-strike PK, SEL and SPL, respectively, since only one strike was considered.

1.2.1.2. Jacket Foundation Piles

A jacket foundation pile is a single hollow cylinder fabricated from steel that is used to secure the jacket structure. The 4 m diameter jacket pin piles proposed for the SRWF represent the expected maximum size that will be installed. Sound fields from jacket foundation piles were modeled at one representative location in the SRWF, ID-200 (Table 1.2-5, see Figure 1.2-1). The jacket foundation pin piles were assumed to be vertical and driven to a maximum expected seabed penetration depth of 90 m. The piles will be 110 m long, and they will be installed in waters ~50 m deep. In their final position, the top of the pile will be submerged in the water, 20 m above the seabed. Additional modelling assumptions are given in Tables 1.2-6 and 1.2-7. Additional modeling details and input parameters are provided in Appendix A.2.

Table 1.2-5. Location for acoustic modeling of jacket foundation pin pile installation.

Foundation/ Pile name	Location (UTM Zone 19N)		Water depth (m)	Source	Source type
	Easting	Northing			
ID-200	327199.2	4537191.1	50.6	Jacket pile	Impulsive

Table 1.2-6. Major pilling assumptions used in underwater acoustic modeling of the jacket foundation pin piles.

Parameter	Value
Hammer	IHC S-4000 (impact)
Modeled maximum impact hammer energy	4000 kJ
Pile length	110 m
Pile diameter	4 m
Pile wall thickness	7.5 mm
Seabed penetration	90 m

Table 1.2-7. Hammer energy schedule and number of strikes for the installation of a jacket foundation pile with an IHC S4000 hammer.

Hammer energy level (kJ)	Strike count	Pile penetration range (m)
Assume pile self-settling	0	0–4
300	1336	4–12
750	2182	12–25
1000	4437	25–43
2000	4058	43–63
3000	3272	63–80
4000	1803	80–90
Total	**17088**	**90**
Strike rate (strikes/min)	32	

1.2.1.3. Casing Pipe

The Project may include a temporary casing pipe to support the sea-to-shore transition of the SRWEC. HDD methods are expected for this transition, and a casing pipe is expected to be installed to collect any drilling fluid at the HDD exit pits. The proposed casing pipe would be installed at an angle towards the exiting drill using a pipe ramming method with a Grundoram pneumatic hammer. Pipe casing ramming activity is expected to produce similar sound source characteristics as impact pile driving; therefore, impact pile driving and pipe ramming is used interchangeably within this report when referring to the casing pipe installation.

Sound fields from the casing pipe installation were modeled at one representative location along the SRWEC route near to the HDD exit pit locations: ID-01 (Table 1.2-8, see Figure 1.2-2). The casing pipe is expected to have a maximum size of 1.2 m diameter and 137.2 m length and is assumed to be driven to a maximum depth of 10 m below the seabed. Casing pipe installation assumptions are shown in Table 1.2-9, and modeling details and input parameters listed in Appendix A.3.

Table 1.2-8. Location for acoustic modeling of 1.2 m casing pipe installation.

Pile name	Location (UTM Zone 19N)		Water depth (m)	Source	Source type
	Easting	Northing			
ID-01	174421	4515659	8.5	Casing Pipe	Impulsive

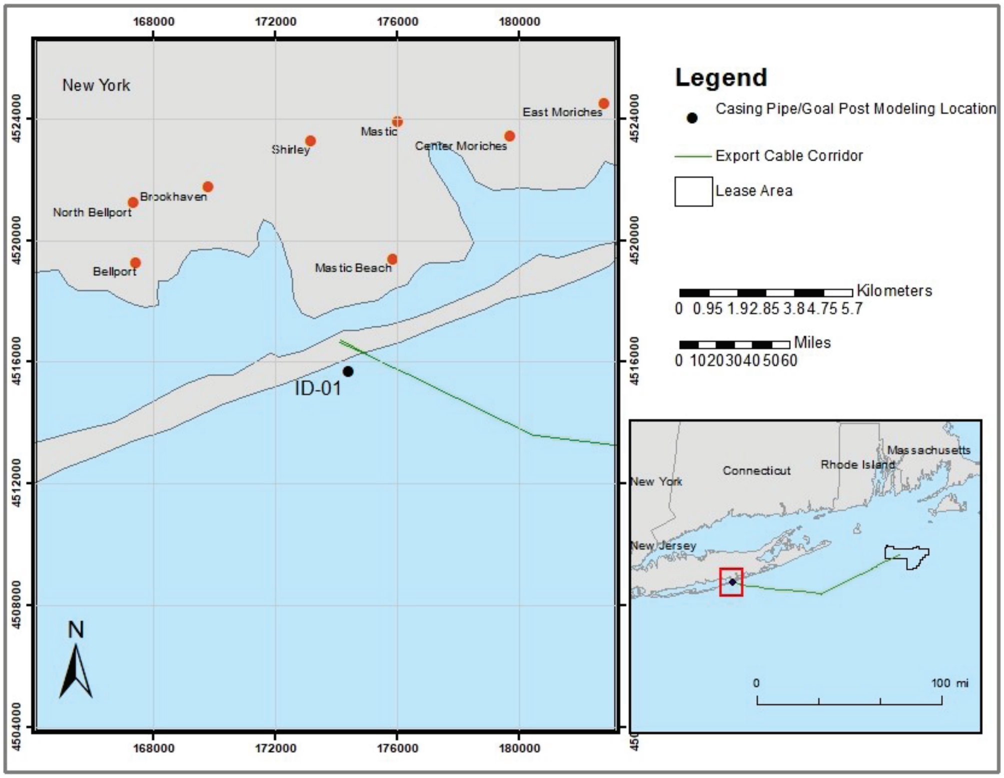

Figure 1.2-2. Sunrise Wind Export Cable corridor and landfall showing location used for casing pipe and goal posts acoustic propagation.

Table 1.2-9. Major pilling assumptions used in underwater acoustic modeling of the casing pipe.

Parameter	Value
Hammer	Grundoram Taurus (impact)
Impact hammer energy	18 kJ
Pile length	Penetration + water depth
Pile diameter	1.2 m
Pile wall thickness	25.4 mm
Seabed penetration	10 m
Angle of installation (relative to horizontal)	11–12 degrees
Piles per day	0.5
Strikes per day	32,400

1.2.2. Vibratory Pile Driving – Goal Posts

Vibratory pile driving of temporary goal post sheet piles at the HDD exit pits is expected to be needed to support casing pipe installation, described above. These goal post piles may be used for casing pipe guidance or for mooring of the installation barge. Acoustic modeling of these piles assumed the use of an American Piledriving Equipment (APE) Model 300 vibratory hammer to drive the piles vertically 10 m below the seabed.

Sound fields from the goal posts were modeled at the same representative location as the casing pipe, along the SRWEC route near to the HDD exit pit locations (ID-01; see Table 1.2-8 and Figure 1.2-2). The goal posts are expected to have a maximum size of 600 mm in width and 30 m in length. Additional goal post assumptions are listed in Table 1.2-10. Additional modeling details and input parameters are listed in Appendix A.4.

Table 1.2-10. Major pilling assumptions used in underwater acoustic modeling of the goal posts.

Parameter	Value
Hammer	APE Model 300 (vibratory)
Pile type	Sheet pile
Pile length	Penetration + water depth
Pile width	600 mm
Pile wall thickness	25 mm
Seabed penetration	10 m
Piles per day	4
Time to install one pile	2 h

1.2.3. Pile Construction Schedules

Construction schedules cannot be fully predicted because of environmental factors like weather and because of installation variation such as drivability. To estimate the number of animals likely to be exposed above the regulatory thresholds, a conservative construction schedule that maximizes activity during the highest density months for each species was assumed. Five potential construction schedules were evaluated. Construction schedules 1 and 2 represent traditional, sequential operations with one pile driving vessel (operating one hammer). Construction schedules 3, 4, and 5 assume a combination of concurrent and sequential operations, where concurrent operations simulate two pile driving vessels, each with one hammer, operating at the same time.

Construction schedule 1 (Table 1.2-11) assumes the installation of 1 OCS-DC jacket foundation (4 pin piles per day for 2 days, for a total of 8 pin piles per foundation) and then 56 of the WTG monopile foundations (2 piles per day for 28 days) during the highest density month for each species, with the remaining 46 WTG monopile foundations (2 piles per day for 23 days) installed in each species second highest density month.

Construction schedule 2 (Table 1.2-12) assumes the installation of 1 OCS-DC jacket foundation (4 pin piles per day for 2 days, for a total of 8 pin piles per foundation) and then 84 of the WTG monopile foundations (3 piles per day for 28 days) during the highest species density month (see Sections 3.1 and 3.2 for details on animal density estimates), with the remaining 18 WTG monopile foundations (3 piles per day for 6 days) installed in the second highest species density month.

Table 1.2-11. Construction Schedule 1: sequential operations; assumptions for WTG (one vessel installing two monopiles per day) foundations and the OCS-DC foundation.

Foundation type	Configuration	Highest density month		2nd highest density month	
		Days of piling	Total piles	Days of piling	Total piles
OCS-DC	Jacket pin pile, 4 per day	2	8	0	0
WTG	Monopile, 2 per day	28	56	23	46

Table 1.2-12. Construction Schedule 2: sequential operations; assumptions for WTG (one vessel installing three monopiles per day) foundations and the OCS-DC foundation.

Foundation type	Configuration	Highest density month		2nd highest density month	
		Days of piling	Total piles	Days of piling	Total piles
OCS-DC	Jacket pin pile, 4 per day	2	8	0	0
WTG	Monopile, 3 per day	28	84	6	18

Construction schedule 3 (Table 1.2-13) assumes concurrent operations of two vessels, each installing two monopile foundations per day. In construction schedule 3, the vessels are assumed to be in their closest likely position relative to each other (proximal), a separation distance of 3 nm (two foundation locations between vessels). The installation consists of the OCS-DC jacket foundation (4 pin piles per day for 2 days, for a total of 8 pin piles for the foundation) and then 102 WTG monopile foundations (2 vessels installing 2 piles per day for 25.5 days) during the highest species density month (see Sections 3.1 and 3.2 for details on animal density estimates).

Construction schedule 4 (Table 1.2-14) is the same as construction schedule 3, except that the two concurrently operating monopile installation vessels are assumed to be most distal from each other, installing foundations on opposite ends of the wind lease area.

Construction schedule 5 (Table 1.2-15) assumes that the jacket foundation will be installed using one vessel at the same time as monopile foundations are installed using another vessel. In construction schedule 5, the vessels are assumed to be within the proximal separation distance as was assumed for construction schedule 3 (a separation distance of 3 nm with two foundation locations between the vessels). The concurrent operations would occur for two days during the highest density month in which time 8 pin piles and 4 monopiles would be installed (4 pin piles per day, and 2 monopiles per day). From one vessel installing 2 monopiles per day, 56 monopiles would be installed in the remaining 28 days of the highest density month, and 42 monopiles in 21 days of the next highest density month.

Table 1.2-13. Construction Schedule 3: concurrent operations; proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation.

Foundation type	Configuration	Highest density month	
		Days of piling	Total piles
OCS-DC	Jacket pin pile, 4 per day	2	8
WTG	2 vessels, each 2 per day	25.5	102
	Total	**27.5**	**110**

Table 1.2-14. Construction Schedule 4: concurrent operations; distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation.

Foundation type	Configuration	Highest density month	
		Days of piling	Total piles
OCS-DC	Jacket pin pile, 4 per day	2	8
WTG	2 vessels, each 2 per day	25.5	102
	Total	**27.5**	**110**

Table 1.2-15. Construction Schedule 5: concurrent operations; proximal assumptions for concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day), and remaining WTG foundations.

Foundation type	Configuration	Highest density month		2nd highest density month	
		Days of piling	Total piles	Days of piling	Total piles
OCS-DC & WTG	Jacket pin pile,4 per day + Monopile, 2 per day	2	8 (pin) + 4 (MP)	0	0
WTG	Monopile, 2 per day	28	56	21	42
	Total	**30**	**68**	**21**	**42**

1.2.4. Exposure Modeling Installation Schedules

JASMINE was run for a representative seven-day period for each scenario. Each of the five construction schedules described in Section 1.2.3 includes a combination of scenarios that assume either fully sequential operations or a combination of sequential and concurrent operations. For each scenario, a subset of simulated sites was chosen to capture the range of acoustic variability across the lease area. The modeling locations used for simulating sequential operations are shown in Figure 1.2-3, and the modeling locations used for simulating concurrent operations are shown in Figure 1.2-4. Details on how these installation schedules are implement in JASMINE are included in Section 2.7.

For sequential operations, different sites were modeled on each day of the simulation (Figure 1.2-3). For one monopile per day, 7 representative locations were selected in the lease area (one location for each day). Similarly, for two monopiles per day, 14 locations were selected, and 21 locations were selected for three monopiles per day. For jacket foundations, 7 representative locations were chosen. For each pile type and each exposure modeling location the closest modeled sound field was used.

Concurrent operations were handled slightly differently to best capture the effects of installing piles spatially close to each other (proximal) or further apart (distal). The sites chosen for exposure modeling for concurrent operations were repeated each day for all seven days (Figure 1.2-4). The installation schedules for concurrent scenarios are as follows:

Construction Schedule 3 includes a concurrent scenario, simulating two vessels, each installing two monopiles per day. The first vessel installs both monopiles in the southeast corner of the lease area (purple circle markers). The second vessel installs both monopiles at the proximal location (light blue circle markers).

Construction Schedule 4 also includes a concurrent scenario with two vessels installing two monopiles per day. In this case, the first vessel installs both monopiles in the southeast corner, while the second vessel installs both monopiles at the distal location (green circle markers).

Construction Schedule 5 includes a concurrent scenario with two vessels, one installing two monopiles per day, and a second installing 4 jacket pin piles per day. In this case, the jacket foundation pin piles are installed at a single location (yellow square marker), while the monopile foundations are installed at two proximal locations (yellow circle markers).

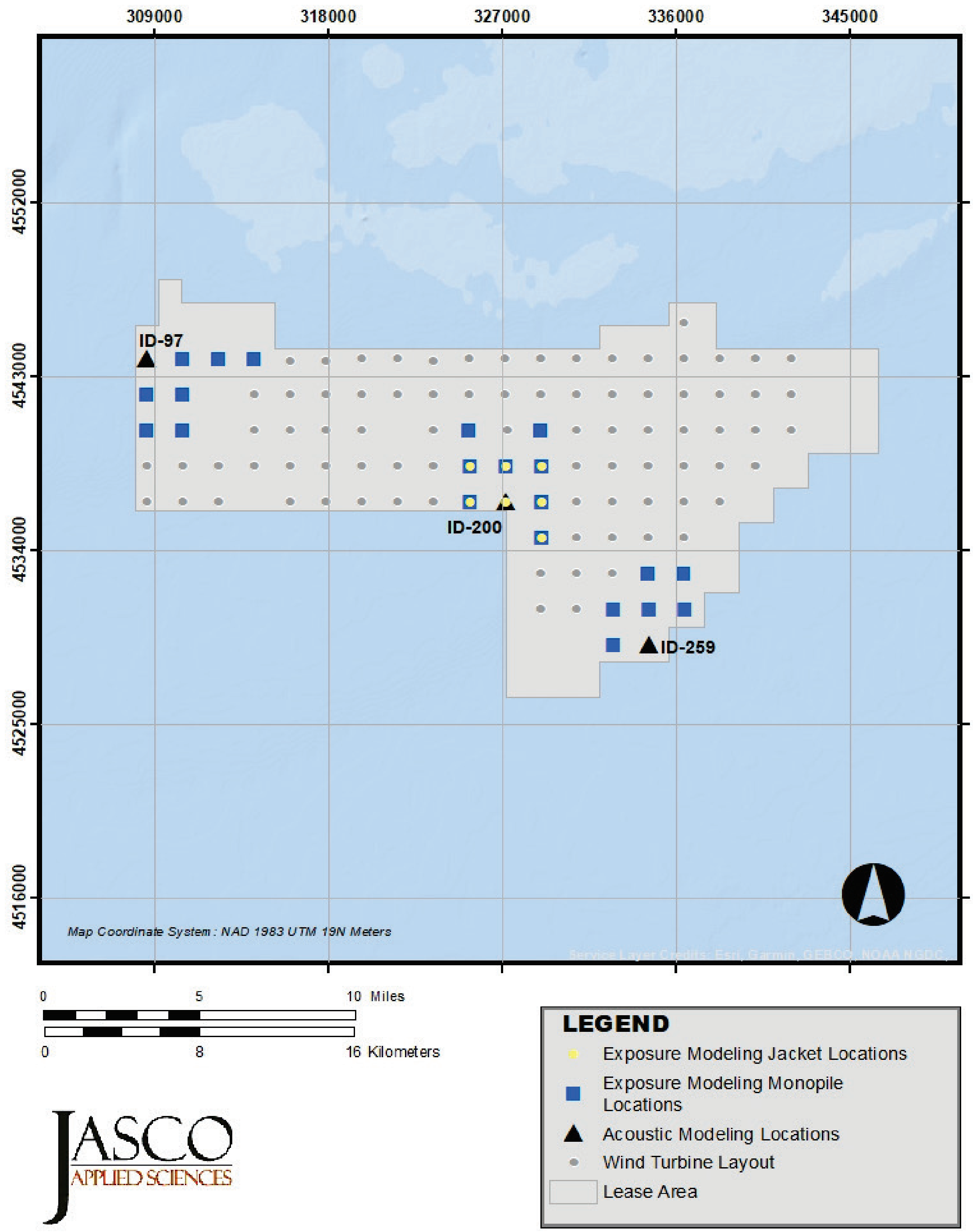

Figure 1.2-3. Sequential Operations: Sunrise Wind Farm monopile and jacket foundation locations used for animal movement modeling.

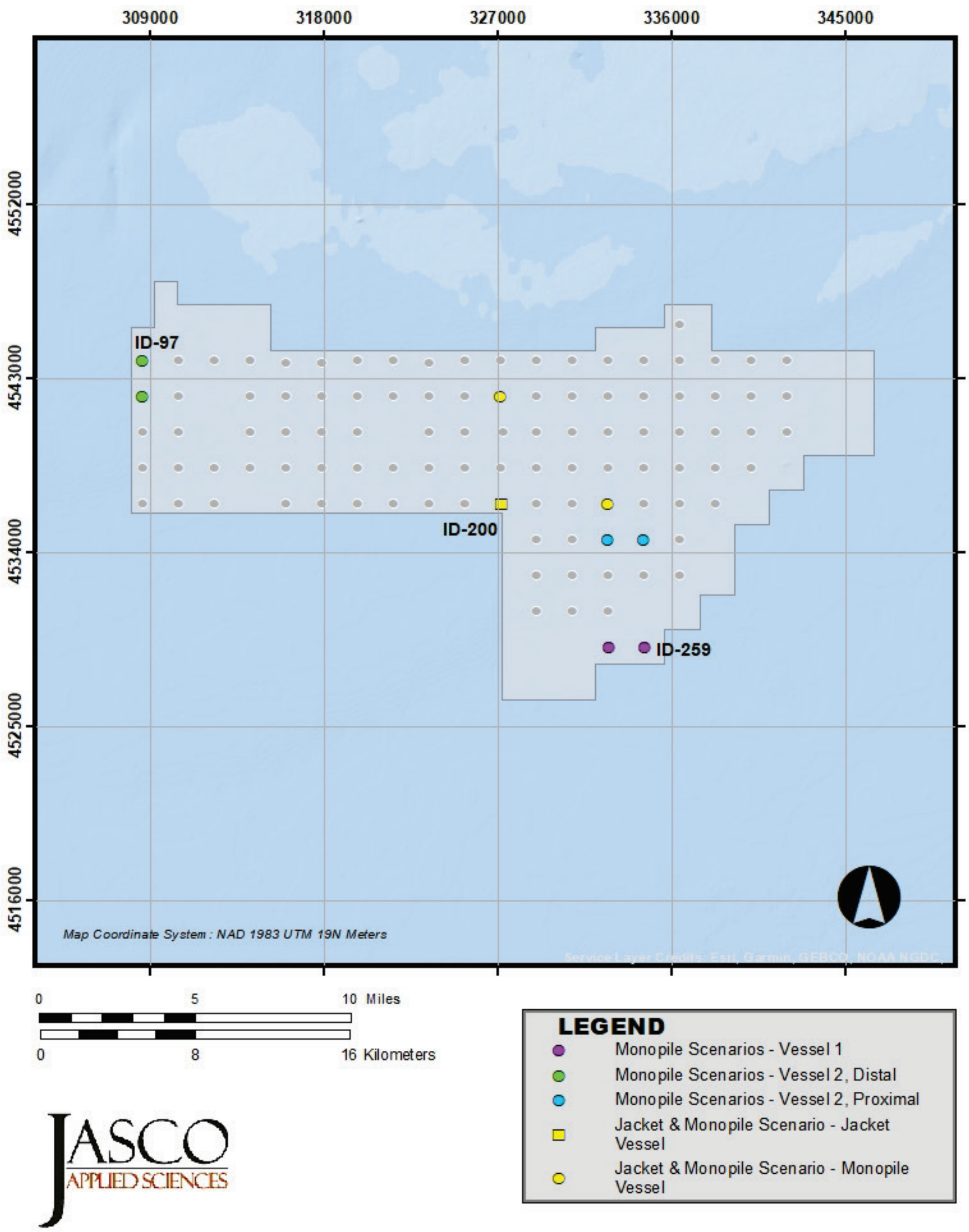

Figure 1.2-4. Concurrent Operations: Sunrise Wind Farm monopile and jacket foundation locations used for animal movement modeling.

2. Methods

The basic modeling approach is to characterize the sounds produced by the source, determine how the sounds propagate within the surrounding water column, and then estimate species-specific exposure probability by considering the range- and depth-dependent sound fields in relation to animal movement in simulated representative scenarios.

For impact pile driving sounds, time-domain representations of the acoustic pressure waves generated in the water are required for calculating sound pressure level (SPL) and peak pressure level (PK) and can be used to calculate the sound exposure level (SEL). The source signatures associated with installation of each of the modeled 7/12 m monopiles, jacket piles, and casing pipes were predicted using a finite-difference model of the physical vibration of the pile caused by pile driving equipment. The pile as a sound source radiating into the environment was simulated as an array of point sources. For vibratory pile driving of sheet piles, a measured spectrum was used and propagated in the environment.

For this study, synthetic pressure waveforms for impact pile driving were computed using a Full Waveform Range-dependent Acoustic Model (FWRAM), which is JASCO's acoustic propagation model capable of producing time-domain waveforms. The sound propagation modeling incorporates site-specific environmental data including bathymetry, sound speed in the water column, and seabed geoacoustics in the proposed construction area. To estimate received levels for animals in the construction area exposed to sounds associated with the installation of the monopiles and jacket piles, JASCO's Animal Simulation Model Including Noise Exposure (JASMINE) was used to integrate the sound fields with species-typical behavioral parameters (e.g., dive patterns). Animats that exceed pre-defined acoustic thresholds/criteria (e.g., NMFS 2018) are identified and the range for the exceedances determined. The number of animals expected to exceed the regulatory thresholds is determined by scaling the probability of exposure by the species-specific density of animals in the area.

This section provides an overview of the modelling and analysis undertaken for this study, and additional details can be found in the appendices. Appendix A summarizes the assumptions made for each acoustic source. Appendix B defines the acoustic metrics and decidecade frequency band analysis used in this study. Appendix C describes the frequency weighting functions that are used in the calculation of some of the acoustic metrics associated with acoustic criteria. Appendices D and E provide details of the acoustic modelling.

2.1. Acoustic Environment

The proposed SRWF is located on the Outer Continental Shelf and is characterized by predominantly sandy seabed sediments. Water depths in the construction area vary between 40 and 58 m. From June to October, the average temperature of the upper 10–15 m of the water column is higher than in the waters below, resulting in an increased sound speed in this surface layer. This creates a downward refracting environment in which propagating sound interacts with the seafloor more than in a well-mixed environment. In winter, from December through February, increased mixing from wind combined with less solar energy, results in a temperature profile, and thus a sound speed profile, that is more uniform with depth. Average summer and average winter sound speed profiles were used in the SRWF acoustic propagation modeling from impact pile driving of monopiles and jacket foundation piles. The propagation modeling for the casing pipe installation and vibratory pile driving for goal posts was performed using an average winter sound speed profile representative of the nearshore location where those constructions will take place. See Appendix E.1 for more details on the environmental parameters used in acoustic propagation and exposure modeling.

2.2. Modeling Acoustic Sources

2.2.1. Impact Pile Driving

When driven with impact hammers, piles deform, 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 2.2-1). 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.

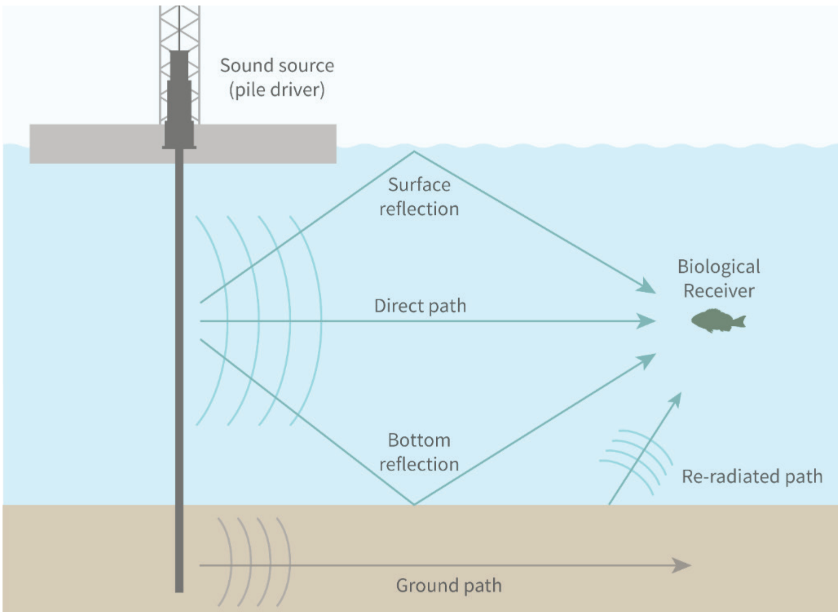

Figure 2.2-1. Sound propagation paths associated with pile driving (adapted from Buehler et al. 2015).

JASCO's physical model of pile vibration and near-field sound radiation (MacGillivray 2014) was used in conjunction with the GRLWEAP 2010 wave equation model (GRLWEAP, Pile Dynamics 2010) to predict source levels associated with impact pile driving activities. Piles are modeled as a vertical installation using a finite-difference structural model of pile vibration based on thin-shell theory. 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 D for a more detailed description.

Forcing functions were computed for the 7/12 m monopiles, jacket foundation piles, and casing pipes using GRLWEAP 2010 (GRLWEAP, Pile Dynamics 2010). The model assumed direct contact between the representative hammers, helmets, and piles (i.e., no cushioning material). The forcing functions serve as the inputs to JASCO's pile driving source model (PDSM), used to estimate equivalent acoustic source characteristics detailed in Appendix D.1.

JASCO's FWRAM (Appendix E.4) propagation model was used to combine the outputs of the source model with spatial and temporal environmental factors (e.g., location, oceanographic conditions, and seabed type) to get time-domain representations of the sound signals in the environment and estimate sound field levels. This model is used to estimate the energy distribution per frequency (source spectrum) at a close distance from the source (10 m). Examples of decidecade spectral levels for each pile type, hammer energy, and modeled location, using average summer sound speed profile are provided in Sections 4.1.1 and 4.1.2 for monopiles and jacket foundation piles, respectively. For jacket foundation pin piles, post-piling was assumed. That is, the pin piles will be driven through sleeves in the jacket foundation after it has already been placed on the seabed. These jacket foundations will also radiate sound as the pin piles are driven. To account for the larger radiating area including the jacket structure, the broadband sound level estimated for the pin piles was increased by 2 dB.

2.2.2. Vibratory Pile Driving

Decidecade band SEL levels were obtained from vibratory pile driving measurements available in the literature (Illingworth & Rodkin 2017). The Illingworth and Rodkin (2017) measurements are for vibratory driving of four 12-in wide connected sheet piles (48 inch/122 cm total width) using an APE Model 300 vibratory hammer (1842.0 kN centrifugal force). Illingworth & Rodkin (2017) included SEL at 10 m from the pile in the frequency band 5–25,000 Hz. The average (from 10 piling measurements) maximum broadband SEL was 182.7 dB re 1 μPa²·s.

For modeling of vibratory driving of sheet piles, at the HDD location, SEL band levels were corrected for spherical spreading (+20 dB, corresponding to 10 m range). The source level spectrum of the vibratory pile driving of a sheet pile for a goal post at the export cable HDD site is shown in Figure 2.2-2. These levels represent the sheet pile as a point source located in the middle of the water column. To account for the influence of bathymetry, seabed, water sound speed, and water attenuation, JASCO's Marine Operations Noise Model (MONM-BELLHOP; see Appendix E.3) was used to predict acoustic propagation for frequencies between 5 Hz and 25 kHz.

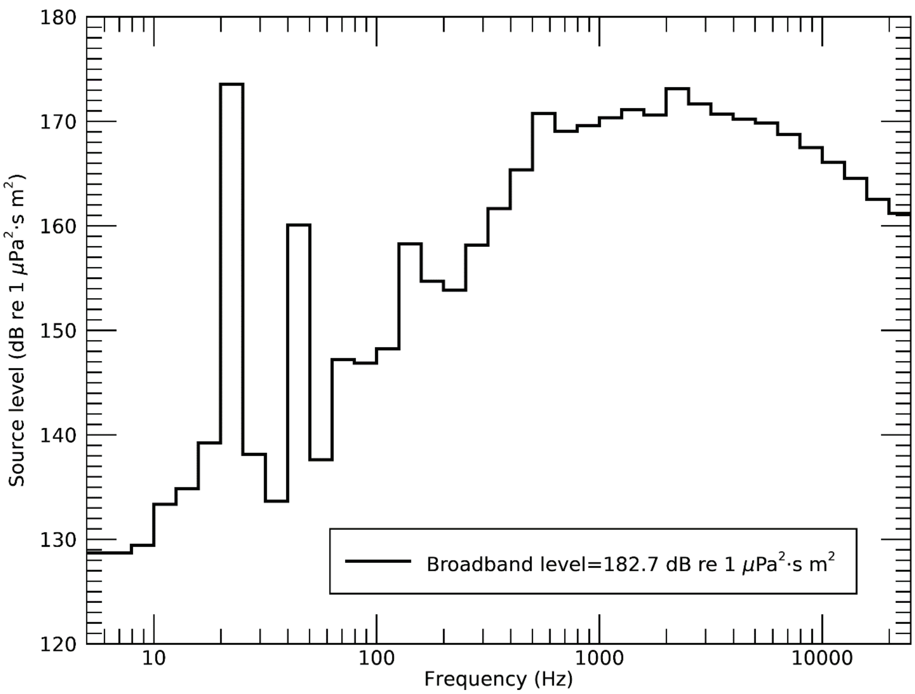

Figure 2.2-2. Decidecade-band spectral source levels, at 10 m, for goal post construction using vibratory pile driving (Illingworth & Rodkin 2017).

2.3. Noise Mitigation

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. Various technologies can achieve attenuation by impedance change, including bubble curtains, evacuated sleeve systems (e.g., IHC-Noise Mitigation System (NMS)), encapsulated bubble systems (e.g, HydroSound Dampers), or Helmholtz resonators (AdBm NMS). The effectiveness of each system is frequency dependent and may be influenced by local environmental conditions such as water 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 in a short radius around the pile) have been measured to reduce sound levels by ~10 dB to more than 20 dB but are highly dependent on water depth, 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, known as double bubble curtains (Koschinski and Lüdemann 2013, Bellmann 2014, Nehls et al. 2016). A California Department of Transportation 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 (10 m [32 ft]) the pile (Buehler et al. 2015).

A recent analysis by Bellmann et al. (2020b) of NAS performance measured during impact driving for wind farm foundation installation provides expected performance for common NAS configurations. Measurements with a single bubble curtain and an air supply of 0.3 m^3/min resulted in 7–11 dB of broadband attenuation for optimized systems in up to 40 m water depth. Increased air flow (0.5 m^3/min) may improve the attenuation levels up to 11–13 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 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 HydroSound Dampers were measured at 10 to 12 dB attenuation and are independent of depth (Bellmann et al. 2020b). 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 (across all frequencies) 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-based radial distance estimation, several levels of broadband attenuation were included for comparison purposes.

2.4. Acoustic Criteria for Marine Fauna – Summary

The acoustic criteria used for this study are from the current US regulatory acoustic criteria and are summarized below (further details on these criteria are in Sections 2.5 and 2.6):

1. Peak sound pressure levels (PK; L_{pk}) and frequency-weighted accumulated sound exposure levels (SEL; $L_{E,\mathrm{24h}}$) are from the US National Oceanic and Atmospheric Administration (NOAA) Technical Guidance (NMFS 2018) for marine mammal injury thresholds.
2. Sound pressure levels (SPL; L_p) for marine mammal behavioral thresholds are based on the unweighted NOAA (2005) and the frequency-weighted Wood et al. (2012) criteria.
3. Injury thresholds (PK and SEL) for fish are from the Fisheries Hydroacoustic Working Group (FHWG 2008) and Stadler and Woodbury (2009) for fish that are equal, greater than, or less than 2 g.
4. Injury thresholds (PK and SEL) for fish are from Popper et al. (2014) for fish without swim bladders, fish with swim bladders not involved in hearing, and fish with swim bladders involved in hearing.
5. Behavioral thresholds for fish are from the NOAA Fisheries Greater Atlantic Regional Fisheries Office (GARFO) (Andersson et al. 2007, Wysocki et al. 2007, Mueller-Blenkle et al. 2010, Purser and Radford 2011)
6. Peak pressure levels (PK; L_{pk}) and frequency-weighted accumulated sound exposure levels (SEL; $L_{E,\mathrm{24h}}$) from Finneran et al. (2017) were used for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in sea turtles.
7. Behavioral response thresholds for sea turtles are from McCauley et al. (2000b).

2.5. Acoustic Criteria – Marine Mammals

The Marine Mammal Protection Act (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 construction and 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 the underwater sound in the SRWF, it is necessary to first establish the acoustic exposure criteria used by United States regulators to estimate marine mammal takes. In 2016, National Oceanographic and Atmospheric Administration (NOAA) Fisheries issued a Technical Guidance document that provides acoustic thresholds for onset of PTS and TTS in marine mammal hearing for most sound sources, which was updated in 2018 (NMFS 2016, 2018). This Technical Guidance document also recognizes two main types of sound sources: impulsive and non-impulsive. Non-impulsive sources are further broken down into continuous or intermittent categories.

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

Sound levels thought to elicit disruptive behavioral response are described using the SPL metric (NMFS and NOAA 2005). NOAA Fisheries (NMFS) currently uses behavioral response thresholds of 160 dB re 1 µPa for impulsive/intermittent sounds and 120 dB re 1 µPa for non-impulsive/continuous sounds for all marine mammal species (NMFS 2018), based on observations of mysticetes (Malme et al. 1983, 1984, Richardson et al. 1986, 1990b). Alternative thresholds used in acoustic assessments include a graded probability of response approach and take into account the frequency-dependence of animal hearing sensitivity (Wood et al. 2012). The 160 dB threshold is used in this assessment as per NOAA guidance (2019).

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 2.5-1).

Table 2.5-1. Summary of relevant acoustic terminology used by US regulators and in the modeling report.

Metric	NMFS (2018)	ISO (2017)	
		Main text	Equations/Tables
Sound pressure level	n/a	SPL	L_p
Peak pressure level	PK	PK	L_{pk}
Cumulative sound exposure level	SEL_{cum}[a]	SEL	L_E

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

2.5.1. Marine Mammal Hearing Groups

Current data and predictions show that marine mammal species differ in their hearing capabilities, in absolute hearing sensitivity as well as frequency band of hearing (Richardson et al. 1995, Wartzok and Ketten 1999, Southall et al. 2007, Au and Hastings 2008). While hearing measurements are available for a small number of species based on captive animal studies, there are no direct measurements of many odontocetes or any mysticetes. As a result, hearing distances 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 NOAA Fisheries using more recent best available science (Table 2.5-2).

Southall et al. (2019) published an updated set of Level A sound exposure criteria (including the onset of temporary threshold shift [TTS] and permanent threshold shift [PTS] in marine mammals). While the authors propose a new nomenclature and classification for the marine mammal functional hearing groups, the proposed thresholds and weighting functions do not differ in effect from those proposed by NOAA Fisheries (2018). The new hearing groups proposed by Southall et al. (2019) have not yet been adopted by NOAA. The NOAA Fisheries (NMFS 2018) hearing groups presented in Table 2.5-2 are used in this analysis.

Table 2.5-2. Marine mammal hearing groups (Sills et al. 2014, NMFS 2018).

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

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

2.5.2. Marine Mammal Auditory Weighting Functions

The potential for anthropogenic sound to impact marine mammals is largely dependent on whether the sound occurs at frequencies that an animal can hear well unless the sound pressure level is so high that it can cause physical tissue damage regardless of frequency. Auditory (frequency) weighting functions reflect an animal's ability to hear a sound (Nedwell and Turnpenny 1998, Nedwell et al. 2007). Auditory weighting functions have been proposed for marine mammals, specifically associated with PTS thresholds expressed in metrics that consider what is known about marine mammal hearing (e.g., SEL) (Southall et al. 2007, Erbe et al. 2016a, Finneran 2016). Marine mammal auditory weighting functions for all hearing groups (see Table 2.5-2) 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 (see Table 2.5-3). (See Appendix C for a detailed description of the weighting functions.)

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

2.5.3. Marine Mammal Auditory Injury Exposure Criteria

Injury to the hearing apparatus of a marine mammal may result from a fatiguing stimulus measured in terms of SEL, which considers the sound level and duration of the exposure signal. Intense sounds may also damage hearing independent of duration, so an additional metric of peak pressure (PK) is 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 2.5-3). 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 2.5-3. 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 $L_{E,24h}$ (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 pinnipeds in water (PPW)	218	185	201

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

2.5.4. Marine Mammal Behavioral Response Exposure Criteria

Numerous studies on marine mammal behavioral responses to sound exposure have not resulted in consensus in the scientific community regarding the appropriate metric for assessing behavioral reactions. It is recognized that the context in which the sound is received affects the nature and extent of responses to a stimulus (Southall et al. 2007, Ellison et al. 2012). Based on the responses of mysticete whales to airgun sounds (Malme et al. 1983, 1984), the High-Energy Seismic Survey (HESS) found that, while responses to sound may occur at lower levels, substantial responses were only likely to occur above an SPL of 140 dB re 1 µPa with notable responses observed at SPL of 160 dB re 1 µPa. Due to the complexity and variability of marine mammal behavioral responses to acoustic exposure, NOAA Fisheries has not yet released technical guidance on behavioral thresholds for calculating animal exposures (NMFS 2018), but currently uses a step function at SPL 160 dB re 1µPa to assess behavioral impact (NOAA 2005)..

An extensive review of behavioral responses to sound was undertaken by Southall et al. (2007, their Appendix B). Southall et al. (2007) found varying responses for most marine mammals between an SPL of 140 and 180 dB re 1 µPa, consistent with the HESS (1999) report, but lack of convergence in the data prevented them from suggesting explicit step functions. In 2012, Wood et al. proposed a graded probability of response for impulsive sounds using a frequency weighted SPL metric. Wood et al. (2012) also designated behavioral response categories for sensitive species (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 2.5-4). Acoustic sound pressure level (SPL) thresholds used in this assessment to evaluate potential behavioral impacts to marine mammals. Probabilities are not additive.

Table 2.5-4. Probabilistic disturbance root mean square (rms) sound pressure level (SPL) thresholds and unweighted Level B thresholds.

Marine mammal group	**Species**	**Probabilistic response**				
		Frequency-weighted threshold[a] (L_p; dB re 1 µPa)				**Unweighted threshold[b] (L_p; dB re 1 µPa)**
		120	140	160	180	160
Sensitive odontocetes	Harbor porpoise	50%	90%	—	—	100%
Migrating mysticete whales	Minke whale	10%	50%	90%	—	100%
	Sei whale					
All other species		—	10%	50%	90%	100%

a Wood et al. (2012).
b NOAA Fisheries recommended threshold.

2.6. Acoustic Criteria – 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 thresholds for sea turtles were developed for use by the US Navy (Blackstock et al. 2018) based on exposure studies (e.g., McCauley et al. 2003). These injury and behavioral response levels for fish and sea turtles were compiled and listed in the NOAA Fisheries Greater Atlantic Regional Fisheries Office (GARFO) tool for assessing the potential effects to ESA-listed fish and sea turtles exposed to elevated levels of underwater sound from pile driving. Dual acoustic thresholds for physiological injury to fish included in the tool are 206 dB PK and either 187 dB SEL (>2 g fish weight) or 183 dB SEL (<2 g fish weight) (Table 2.6-1) (FHWG 2008, Stadler and Woodbury 2009). The behavioral threshold for fish is ≥150 dB SPL (Table 2.6-1) (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. 2000b). 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. 2000b, Finneran et al. 2017) (Table 2.6-1).

Table 2.6-1. Acoustic metrics and thresholds for fish and sea turtles for impulsive and non-impulsive sound sources.

Faunal group	Impulsive					Non-Impulsive			
	Injury PTS		Impairment TTS		Behavior	Injury PTS		Impairment TTS	Behavior
	L_{pk}	L_E	L_{pk}	L_E	L_p	L_E	L_p	L_p	L_p
Large Fish (≥2 g[a,b])	206	187	--	--	150	--	--	--	150
Small Fish (<2 g[a,b])	206	183	--	--	150	--	--	--	150
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	--	--	--	--	170	158	--
Sea turtles[d,e]	232	204	226	189	175	220	--	--	175

L_{pk} = peak sound pressure level (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 are recoverable hearing effects.
[a] NMFS recommended criteria adopted from the Fisheries Hydroacoustic Working Group (FHWG 2008).
[b] Andersson et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011), Wysocki et al. (2007).
[c] Popper et al. (2014).
[d] Finneran et al. (2017).
[e] McCauley et al. (2000b).

2.7. Animal Movement Modeling and Exposure Estimation

JASMINE was used to estimate the probability of exposure of animals to sound arising from pile driving operations during construction of the SRWF. 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 H.2). An overview of the exposure modeling process using JASMINE is shown in Figure 2.7-1.

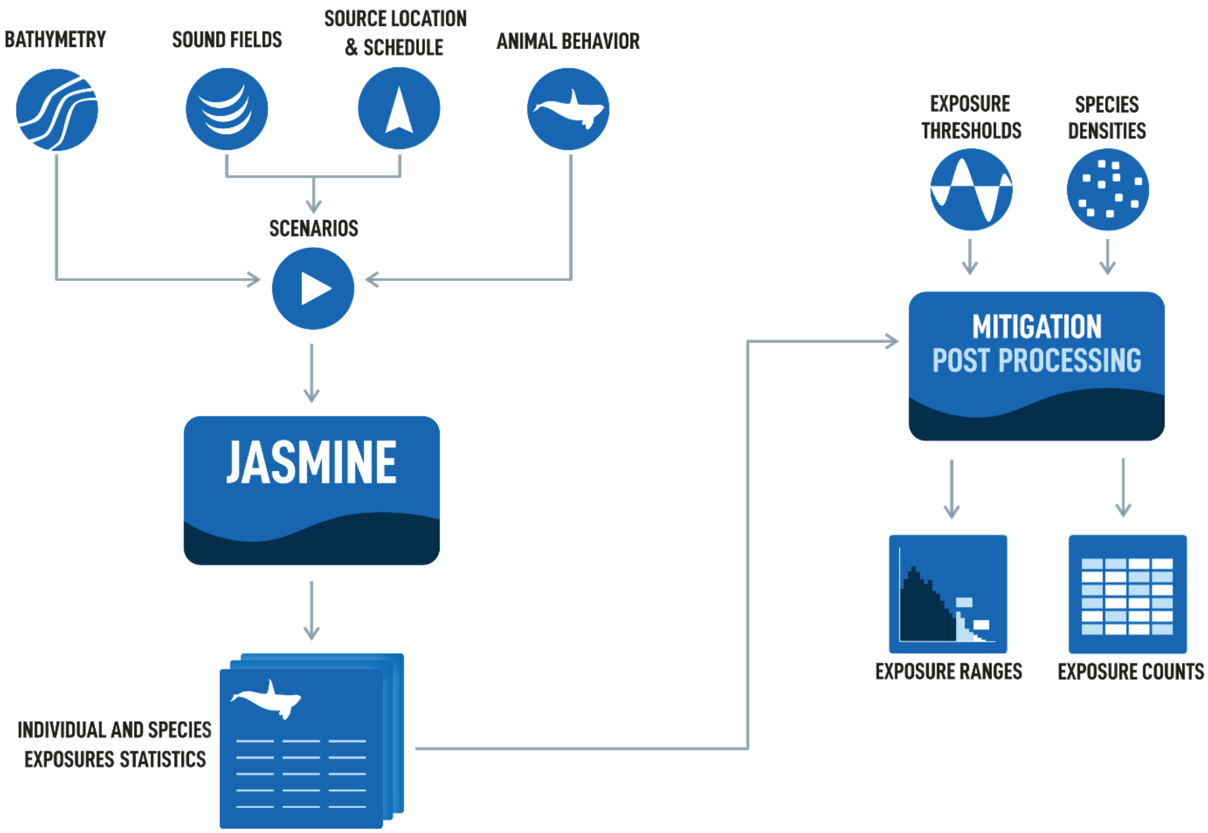

Figure 2.7-1. Exposure modeling process overview.

Model inputs include bathymetry, animal behavior parameters, and sound fields. Local bathymetry is needed to inform depth preferences and swimming and diving behaviors. Time-varying, three-dimensional sound fields are used to simulate the sounds that animals would be exposed to over the course of the operations, and the sound fields are sampled by model receivers (animats). By programming animats to behave like marine species that may be present near the SRWF (Figure 2.7-2) the sound fields are sampled in a way that real animals in the area are expected to. The parameters used for forecasting realistic behaviors (e.g., diving, foraging, and surface times) were determined and interpreted from marine species studies (e.g., tagging studies) where available, or reasonably extrapolated from related species (Appendix H.2). The outputs of the simulation are the exposure summary statistics for each animat.

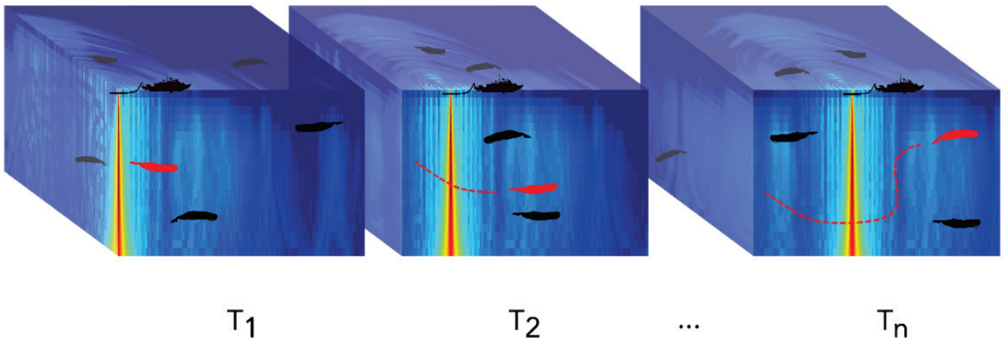

Figure 2.7-2. Depiction of animats in an environment with a moving sound field. Example animat (red) shown moving with each time step. The acoustic exposure of each animat is determined by where it is in the sound field, and its exposure history is accumulated as the simulation steps through time.

Sequential Operations

When simulating sequential operations in JASMINE, animats are exposed to only one sound field at a time. Received levels are summed over each animat's track over a 24-hour time window for cumulative metrics (SEL) (Appendix I.1.1). Single-exposure metrics (e.g., SPL) are recorded at each simulation time step, and the maximum received level is reported.

Cumulative Operations

When simulating concurrent operations in JASMINE, sound fields from separate sources may be overlapping. For cumulative metrics (SEL), received energy from each source is summed over a 24-hour time window. For SPL, received levels are summed within each simulation time step and the resultant maximum SPL over all time steps is reported. Sources are summed such that receiving two equally loud sounds results in a 3-dB increase (incoherent summation).

Whether sequential or concurrent operations are done, the resulting cumulative or maximum receive levels are then compared to the threshold criteria described in Section 2.4 within each analysis period.

While most of the 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. Results with aversive behavior are included as a supplement and are presented for comparison purposes only (see Section 4.4.1.1.1). Appendix H.2 provides fuller description of animal movement modeling and the parameters used in the JASMINE simulations.

2.7.1. Implementing Pile Installation Schedules in JASMINE

Exposure modeling locations were chosen to represent expected construction activity in the lease area over a seven-day period. The pile installation schedules for both sequential and concurrent scenarios are described in Section 1.2.4.

The hammering schedule for each foundation type is determined from pile driving parameters. For a single pile, the installation time is calculated using the blow rate and blow count at each hammer energy level. A pile installation schedule is created for the simulation by assigning each strike of the pile to a time in the simulation, along with the closest associated sound field for that pile type and scenario. When multiple piles are driven per day, the same hammering schedule is used for the additional piles, with a delay between piles to allow for vessel movement and set up. Figure 2.7-3 displays a sequential operations scenario where one pile is installed at a time from one vessel. Figure 2.7-4 displays a concurrent operations scenario where two piles are installed simultaneously with two vessels operating, followed by another two piles simultaneously installed later in the day.

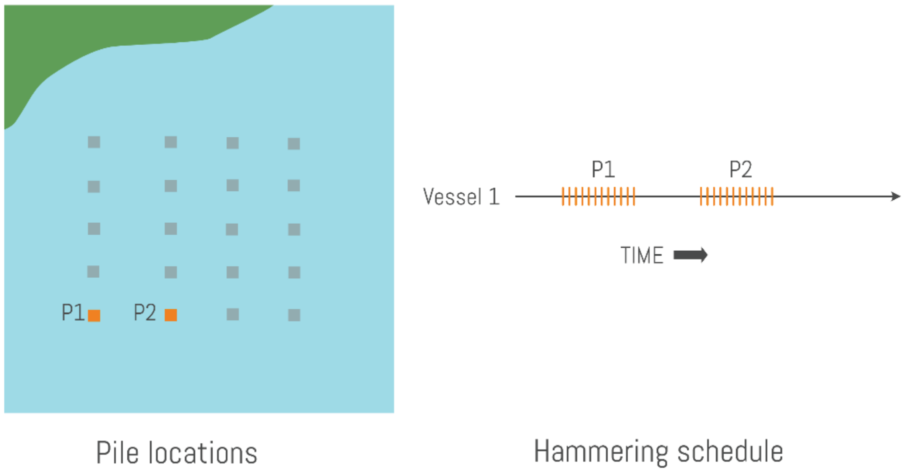

Figure 2.7-3. Pile installation schedule for sequential operations. Vertical orange tick marks show conceptual representations of each hammer strike.

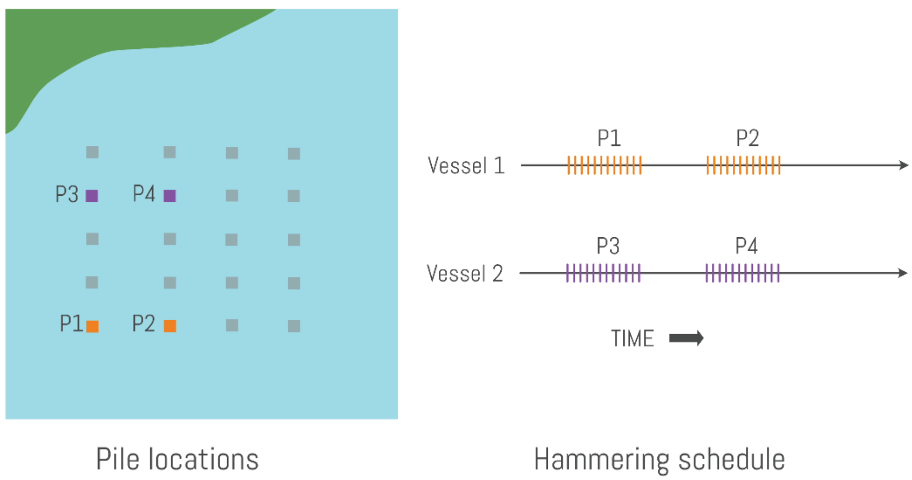

Figure 2.7-4. Pile installation schedule for concurrent operations. Vertical orange and purple tick marks show conceptual representations of each hammer strike.

2.8. Estimating Monitoring Zones for Mitigation

Monitoring zones for mitigation purposes have traditionally been estimated by determining the distance to injury and behavioral thresholds based only on acoustic information (see Appendix E.5). The traditional method tacitly assumes that all receivers (animals) in the area remain stationary for the duration of the sound event. Because where an animal is in a sound field, and the pathway it takes through the sound field, determines the received level for each animal, treating animals as stationary may not produce realistic estimates for the monitoring zones.

Animal movement and exposure modeling can be used to account for the movement of receivers when estimating distances for monitoring zones. The closest point of approach (CPA) for each of the species-specific animats during a simulation is recorded and then the CPA range that accounts for 95% of the animats that exceed an acoustic impact threshold is determined (Figure 2.8-1). 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 mammal and sea turtle species, and for each metric (PK, SEL, and SPL). 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 (Section 4.3.1.1).

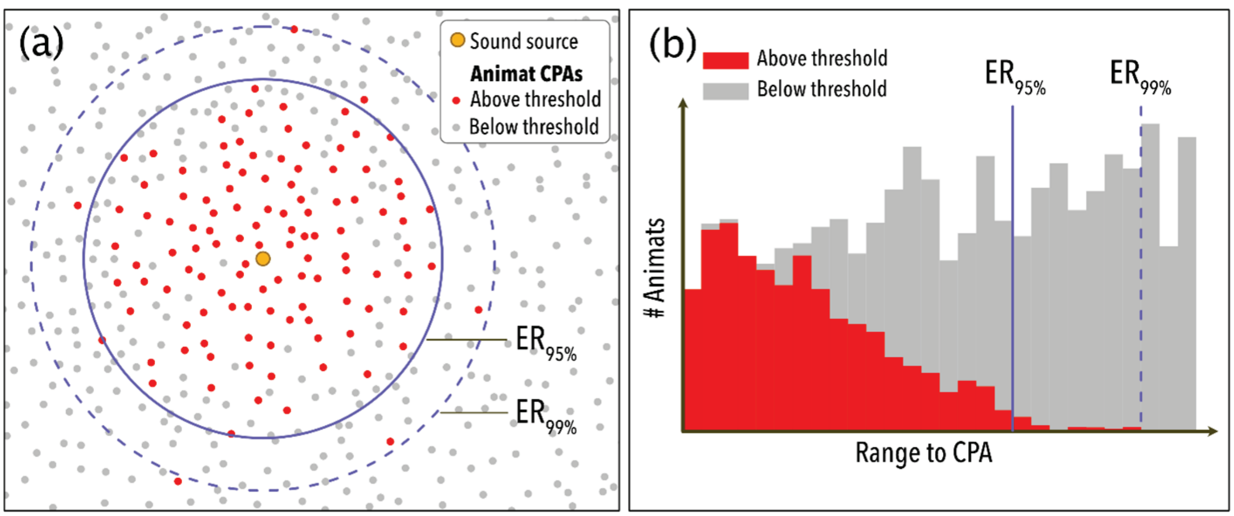

Figure 2.8-1. Example distribution of animat closest points of approach (CPAs). Panel (a) shows the horizontal distribution of animat CPAs near a sound source. Panel (b) shows the distribution of ranges to animat CPAs. The 95% and 99% Exposure Ranges ($ER_{95\%}$ and $ER_{99\%}$) are indicated in both panels.

3. Marine Fauna Included in the Acoustic Assessment

Marine mammals (cetaceans and pinnipeds), sea turtles, and fish were considered in this assessment. Common and uncommon marine mammals (Table 3.0-1) and sea turtle (Table 3.0-2) species were selected for quantitative assessment by acoustic impact analysis and exposure modeling. Quantitative assessment of rare species was not conducted because impacts to those species approach zero due to their low densities.

Table 3.0-1. Marine mammals potentially occurring within the regional waters of the Western North Atlantic OCS and the SRWF Project Area (table adapted from Section O of the COP).

Species	Stock	Regulatory status[a]	Relative occurrence in SRWF area	Abundance[b]
Suborder Mysticeti (Baleen Whales)				
Blue whale *(Balaenoptera musculus)*	Western North Atlantic	ESA Endangered MMPA Depleted NY State Endangered MA State Endangered	Uncommon	402
Fin whale[i] *(Balaenoptera physalus)*	Western North Atlantic	ESA Endangered MMPA Depleted NY State Endangered RI State SGCN MA State Endangered	Common	6,802
Humpback whale[i] (*Megaptera novaeangliae)*	Gulf of Maine	MMPA	Common	1,396
Minke whale[i] (*Balaenoptera acutorostrata)*	Canadian Eastern Coast	MMPA	Common	21,968
North Atlantic right whale[i] (*Eubalaena glacialis)*	Western North Atlantic	ESA Endangered MMPA Depleted NY State Endangered RI State SGCN MA State Endangered	Common	368[c]
Sei whale[i] (*Balaenoptera borealis)*	Nova Scotia[b]	ESA Endangered MMPA Depleted NY State Endangered MA State Endangered	Common	6,292
Suborder Odontoceti (Toothed Whales, Dolphins and Porpoises)				
Sperm whale[i] (*Physeter macrocephalus)*	North Atlantic	ESA Endangered MMPA Depleted NY State Endangered MA State Endangered	Uncommon	4,349
Pygmy sperm whale (*Kogia breviceps*)	Western North Atlantic	MMPA	Rare	7,750[d]
Dwarf sperm whale (*Kogia sima)*	Western North Atlantic	MMPA	Rare	
Cuvier's beaked whale (*Ziphius cavirostris)*	Western North Atlantic	MMPA	Rare	5,744
Mesoplodont beaked whales (*Mesoplodon spp*)	Western North Atlantic	MMPA	Rare	10,107[e]
Killer whale (*Orcinus orca)*	Western North Atlantic	MMPA	Rare	Unknown
False killer whale (*Pseudorca crassidens)*	Western North Atlantic	MMPA	Rare	1,791
Pygmy killer whale (*Feresa attenuata*)	Western North Atlantic	MMPA	Rare	Unknown
Short-finned pilot whale[i] (*Globicephala macrorhynchus*)	Western North Atlantic	MMPA	Uncommon	28,924
Long-finned pilot whale[i] *(Globicephala melas)*	Western North Atlantic	MMPA	Uncommon	39,215

Species	Stock	Regulatory status[a]	Relative occurrence in SRWF area	Abundance[b]
Melon-headed whale (*Peponocephala electra*)	Western North Atlantic	MMPA	Rare	Unknown
Risso's dolphin[i] (*Grampus griseus)*	Western North Atlantic	MMPA	Uncommon	35,215
Short-beaked common dolphin[i] (*Delphinus delphis)*	Western North Atlantic	MMPA	Common	172,974
Fraser's dolphin (*Lagenodelphis hosei)*	Western North Atlantic	MMPA	Rare	Unknown
Atlantic white-sided dolphin[i] *(Lagenorhynchus acutus)*	Western North Atlantic	MMPA	Common	93,233
Pan-tropical spotted dolphin (*Stenella attenuate)*	Western North Atlantic	MMPA	Rare	6,593
Clymene dolphin (*Stenella clymene)*	Western North Atlantic	MMPA	Rare	4,237
Striped dolphin (*Stenella coeruleoalba)*	Western North Atlantic	MMPA	Rare	67,036
Atlantic spotted dolphin[i] (*Stenella frontalis)*	Western North Atlantic	MMPA	Uncommon	39,921
Spinner dolphin (*Stenella longirostris)*	Western North Atlantic	MMPA	Rare	4,102
Rough-toothed dolphin (*Steno bredanensis)*	Western North Atlantic	MMPA	Rare	136
Common bottlenose dolphin[i] (*Tursiops truncates)*	Western North Atlantic, offshore[f]	MMPA	Common	62,851
	Western North Atlantic, Northern migratory coastal	MMPA Depleted	Rare	6,639
Harbor porpoise[i] (*Phocoena phocoena)*	Gulf of Maine/Bay of Fundy	RI State SGCN MMPA	Common	95,543
Suborder Pinnipedia				
Harbor seal[i] (*Phoca vitulina)*	Western North Atlantic	NY State SC RI State SGCN MMPA	Regular	61,336
Gray seal[i] (*Halichoerus grypus)*	Western North Atlantic	MMPA	Common	27,300[g]
Harp seal (*Pagophilus groenlandicus)*	Western North Atlantic	MMPA	Uncommon	Unknown[h]
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 2021).
[c] NARW consortium has released the preliminary 2021 report card results predicting a NARW population of 336 (Pettis and et al. 2021 in draft). However, the consortium “alters” the methods of Pace et al. (2017) to subtract additional mortality. This method is used in order to estimate all mortality, not just the observed mortality, therefore the (NOAA Fisheries 2021) SAR will be used to report an unaltered output of the Pace et al. (2017) model (DoC and NOAA 2020).
[d] This estimate includes both dwarf and pygmy sperm whales. Source: Hayes et al. (2021).
[e] 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).
[f] Bottlenose dolphins occurring in the SRWF Area likely belong to the Western North Atlantic Offshore stock (Hayes et al. 2021).
[g] Estimate of gray seal population in US waters. Data are derived from pup production estimates; Hayes et al. (2019, 2020, 2021) notes that uncertainty about the relationship between whelping areas along with a lack of reproductive and mortality data make it difficult to reliably assess the population trend.
[h] NOAA Fisheries (2021) reports insufficient data to estimate the population size in US waters; the best estimate for the whole population is 7.6 million.
[I] Modeled species.

Table 3.0-2. Sea turtle species potentially occurring within the regional waters of the Western North Atlantic OCS and Project Area (Table adapted from Appendix O of the COP).

Species	Current listing status[a]	Relative occurrence in SRWF area
Leatherback sea turtle(*Dermochelys coriacea*)	ESA Endangered NY State Endangered RI State Endangered MA State Endangered	Common
Loggerhead sea turtle (*Caretta caretta*)	ESA Threatened NY State Threatened RI State Endangered MA State Threatened	Common
Kemp's ridley sea turtle (*Lepidochelys kempii*)	ESA Endangered NY State Endangered RI State Endangered MA State Endangered	Uncommon
Green sea turtle (*Cheloria mydas*)	ESA Threatened NY State Threatened RI State Endangered MA State Threatened	Uncommon

[a] Listing status as stated in NOAA Fisheries (n.d.), MA NHESP (2019); RI DEM (2011); NYSDEC (2020a).

Atlantic and shortnose sturgeon (*Acipenser oxyrinchus oxyrinchus* and *A. brevirostrum*) are endangered fish species that may occur off the northeast Atlantic coast. 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). It is therefore unlikely that Atlantic sturgeon will be in the Project Area during the pile installation phase of this Project. Shortnose sturgeon occur primarily in fresh and estuarine waters and only occasionally enter the coastal ocean. Adults ascend rivers to spawn from February to April, and eggs are deposited over hard bottom, in shallow, fast-moving water (Dadswell et al. 1984). Because of their preference for mainland rivers and fresh and estuarine waters, shortnose sturgeon are unlikely to be found in the vicinity of the Project Area.

3.1. 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 3.1-1. These were obtained using the Duke University Marine Geospatial Ecological Laboratory model results (Roberts et al. 2016a, 2016b, 2017, 2018, 2021) and include recently updated model results for North Atlantic right whale (NARW). The updated model includes new estimates for NARW abundance in Cape Cod Bay in December. The updated NARW density 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 this report uses the 2010–2018 density predictions.

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

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 3.1-1). Densities were computed for an entire year to coincide with possible planned activities. In cases where monthly densities were unavailable, annual mean densities were used instead.

Long-finned and short-finned pilot whales were modeled separately, although there is only one density model for pilot whales from Roberts et al. (2016a, 2016b, 2017). Densities were adjusted based on their relative abundances, e.g.,

$$D_{long\text{-}finned} = D_{\mathrm{overall}} \times N_{\mathrm{long\text{-}finned}} / (N_{\mathrm{long\text{-}finned}} + N_{\mathrm{short\text{-}finned}}) \quad (1)$$

where D is density and N is abundance.

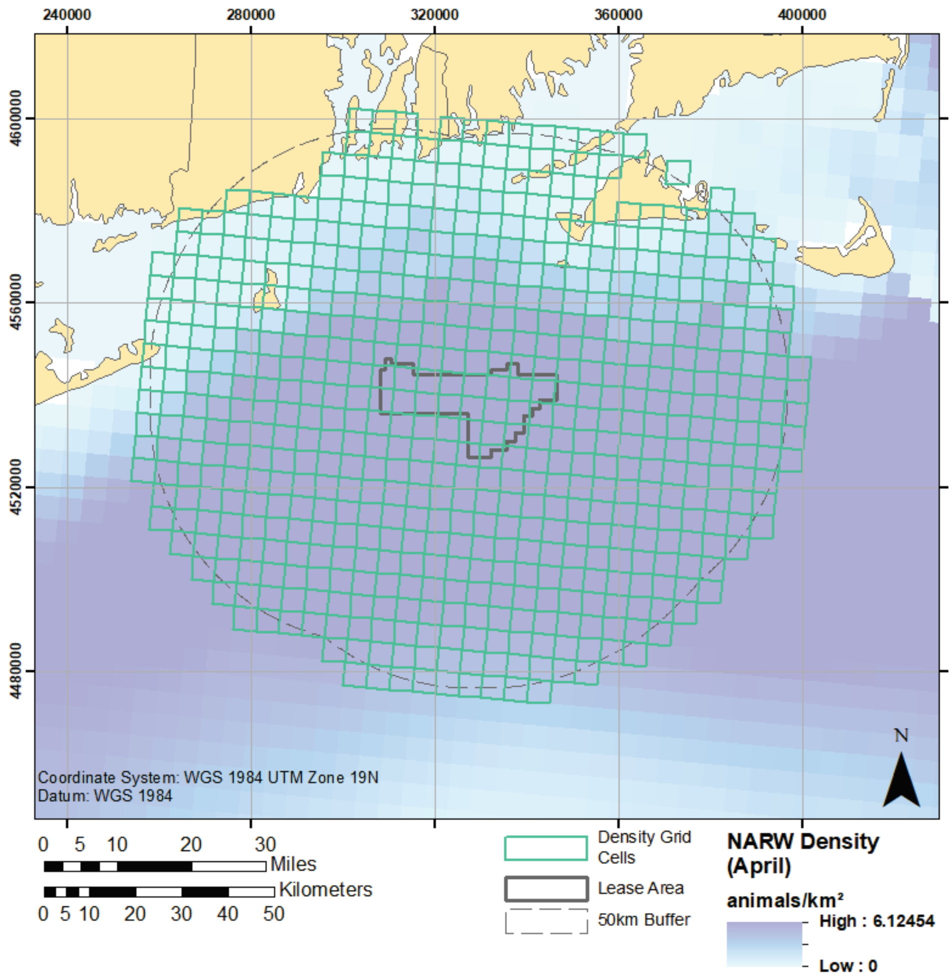

Figure 3.1-1. Marine mammal (e.g., NARW) density map showing highlighted grid cells used to calculate mean monthly species estimates within a 50 km buffer around the lease area (Roberts et al. 2016a, 2021).

Table 3.1-1. Mean monthly marine mammal density estimates for all modeled species within a 50 km buffer around the lease area.

Species	Monthly densities (animals/100 km²)[a]												Annual mean
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Fin whale[b]	0.144	0.141	0.152	0.282	0.254	0.263	0.301	0.282	0.251	0.148	0.116	0.116	0.204
Minke whale (migrating)	0.049	0.060	0.063	0.141	0.207	0.179	0.060	0.039	0.044	0.062	0.025	0.036	0.080
Humpback whale	0.044	0.024	0.028	0.131	0.124	0.134	0.084	0.061	0.190	0.123	0.050	0.064	0.088
North Atlantic right whale[b]	0.381	0.493	0.540	0.603	0.204	0.013	0.002	0.002	0.002	0.006	0.031	0.163	0.203
Sei whale[b] (migrating)	0.001	0.002	0.001	0.027	0.025	0.015	0.004	0.002	0.005	0.001	0.001	0.001	0.007
Atlantic white sided dolphin	2.719	1.533	1.650	3.576	6.012	5.391	3.135	1.619	2.101	3.030	3.215	3.829	3.151
Atlantic spotted dolphin	0.001	0.001	0.002	0.010	0.019	0.039	0.074	0.103	0.097	0.125	0.060	0.009	0.045
Short-beaked common dolphin	14.196	3.424	1.287	2.812	4.902	5.779	5.470	8.028	11.868	14.398	10.990	19.833	8.582
Bottlenose dolphin, offshore	0.628	0.094	0.025	0.681	0.957	2.911	6.333	5.916	5.485	3.206	1.690	1.171	2.425
Risso's dolphin	0.018	0.010	0.004	0.005	0.012	0.016	0.047	0.082	0.053	0.018	0.020	0.038	0.027
Long-finned pilot whale[c]	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402
Short-finned pilot whale[c]	0.297	0.297	0.297	0.297	0.297	0.297	0.297	0.297	0.297	0.297	0.297	0.297	0.297
Sperm whale[b]	0.002	0.003	0.002	0.003	0.005	0.011	0.029	0.024	0.010	0.009	0.007	0.002	0.009
Harbor porpoise	4.016	7.447	11.086	6.681	3.393	0.501	0.362	0.358	0.284	0.433	2.380	2.638	3.298
Gray seal	14.325	13.390	7.913	7.733	9.346	3.629	1.007	0.435	0.598	1.227	1.953	10.207	5.980
Harbor seal	14.325	13.390	7.913	7.733	9.346	3.629	1.007	0.435	0.598	1.227	1.953	10.207	5.980
Harp seal	14.325	13.390	7.913	7.733	9.346	3.629	1.007	0.435	0.598	1.227	1.953	10.207	5.980

[a] Density estimates are from habitat-based density modeling of the entire Atlantic Exclusive Economic Zone (EEZ) (Roberts et al. 2016a, 2016b, 2017, 2018, 2021).
[b] Listed as Endangered under the ESA.
[c] Density adjusted by relative abundance.

3.2. 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 3.2-1.

Table 3.2-1. Sea turtle density estimates for all modeled species within a 50 km buffer around the lease area.

Species	Density[a] (animals/100 km^2)			
	Spring	Summer	Fall	Winter
Kemp's ridley sea turtle[b]	0.018	0.018	0.018	0.018
Leatherback sea turtle[b]	0.021	0.630[c]	0.873[c]	0.021
Loggerhead sea turtle	0.141	0.206[d]	0.755[d]	0.141
Green sea turtle[e]	0.018	0.018	0.018	0.018

[a] Density estimates are extracted from SERDP-SDSS NODE database within a 50 km buffer of the 501 South area, unless otherwise noted.
[b] Listed as Endangered under the ESA.
[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).
[e] 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.

4. Results

The primary sources of underwater sound generated during the Project are associated with the installation of monopiles, jacket pile foundations, casing pipes, and goal posts. Results associated with these primary sound sources are presented in this section. For secondary sound sources associated with the Project, including support vessels, aircraft, high resolution geophysical surveys, drilling, dredging, and wind turbine operations, a qualitative description of their effects is provided in Appendix F. These effects are expected to be of very low or low risk.

Sound fields were modeled for monopiles, jacket foundation piles, the casing pipe, and goal post installations at locations representative of the range of water depths within the SRWF and SRWEC (Table 1.2-2, Table 1.2-5, and Table 1.2-8; Figure 1.2-1 and Figure 1.2-2). This section summarizes the source modeling results (Section 4.1), the acoustic propagation modeling results (Section 4.2), the acoustic range results to species' thresholds from impact and vibratory pile driving (Section 4.3), and the exposure range estimates for marine mammals (Section 4.5.1) and sea turtles (Section 4.5.1.2).

For exposure-based range estimates ($ER_{95\%}$), animal movement modeling was used to estimate ranges to regulatory-defined acoustic thresholds for marine mammals and sea turtles for monopile and jacket foundations (Section 4.4.2.2). Results based on both summer and winter sound speed profiles are reported. NAS mitigation was considered by attenuating the sound fields in the simulations by 0, 6, 10, and 15 dB. The report tables indicate the relevant Wood step function for each species (migrating, sensitive (harbor porpoise only), or general (all others)) and the reader should refer to Table 2.5-4 for more details.

4.1. Modeled Sound Sources

4.1.1. Monopile Foundations – Impact Pile Driving

Forcing functions were computed for the 7/12 m monopile using GRLWEAP 2010 (GRLWEAP, Pile Dynamics 2010) (Figure 4.1-1). The model assumed direct contact between the representative hammer, helmet, and pile (i.e., no cushion material). The forcing functions serve as the inputs to JASCO's pile driving source model used to estimate equivalent acoustic source characteristics as detailed in Appendix D.1. Decidecade spectral source levels were modeled at 10 m range from the monopile and results using an average summer sound speed profile are shown in Figures 4.1-2 and 4.1-3 for both locations considered. The spectral levels at 10 m range from the pile corresponding to an average *winter* sound speed profile are almost identical, and therefore are not shown in this report.

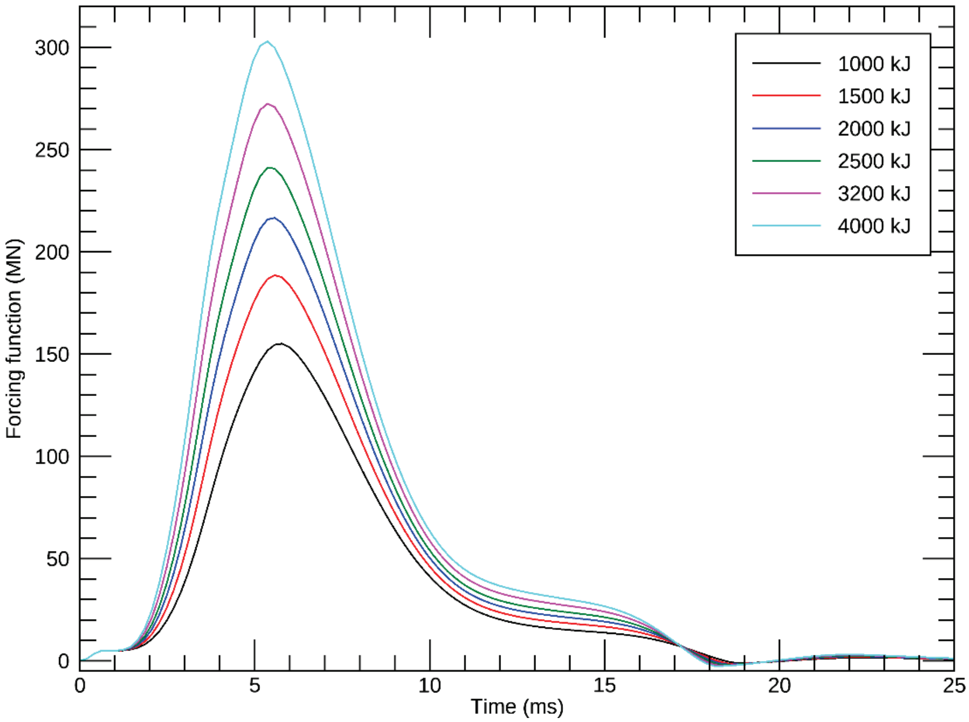

Figure 4.1-1. Modeled forcing functions versus time for a 7/12 m diameter monopile, for each hammer energy setting.

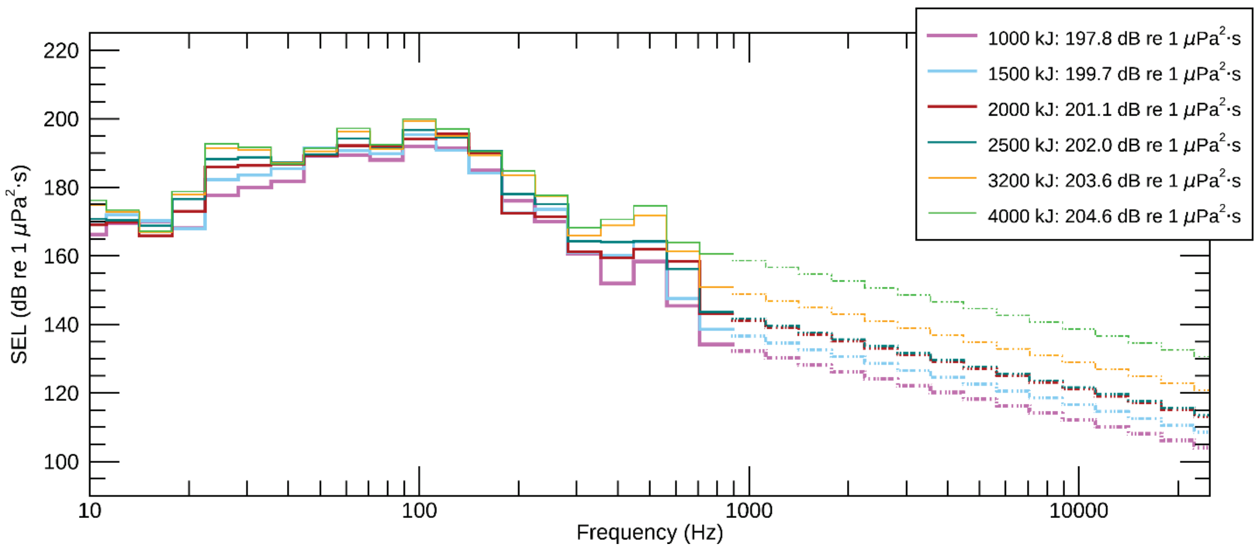

Figure 4.1-2. Location ID-97: Decidecade band spectral levels at 10 m range from the 7/12 m diameter monopile, assuming an expected installation scenario using an IHC S-4000 kJ hammer (see Figure 1.2-1) with an average summer sound speed profile.

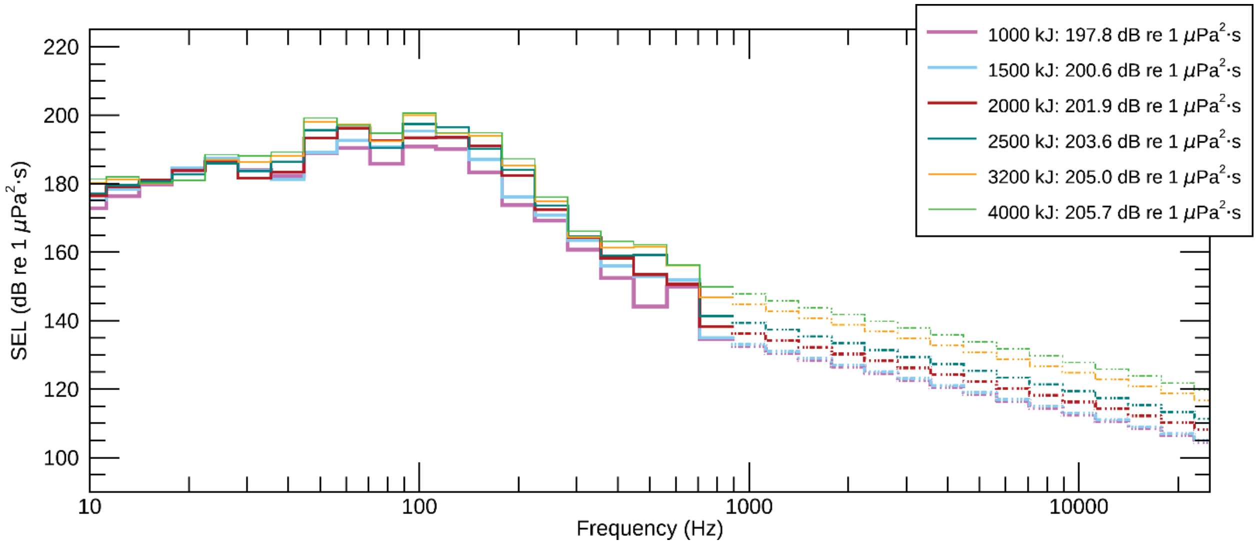

Figure 4.1-3. Location ID-259: Decidecade band spectral levels at 10 m range from the 7/12 m diameter monopile assuming an expected installation scenario using an IHC S-4000 kJ hammer (see Figure 1.2-1) with an average summer sound speed profile.

4.1.2. Jacket Foundation Piles – Impact Pile Driving

Forcing functions for the jacket foundation piles were obtained by the same procedure described in Section 4.1.1. Figure 4.1-4 shows the forcing functions for each hammer energy setting, and Figure 4.1-5 shows the corresponding decidecade spectral levels at 10 m range from the jacket foundation pile, using an average summer sound speed profile.

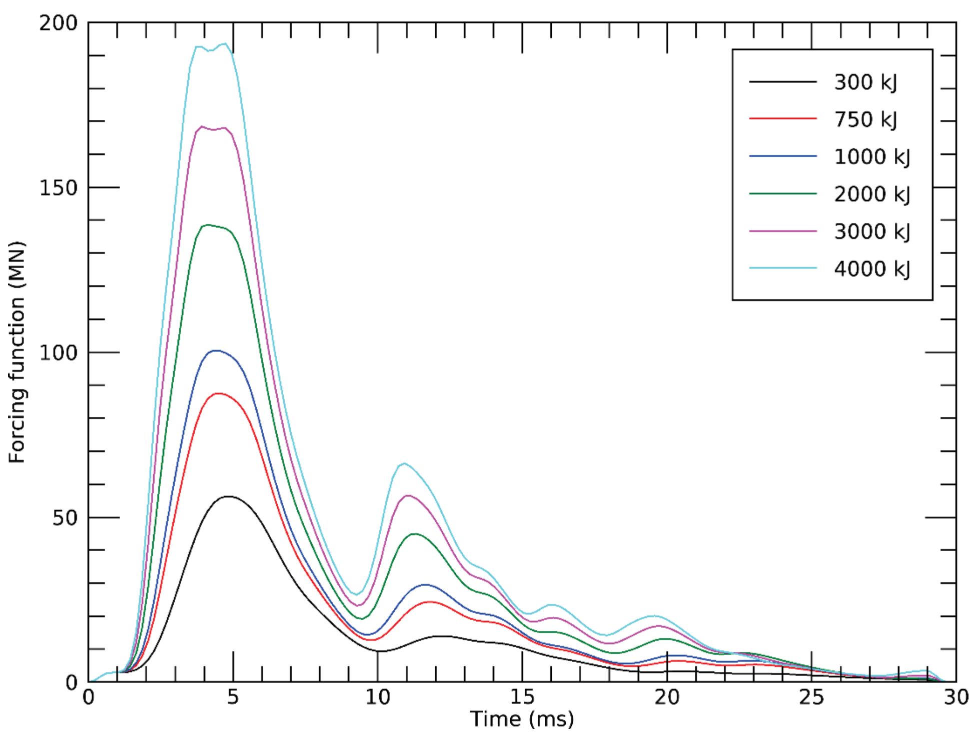

Figure 4.1-4. Modeled forcing functions versus time for jacket foundation piles, for each hammer energy setting.

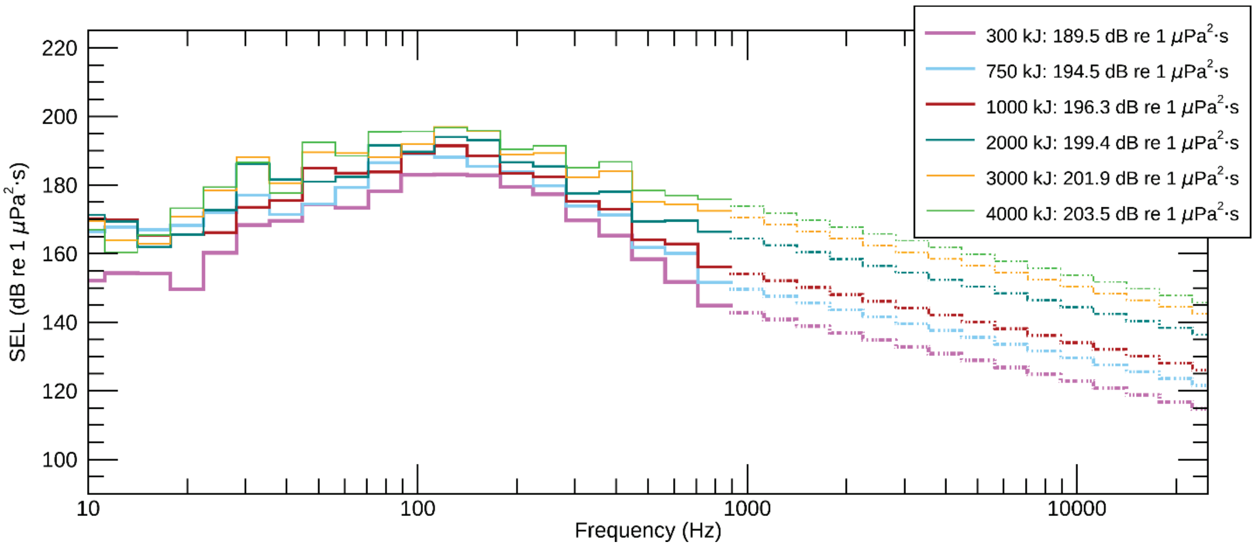

Figure 4.1-5. Location ID-200: Decidecade band spectral levels at 10 m range from the jacket foundation pile assuming an expected installation scenario using an IHC S-4000 kJ hammer (see Figure 1.2-1) with an average summer sound speed profile.

4.1.3. Casing Pipe – Impact Pile Driving

The forcing function for driving angled casing pipes was obtained by the same procedure described in Section 4.1.1 and is shown in Figure 4.1-6. Figure 4.1-7 shows the corresponding decidecade spectral levels in four different radial directions from the pipe, using an average summer sound speed profile.

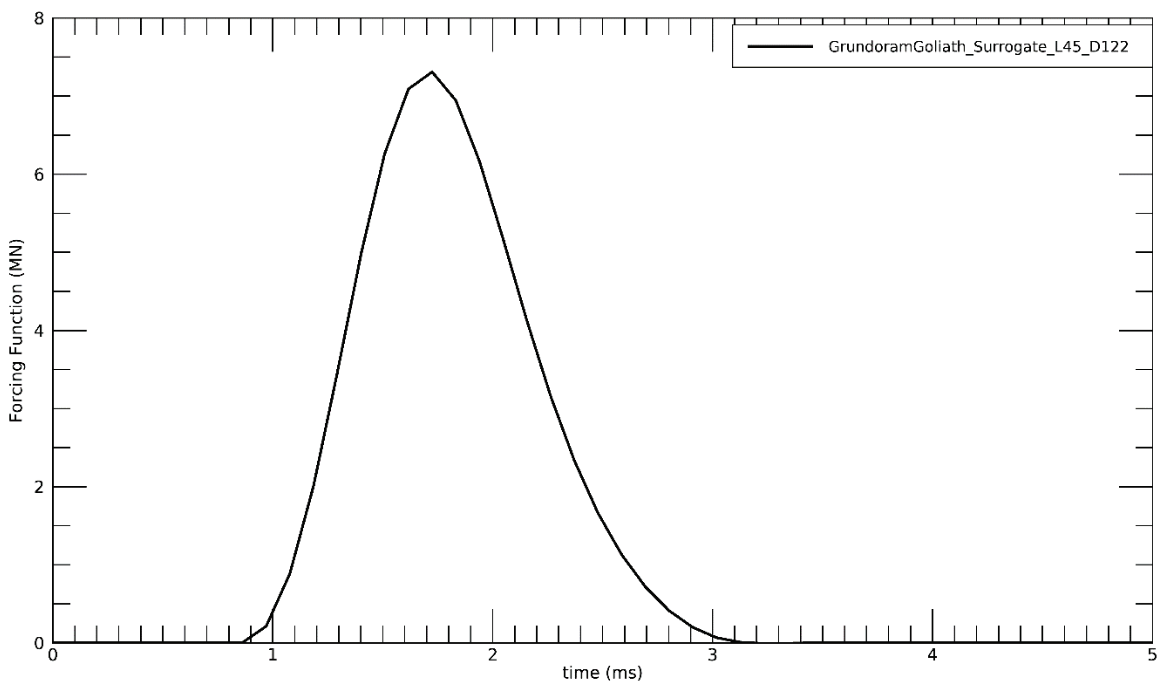

Figure 4.1-6. Modeled forcing function versus time for casing pipe, for Grundoram Goliath operating at 18 kJ.

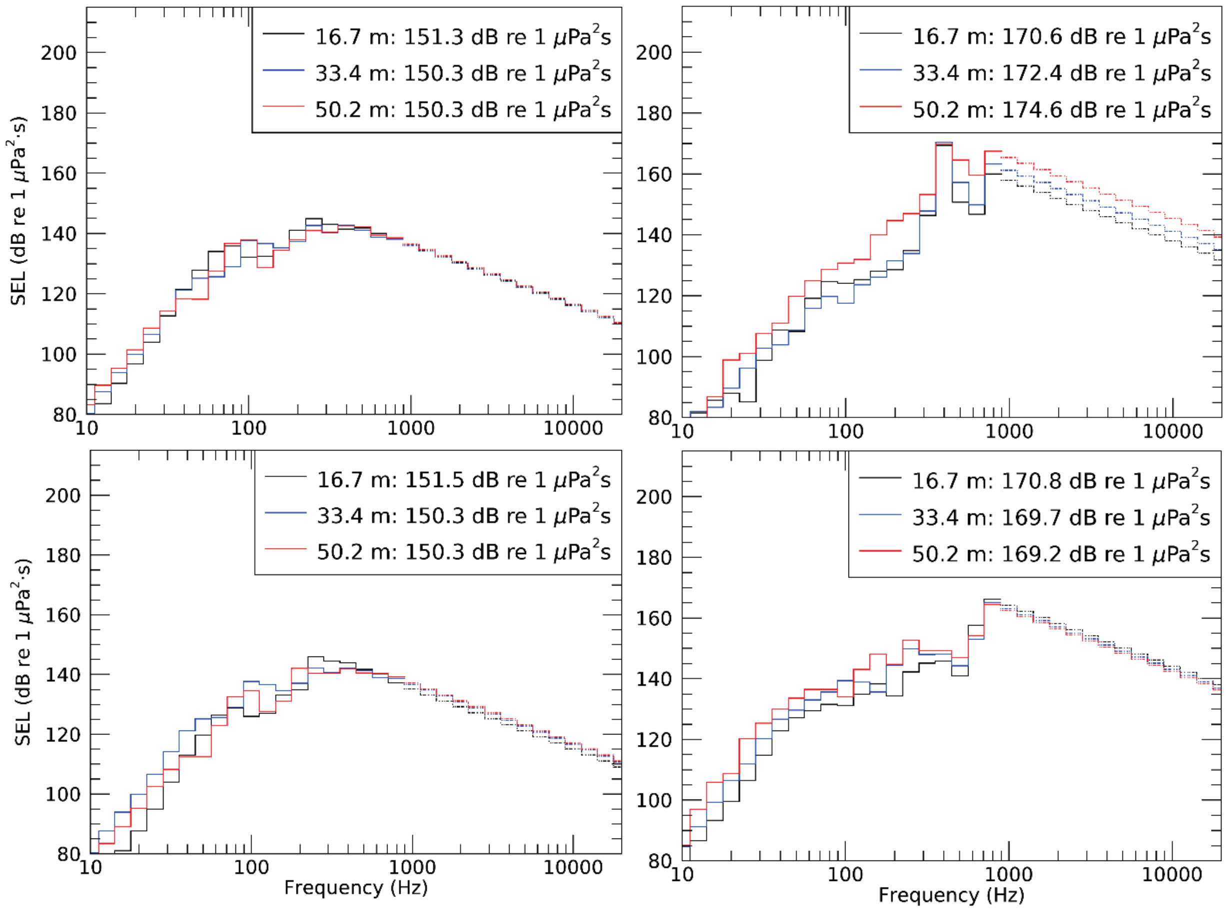

Figure 4.1-7. Decidecade band spectral levels at 44 m range from the casing pipe installed with a Grundoram Goliath operating at 18 kJ with an average summer sound speed profile. Top left: 60°, top right: 150°, bottom left: 240°, and bottom right: 330°.

4.2. Modeled Sound Fields

Three dimensional (3-D) sound fields for the 7/12 m monopiles and the jacket foundation piles, the casing pipe, and goal posts were calculated using the source characteristics (Sections 4.1.1 to 4.1.2, and Appendix D.1) at representative locations (Table 1.2-2, Table 1.2-5, Table 1.2-8, and Table 1.2-10). Environmental parameters (bathymetry, geoacoustic information, and sound speed profiles) chosen for the propagation modeling and the modeling procedures are found in Appendix E.

4.3. Acoustic Range Estimates (R_{max} and $R_{95\%}$)

This section provides tabulated results of the estimated ranges to the regulatory acoustic thresholds. These acoustic ranges, within which sound levels could exceed regulatory thresholds, were determined using a maximum-over-depth approach. The results are presented as radial distances R_{max} and $R_{95\%}$, where R_{max} is the maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field, and $R_{95\%}$ is the maximum range at which the sound level was encountered after the 5% farthest such points were excluded (see Appendix E.5 for details).

4.3.1. Monopile Foundations and Jacket Foundation Piles – Impact Pile Driving

Radial distances to various sound level isopleths for single hammer strikes of the 7/12 m monopiles and the jacket foundation piles at the different hammer energy levels are shown in Appendix G. For the monopiles, a comparison of unweighted broadband received levels at 750 m was made between the computed sound fields in this study and the forecasted levels for 7/12 m monopiles from the ITAP empirical model (Bellmann et al. 2020b) with the results presented in Appendix H.

The following section describes acoustic ranges where sound levels could exceed fish regulatory thresholds. Acoustic ranges specific to marine mammal and sea turtle threshold exceedances from impact pile driving of the 7/12 m monopile foundations and the jacket foundation piles are provided in Appendix G.

4.3.1.1. Fish Acoustic Range Estimates

Fish were considered static receivers, i.e., they do not move during the pile driving event. The calculated acoustic ranges for fish to the GARFO (2019) and Popper et al. (2014) thresholds with 10 dB of broadband attenuation are shown in Tables 4.3-1 and 4.3-2 for summer and winter seasons, respectively. Tables corresponding to 0, 6, and 15 dB attenuation can be found in Appendix G.5.

Table 4.3-1. All locations, summer: Modelled acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish, for each hammer energy assuming 10 dB attenuation, for pile installations in average summer sound speed conditions.

Faunal group	Metric	Threshold	Location ID-97 (7/12 m monopile)					Location ID-259 (7/12 m monopile)					Location ID-200 (jacket foundation piles)					
			Hammer energy (kJ)					Hammer energy (kJ)					Hammer energy (kJ)					
			1000	1500	2000	2500	3200	1000	1500	2000	2500	3200	300	750	1000	2000	3000	4000
Small fish[a]	L_E	183	8.04					9.01					**1 pile**:9.94; **2 piles**:12.53; **3 piles**:14.03; **4 piles**:15.17;					
	L_{pk}	206	0.06	0.09	0.11	0.12	0.13	0.08	0.11	0.13	0.13	0.15	-	0.09	0.10	0.13	0.11	0.09
Large fish[a]	L_E	187	6.19					7.14					**1 pile**:7.52; **2 piles**:9.20; **3 piles**:10.65; **4 piles**:11.73;					
	L_{pk}	206	0.06	0.09	0.11	0.12	0.13	0.08	0.11	0.13	0.13	0.15	-	0.09	0.10	0.13	0.11	0.09
All fish[b]	L_p	150	6.57	7.91	8.95	9.60	11.18	7.61	8.96	10.05	10.67	11.77	4.80	6.17	6.90	8.10	12.03	14.85
Fish without swim bladder[c]	L_E	219	0.14					0.16					**1 pile**:0.20; **2 piles**:0.31; **3 piles**:0.44; **4 piles**:0.52;					
	L_{pk}	213	-	-	0.01	0.02	0.03	-	-	-	0.02	0.03	-	-	-	-	0.06	0.05
Fish with swim bladder not involved in hearing[c]	L_E	210	0.64					0.69					**1 pile**:0.83; **2 piles**:1.27; **3 piles**:1.58; **4 piles**:1.83;					
	L_{pk}	207	0.02	0.08	0.09	0.11	0.12	0.03	0.09	0.11	0.13	0.14	-	0.09	0.09	0.12	0.09	0.09
Fish with swim bladder involved in hearing[c]	L_E	207	0.95					1.10					**1 pile**:1.27; **2 piles**:1.83; **3 piles**:2.22; **4 piles**:2.51;					
	L_{pk}	207	0.02	0.08	0.09	0.11	0.12	0.03	0.09	0.11	0.13	0.14	-	0.09	0.09	0.12	0.09	0.09
Eggs and larvae[c]	L_E	210	0.64					0.69					**1 pile**:0.83; **2 piles**:1.27; **3 piles**:1.58; **4 piles**:1.83;					
	L_{pk}	207	0.02	0.08	0.09	0.11	0.12	0.03	0.09	0.11	0.13	0.14	-	0.09	0.09	0.12	0.09	0.09

Dashes indicate that the acoustic threshold was not reached.
Small fish are defined as having a total mass of less than 2 g; large fish are defined as having a total mass of greater than or equal to 2 g.
L_E = unweighted sound exposure level (dB re 1 µPa^2·s) over the entire pile (so encompasses all hammer energies); L_p = unweighted sound pressure level (dB re 1 µPa); L_{pk} = unweighted peak sound pressure level (dB re 1 µPa).

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

Table 4.3-2. All locations, winter: Modelled acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish, for each hammer energy with 10 dB attenuation, for pile installations in average winter sound speed conditions.

Faunal group	Metric	Threshold	Location ID-97 (7/12 m monopile)					Location ID-259 (7/12 m monopile)					Location ID-200 (jacket foundation piles)					
			Hammer energy (kJ)					Hammer energy (kJ)					Hammer energy (kJ)					
			1000	1500	2000	2500	3200	1000	1500	2000	2500	3200	300	750	1000	2000	3000	4000
Small fish[a]	L_E	183	9.36					10.14					**1 pile**:12.49; **2 piles**:16.42; **3 piles**:18.98; **4 piles**:21.61;					
	L_{pk}	206	0.05	0.09	0.11	0.12	0.13	0.06	0.11	0.13	0.14	0.15	-	0.09	0.11	0.13	0.11	0.09
Large fish[a]	L_E	187	6.97					7.82					**1 pile**:8.52; **2 piles**:11.38; **3 piles**:13.39; **4 piles**:15.03;					
	L_{pk}	206	0.05	0.09	0.11	0.12	0.13	0.06	0.11	0.13	0.14	0.15	-	0.09	0.11	0.13	0.11	0.09
All fish[b]	L_p	150	7.36	9.25	10.90	12.53	14.57	8.43	10.29	11.61	12.27	13.06	5.01	6.54	7.40	8.82	16.68	19.36
Fish without swim bladder[c]	L_E	219	0.14					0.16					**1 pile**:0.16; **2 piles**:0.33; **3 piles**:0.45; **4 piles**:0.53;					
	L_{pk}	213	-	-	0.01	0.02	0.03	-	-	-	0.02	0.03	-	-	-	-	0.06	0.05
Fish with swim bladder not involved in hearing[c]	L_E	210	0.67					0.71					**1 pile**:0.85; **2 piles**:1.30; **3 piles**:1.61; **4 piles**:1.86;					
	L_{pk}	207	0.02	0.08	0.10	0.11	0.12	0.03	0.09	0.11	0.13	0.14	-	0.08	0.09	0.12	0.10	0.09
Fish with swim bladder involved in hearing[c]	L_E	207	0.98					1.16					**1 pile**:1.30; **2 piles**:1.86; **3 piles**:2.28; **4 piles**:2.58;					
	L_{pk}	207	0.02	0.08	0.10	0.11	0.12	0.03	0.09	0.11	0.13	0.14	-	0.08	0.09	0.12	0.10	0.09
Eggs and larvae[c]	L_E	210	0.67					0.71					**1 pile**:0.85; **2 piles**:1.30; **3 piles**:1.61; **4 piles**:1.86;					
	L_{pk}	207	0.02	0.08	0.10	0.11	0.12	0.03	0.09	0.11	0.13	0.14	-	0.08	0.09	0.12	0.10	0.09

Dashes indicate that the acoustic threshold was not reached.
Small fish are defined as having a total mass of less than 2 g; large fish are defined as having a total mass of greater than or equal to 2 g.
L_E = unweighted sound exposure level (dB re 1 µPa²·s) over the entire pile (so encompasses all hammer energies); L_p = unweighted sound pressure level (dB re 1 µPa); L_{pk} = unweighted peak sound pressure level (dB re 1 µPa).
[a] FHWG (2008), Stadler and Woodbury (2009).
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011).
[c] Popper et al. (2014).

4.3.2. Casing Pipe – Impact Pile Driving

The acoustic radial distances (R_{max} and $R_{95\%}$) to thresholds when driving the casing pipe are shown for marine mammals in Table 4.3-3 and for fish and sea turtles in Table 4.3-4.

Table 4.3-3. Casing pipe (1.2 m diameter, Grundoram Taurus, 10 m penetration depth) acoustic ranges (R_{max} and $R_{95\%}$ in km) to auditory injury (PTS) thresholds for marine mammal functional hearing groups in average winter sound speed conditions.

Faunal group	Metric	Threshold	R_{max}	$R_{95\%}$
All cetaceans	L_p [a]	160	1.38	0.92
Low-frequency (LF) cetaceans	L_E [b]	183	4.35	3.87
	L_{pk} [b]	219	-	-
Mid-frequency (MF) cetaceans	L_E [b]	185	0.29	0.23
	L_{pk} [b]	230	-	-
High-frequency (HF) cetaceans	L_E [b]	155	5.07	3.95
	L_{pk} [b]	202	0.13	0.13
Phocid pinnipeds in water (PPW)	L_E [b]	185	1.67	1.29
	L_{pk} [b]	218	-	-

Dashes indicate that the acoustic threshold was not reached.
L_E = frequency-weighted sound exposure level (dB re 1 µPa²·s); L_p = unweighted sound pressure level (dB re 1 µPa); L_{pk} = unweighted peak sound pressure level (dB re 1 µPa).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.
[a] NMFS (2005). [b] NMFS (2018).

Table 4.3-4. Casing pipe (1.2 m diameter, Grundoram Taurus, 10 m penetration depth) acoustic ranges (R_{max} and $R_{95\%}$ in km) for fish and sea turtle hearing groups at modeling location ID-01 considering 0.5 pile installation per day and using average winter sound speed conditions.

Faunal group	Metric	Threshold	R_{max}	$R_{95\%}$
Fish equal to or greater than 2 g	L_E [a]	186	3.15	2.82
	L_{pk} [a]	206	-	-
	L_p [b]	150	2.84	2.51
Fish less than 2 g	L_E [a]	183	4.72	4.12
	L_{pk} [a]	206	-	-
	L_p [b]	150	2.84	2.51
Fish without swim bladder	L_E [c]	216	0.16	0.16
	L_{pk} [c]	213	-	-
Fish with swim bladder not involved in hearing	L_E [c]	203	0.85	0.62
	L_{pk} [c]	207	-	-
Fish with swim bladder involved in hearing	L_E [c]	203	0.85	0.62
	L_{pk} [c]	207	-	-
Sea turtles	L_E [d]	204	0.50	0.42
	L_{pk} [d]	232	-	-
	L_p [e]	175	0.34	0.29

Dashes indicate that the acoustic threshold was not reached.
L_E = sound exposure level (dB re 1 µPa²·s); L_p = sound pressure level (dB re 1 µPa); L_p = peak sound pressure level (dB re 1 µPa).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.
[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] Blackstock et al. (2018). [e] Finneran et al. (2017).

4.3.3. Goal Posts – Vibratory Pile Driving

The acoustic radial distances (R_{max} and $R_{95\%}$) to thresholds for vibratory driving of goal-post sheet piles for marine mammals, sea turtles, and fish are shown in Table 4.3-5. Acoustic radial distances were calculated by propagating the source spectra (Section 2.2.2) using average winter sound speed conditions.

Table 4.3-5. Goal post sheet pile (600 mm width, APE Model 300, 10 m penetration depth) acoustic ranges (R_{max} and $R_{95\%}$ in km) for marine mammal, sea turtle, and fish hearing groups for average winter sound speed conditions.

Faunal group	Metric	Threshold	R_{max}	$R_{95\%}$
Unweighted, all cetaceans	L_p [a]	120	10.60	9.74
Low-frequency (LF) cetaceans	L_E [b]	199	0.05	0.05
Mid-frequency (MF) cetaceans	L_E [b]	198	-	-
High-frequency (HF) cetaceans	L_E [b]	173	0.21	0.19
Phocid pinnipeds in water (PPW)	L_E [b]	201	0.01	0.01
Sea turtles	L_E [c]	220	-	-
	L_p [c]	175	-	-
Fish with swim bladder involved in hearing	L_p [d]	170 (PTS)	-	-
	L_p [d]	158 (TTS)	0.02	0.02
Fish of all sizes	L_p [e]	150	0.10	0.10

Dashes indicate that the acoustic threshold was not reached.
L_E = weighted sound exposure level (dB re 1 µPa²·s); L_p = unweighted sound pressure level (dB re 1 µPa).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.
[a] NMFS (2005).
[b] NMFS (2018).
[c] Finneran et al. (2017).
[d] Popper et al. (2014).
[e] Andersson et al. (2007); Mueller-Blenke et al. (2010); Purser and Radford (2011); Wysocki et al. (2007).

4.4. Exposure Estimates

Exposure estimates were calculated for marine mammals and sea turtles for each of the proposed construction schedules (see Section 1.2.3). Sections 4.4.1, 4.4.1.3.2, 4.4.1.3, and 4.4.2.2 include results for each species and metric, assuming 10 dB attenuation and an average summer sound speed profile. For full results, including all modeled attenuation levels and both summer and winter average sound speed profiles, see Appendix I.2. See Table 2.5-4 for the Wood et al. step function categories that are used throughout the report.

4.4.1. Marine Mammals

4.4.1.1. Sequential Operations

The numbers of individual marine mammals predicted to receive sound levels above threshold criteria were determined using animal movement modeling. The construction schedules described in Tables 1.2-11 and 1.2-12 were used to calculate the total number of real-world individual marine mammals predicted to receive sound levels above injury and behavior thresholds in the Lease Area assuming no concurrent operations. Table 4.4-1 and Table 4.4-2 show the results for a broadband attenuation of 10 dB.

Table 4.4-1. Construction Schedule 1 (WTG monopile 2 piles per day, OCS-DC jacket 4 pin piles per day): Mean number of marine mammals predicted to receive sound levels above exposure criteria with 10 dB attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	12.95	0.04	26.15	32.26
	Minke whale (migrating)	13.60	<0.01	40.48	150.19
	Humpback whale	9.26	0	17.34	19.61
	North Atlantic right whale[c]	8.08	<0.01	22.49	24.82
	Sei whale[c] (migrating)	0.79	<0.01	2.21	13.66
MF	Atlantic white sided dolphin	0	0	1147.75	451.05
	Atlantic spotted dolphin	0	0	4.11	2.25
	Short-beaked common dolphin	0	0	5476.86	2134.04
	Bottlenose dolphin, offshore	0	0	909.27	368.54
	Risso's dolphin	0	0	9.37	4.00
	Long-finned pilot whale	0	0	75.52	29.01
	Short-finned pilot whale	0	0	51.42	19.76
	Sperm whale[c]	0	0	3.27	1.29
HF	Harbor porpoise	2.51	6.16	387.50	3870.23
PW	Gray seal	3.27	0	866.10	811.01
	Harbor seal	6.27	2.98	1063.59	884.99
	Harp seal	4.43	0	1051.55	951.13

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

Table 4.4-2. Construction Schedule 2 (WTG monopile 3 piles per day, OCS-DC jacket 4 pin piles per day): Mean number of marine mammals predicted to receive sound levels above exposure criteria with 10 dB attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	12.33	0.06	27.19	30.55
	Minke whale (migrating)	13.44	<0.01	41.62	134.76
	Humpback whale	9.88	0.02	19.72	20.10
	North Atlantic right whale[c]	8.84	<0.01	23.85	22.71
	Sei whale[c] (migrating)	0.92	<0.01	2.50	12.99
MF	Atlantic white sided dolphin	0	0	1193.26	459.53
	Atlantic spotted dolphin	0	0	3.59	1.96
	Short-beaked common dolphin	0	0	5783.17	2303.89
	Bottlenose dolphin, offshore	0	0	877.58	355.61
	Risso's dolphin	0	0	10.72	4.32
	Long-finned pilot whale	0	0	75.53	28.33
	Short-finned pilot whale	0	0	50.66	19.06
	Sperm whale[c]	0	0	3.52	1.36
HF	Harbor porpoise	2.51	5.44	398.97	2582.84
PW	Gray seal	4.24	0	962.81	855.07
	Harbor seal	6.79	2.07	1165.92	931.54
	Harp seal	6.39	0	1170.10	1000.65

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

4.4.1.1.1. Effect of Aversion

The mean exposure estimates reported in Tables 4.4-1 and 4.4-2 do not consider animals avoiding loud sounds (aversion) or implementation of mitigation measures other than sound attenuation using NAS. Some marine mammals are known for their aversive responses to anthropogenic sound (e.g., harbor porpoise), although it is assumed that most species will avert from noise. The Wood et al. (2012) step function includes a probability of response that is based primarily on observed aversive behavior in field studies. Additional exposure estimates with aversion based on the Wood et al. (2012) response probabilities were calculated for NARW and harbor porpoise in this study. For comparative purposes only, the results are shown with and without aversion for construction schedule 1 (Table 4.4-3). Aversion was not applied to exposure estimates and is only presented here for comparison.

Table 4.4-3. Construction Schedule 1 (WTG monopile 2 piles per day, OCS-DC jacket 4 pin piles per day): Mean number of marine mammals predicted to receive sound levels above exposure criteria with 10 dB attenuation, with and without aversion for aversive species. Construction schedule assumptions are summarized in Section 1.2.3.

Species	10 dB attenuation – no aversion				10 dB attenuation – with aversion			
	Injury		Behavior		Injury		Behavior	
	L_E	L_{pk}	L_p [a]	L_p [b]	L_E	L_{pk}	L_p [a]	L_p [b]
North Atlantic right whale[c]	8.08	<0.01	22.49	24.82	0.80	0	8.08	17.32
Harbor porpoise	2.51	6.16	387.50	3870.23	0	0	25.95	3228.28

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

4.4.1.2. Concurrent Operations

The construction schedules described in Table 1.2-15 through Table 1.2-15 were used to calculate the total number of real-world individual marine mammals predicted to receive sound levels above injury and behavior thresholds in the Lease Area assuming concurrent operations. Table 4.4-4 through Table 4.4-6 shows the results for a broadband attenuation of 10 dB.

Table 4.4-4. Construction Schedule 3 (proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): Marine mammal exposures as a percentage of abundance with 10 dB sound attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	13.18	0.04	23.19	25.78
	Minke whale (migrating)	15.02	0.02	33.13	111.67
	Humpback whale	9.91	0.01	16.62	17.12
	North Atlantic right whale[c]	9.53	<0.01	19.10	17.97
	Sei whale[c] (migrating)	0.98	<0.01	2.19	11.91
MF	Atlantic white sided dolphin	0	0	938.54	383.61
	Atlantic spotted dolphin	0	0	7.99	3.59
	Short-beaked common dolphin	0	0	4812.63	1992.26
	Bottlenose dolphin, offshore	0	0	750.74	312.43
	Risso's dolphin	0	0	8.61	3.77
	Long-finned pilot whale	0	0	59.23	24.11
	Short-finned pilot whale	0	0	41.44	16.58
	Sperm whale[c]	0	0	2.80	1.13
HF	Harbor porpoise	2.51	5.21	334.86	1824.18
PW	Gray seal	3.27	0	762.94	674.62
	Harbor seal	5.58	0.86	1000.14	773.76
	Harp seal	5.18	0	915.75	813.71

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

Table 4.4-5. Construction Schedule 4 (distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): Marine mammal exposures as a percentage of abundance with 10 dB sound attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	12.90	0.06	25.92	30.68
	Minke whale (migrating)	13.66	0.02	41.91	129.35
	Humpback whale	8.94	0.01	18.37	20.13
	North Atlantic right whale[c]	9.47	0.01	24.84	23.00
	Sei whale[c] (migrating)	0.98	<0.01	2.58	13.53
MF	Atlantic white sided dolphin	0	0	1195.27	456.86
	Atlantic spotted dolphin	0	0	7.70	3.68
	Short-beaked common dolphin	0	0	6136.16	2450.03
	Bottlenose dolphin, offshore	0	0	886.89	359.08
	Risso's dolphin	0	0	11.21	4.75
	Long-finned pilot whale	0	0	73.39	28.47
	Short-finned pilot whale	0	0	51.92	19.92
	Sperm whale[c]	0	0	3.32	1.36
HF	Harbor porpoise	2.51	5.21	402.53	2158.17
PW	Gray seal	4.01	0	936.95	917.04
	Harbor seal	6.33	0.86	1183.08	996.11
	Harp seal	6.66	0	1156.68	1075.91

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

Table 4.4-6. Construction Schedule 5 (proximal assumptions for concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day), and remaining WTG foundations): Marine mammal exposures as a percentage of abundance with 10 dB sound attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	12.81	0.04	25.75	31.45
	Minke whale (migrating)	13.49	<0.01	39.70	146.23
	Humpback whale	9.30	0	17.34	19.43
	North Atlantic right whale[c]	8.03	<0.01	22.09	23.88
	Sei whale[c] (migrating)	0.80	<0.01	2.23	13.57
MF	Atlantic white sided dolphin	0	0	1121.25	441.01
	Atlantic spotted dolphin	0	0	4.02	2.21
	Short-beaked common dolphin	0	0	5455.89	2125.58
	Bottlenose dolphin, offshore	0	0	892.17	360.88
	Risso's dolphin	0	0	9.36	3.98
	Long-finned pilot whale	0	0	73.37	28.19
	Short-finned pilot whale	0	0	49.99	19.20
	Sperm whale[c]	0	0	3.22	1.27
HF	Harbor porpoise	2.57	6.66	380.34	3547.74
PW	Gray seal	3.56	0	868.07	808.81
	Harbor seal	6.86	2.94	1054.69	878.30
	Harp seal	5.13	0.06	1041.60	947.53

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

4.4.1.3. 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 exposure criteria. Those individual exposure numbers must then be assessed in the context of the species populations or stocks.

Defining biologically significant impacts to a population of animals that result from injury or behavioral responses estimated from exposure models and acoustic thresholds remains somewhat subjective. The percentage of the stock or population exposed has been commonly used as an indication of the extent of potential impact (e.g., NSF 2011). In this way, the potential number of exposed animals can be interpreted in an abundance context, which allows for consistency across different population or stock sizes.

The exposure results shown in Table 4.4-1 through Table 4.4-6 estimated using the schedules described in Section 1.2.3, are presented as a percentage of species abundance at 10 dB attenuation level in Table 4.4-7 and Table 4.4-8 for sequential operations, and Table 4.4-9 to Table 4.4-11 for concurrent operations. Table 2.8-1 shows the abundance numbers used to calculate the percentage of population estimated to receive sound levels above exposure criteria thresholds.

4.4.1.3.1. Sequential Operations

Table 4.4-7. Construction Schedule 1 (WTG monopile 2 piles per day, OCS-DC jacket 4 pin piles per day): Marine mammal exposures as a percentage of abundance with 10 dB sound attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	0.19	<0.01	0.38	0.47
	Minke whale (migrating)	0.06	<0.01	0.18	0.68
	Humpback whale	0.66	0	1.24	1.40
	North Atlantic right whale[c]	2.20	<0.01	6.11	6.74
	Sei whale[c] (migrating)	0.01	<0.01	0.04	0.22
MF	Atlantic white sided dolphin	0	0	1.23	0.48
	Atlantic spotted dolphin	0	0	0.01	<0.01
	Short-beaked common dolphin	0	0	3.17	1.23
	Bottlenose dolphin, offshore	0	0	1.45	0.59
	Risso's dolphin	0	0	0.03	0.01
	Long-finned pilot whale	0	0	0.19	0.07
	Short-finned pilot whale	0	0	0.18	0.07
	Sperm whale[c]	0	0	0.08	0.03
HF	Harbor porpoise	<0.01	<0.01	0.41	4.05
PW	Gray seal	0.01	0	3.17	2.97
	Harbor seal	0.01	<0.01	1.73	1.44
	Harp seal	<0.01	0	0.01	0.01

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

Table 4.4-8. Construction Schedule 2 (WTG monopile 3 piles per day, OCS-DC jacket 4 pin piles per day): Marine mammal exposures as a percentage of abundance with 10 dB sound attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	0.18	<0.01	0.40	0.45
	Minke whale (migrating)	0.06	<0.01	0.19	0.61
	Humpback whale	0.71	<0.01	1.41	1.44
	North Atlantic right whale[c]	2.40	<0.01	6.48	6.17
	Sei whale[c] (migrating)	0.01	<0.01	0.04	0.21
MF	Atlantic white sided dolphin	0	0	1.28	0.49
	Atlantic spotted dolphin	0	0	<0.01	<0.01
	Short-beaked common dolphin	0	0	3.34	1.33
	Bottlenose dolphin, offshore	0	0	1.40	0.57
	Risso's dolphin	0	0	0.03	0.01
	Long-finned pilot whale	0	0	0.19	0.07
	Short-finned pilot whale	0	0	0.18	0.07
	Sperm whale[c]	0	0	0.08	0.03
HF	Harbor porpoise	<0.01	<0.01	0.42	2.70
PW	Gray seal	0.02	0	3.53	3.13
	Harbor seal	0.01	<0.01	1.90	1.52
	Harp seal	<0.01	0	0.02	0.01

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

4.4.1.3.2. Concurrent Operations

Table 4.4-9. Construction Schedule 3 (proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): Marine mammal exposures as a percentage of abundance with 10 dB sound attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	0.19	<0.01	0.34	0.38
	Minke whale (migrating)	0.07	<0.01	0.15	0.51
	Humpback whale	0.71	<0.01	1.19	1.23
	North Atlantic right whale[c]	2.59	<0.01	5.19	4.88
	Sei whale[c] (migrating)	0.02	<0.01	0.03	0.19
MF	Atlantic white sided dolphin	0	0	1.01	0.41
	Atlantic spotted dolphin	0	0	0.02	<0.01
	Short-beaked common dolphin	0	0	2.78	1.15
	Bottlenose dolphin, offshore	0	0	1.19	0.50
	Risso's dolphin	0	0	0.02	0.01
	Long-finned pilot whale	0	0	0.15	0.06
	Short-finned pilot whale	0	0	0.14	0.06
	Sperm whale[c]	0	0	0.06	0.03
HF	Harbor porpoise	<0.01	<0.01	0.35	1.91
PW	Gray seal	0.01	0	2.79	2.47
	Harbor seal	<0.01	<0.01	1.63	1.26
	Harp seal	<0.01	0	0.01	0.01

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

Table 4.4-10. Construction Schedule 4 (distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): Marine mammal exposures as a percentage of abundance with 10 dB sound attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	0.19	<0.01	0.38	0.45
	Minke whale (migrating)	0.06	<0.01	0.19	0.59
	Humpback whale	0.64	<0.01	1.32	1.44
	North Atlantic right whale[c]	2.57	<0.01	6.75	6.25
	Sei whale[c] (migrating)	0.02	<0.01	0.04	0.22
MF	Atlantic white sided dolphin	0	0	1.28	0.49
	Atlantic spotted dolphin	0	0	0.02	<0.01
	Short-beaked common dolphin	0	0	3.55	1.42
	Bottlenose dolphin, offshore	0	0	1.41	0.57
	Risso's dolphin	0	0	0.03	0.01
	Long-finned pilot whale	0	0	0.19	0.07
	Short-finned pilot whale	0	0	0.18	0.07
	Sperm whale[c]	0	0	0.08	0.03
HF	Harbor porpoise	<0.01	<0.01	0.42	2.26
PW	Gray seal	0.01	0	3.43	3.36
	Harbor seal	0.01	<0.01	1.93	1.62
	Harp seal	<0.01	0	0.02	0.01

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

Table 4.4-11. Construction schedule 5 (proximal assumptions for concurrent piling of WTG (one vessel doing two monopiles per day) and OCS-DC foundations (one vessel doing four pin piles per day), and WTG foundations): Marine mammal exposures as a percentage of abundance with 10 dB sound attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	0.19	<0.01	0.38	0.46
	Minke whale (migrating)	0.06	<0.01	0.18	0.67
	Humpback whale	0.67	0	1.24	1.39
	North Atlantic right whale[c]	2.18	<0.01	6.00	6.49
	Sei whale[c] (migrating)	0.01	<0.01	0.04	0.22
MF	Atlantic white sided dolphin	0	0	1.20	0.47
	Atlantic spotted dolphin	0	0	0.01	<0.01
	Short-beaked common dolphin	0	0	3.15	1.23
	Bottlenose dolphin, offshore	0	0	1.42	0.57
	Risso's dolphin	0	0	0.03	0.01
	Long-finned pilot whale	0	0	0.19	0.07
	Short-finned pilot whale	0	0	0.17	0.07
	Sperm whale[c]	0	0	0.07	0.03
HF	Harbor porpoise	<0.01	<0.01	0.40	3.71
PW	Gray seal	0.01	0	3.18	2.96
	Harbor seal	0.01	<0.01	1.72	1.43
	Harp seal	<0.01	<0.01	0.01	0.01

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

4.4.2. Sea Turtles

4.4.2.1. Sequential Operations

As was done for marine mammals (see Section 4.4.1), the numbers of individual sea turtles predicted to receive sound levels above threshold criteria were determined using animal movement modeling. The construction schedules described in Tables 1.2-11 and 1.2-12 were used to calculate the total number of real-world individual turtles predicted to receive sound levels above injury and behavior thresholds (Finneran et al. 2017) in the Lease Area assuming no concurrent operations. Tables 4.4-12 and 4.4-13 include results assuming broadband attenuation of 10 dB, calculated in the same way as the marine mammal exposures.

Table 4.4-12. Construction Schedule 1 (WTG monopile 2 piles per day, OCS-DC jacket 4 pin piles per day): Mean number of sea turtles predicted to receive sound levels above exposure criteria with 10 dB attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species	Injury		Behavior
	L_E	L_{pk}	L_p
Kemp's ridley turtle[a]	0.05	0	0.30
Leatherback turtle[a]	3.01	0	8.63
Loggerhead turtle	0.24	0	8.16
Green turtle	0.10	0	0.29

[a] Listed as Endangered under the ESA.

Table 4.4-13. Construction Schedule 2 (WTG monopile 3 piles per day, OCS-DC jacket 4 pin piles per day): Mean number of sea turtles predicted to receive sound levels above exposure criteria with 10 dB attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species	Injury		Behavior
	L_E	L_{pk}	L_p
Kemp's ridley turtle[a]	0.05	0	0.31
Leatherback turtle[a]	3.01	0	9.57
Loggerhead turtle	0.50	0	9.30
Green turtle	0.07	0	0.27

[a] Listed as Endangered under the ESA.

4.4.2.2. Concurrent Operations

The construction schedules described in Table 2.5-1 through Table 1.2-15 were used to calculate the total number of real-world individual turtles predicted to receive sound levels above injury and behavior thresholds (Finneran et al. 2017) in the Lease Area assuming concurrent operations. Table 4.4-14 through Table 4.4-16 include results assuming broadband attenuation of 10 dB, calculated in the same way as the marine mammal exposures.

Table 4.4-14. Construction Schedule 3 (proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): Mean number of sea turtles predicted to receive sound levels above exposure criteria with 10 dB attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species	Injury		Behavior
	L_E	L_{pk}	L_p
Kemp's ridley turtle[a]	0.05	0	0.28
Leatherback turtle[a]	2.83	0	6.51
Loggerhead turtle	0.35	0	8.82
Green turtle	0.08	0	0.25

[a] Listed as Endangered under the ESA.

Table 4.4-15. Construction Schedule 4 (distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): Mean number of sea turtles predicted to receive sound levels above exposure criteria with 10 dB attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species	Injury		Behavior
	L_E	L_{pk}	L_p
Kemp's ridley turtle[a]	0.05	0	0.30
Leatherback turtle[a]	4.30	0	9.51
Loggerhead turtle	0.30	0	9.26
Green turtle	0.07	0	0.24

[a] Listed as Endangered under the ESA.

Table 4.4-16. Construction Schedule 5 (proximal assumptions for concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day), and remaining WTG foundations): Mean number of sea turtles predicted to receive sound levels above exposure criteria with 10 dB attenuation. Construction schedule assumptions are summarized in Section 1.2.3.

Species	Injury		Behavior
	L_E	L_{pk}	L_p
Kemp's ridley turtle[a]	0.05	0	0.29
Leatherback turtle[a]	2.95	0	8.76
Loggerhead turtle	0.25	0	8.16
Green turtle	0.10	0	0.29

[a] Listed as Endangered under the ESA.

4.5. Exposure Range Estimates (*$ER_{95\%}$*)

The following subsections contain tables of exposure ranges (*$ER_{95\%}$*, defined in Section 2.8) calculated for Level A sound exposure thresholds (SEL) and peak thresholds (PK), and Level B sound pressure thresholds (SPL) for thresholds described in Sections 2.5.3 and 2.5.4. *$ER_{95\%}$* values were calculated for both marine mammals and sea turtles, with summarized results shown in Figure 4.5-1 for each of the foundation types and installation schedules for sequential operations, and in Figure 4.5-2 for concurrent operations (see Table 4.5-1 for modeled operations scenarios). Sections 4.5.1 and 4.5.1.2 provide additional details for each species and metric, assuming 10 dB attenuation and an average summer sound speed profile. For full results, including all modeled attenuation levels and both summer and winter average sound speed profiles, see Appendices I.2.3.2 and I.2.4.2. See Table 2.5-4 for the Wood et al. step function categories that are used throughout the report.

Table 4.5-1. Sequential and concurrent operations scenarios.

Operations type	Foundation types	Configuration	Distance between foundations
Sequential	WTG	Monopile, 2 per day	Not applicable
Sequential	WTG	Monopile, 3 per day	Not applicable
Sequential	OCS-DC	Jacket pin pile, 4 per day	Not applicable
Concurrent	WTG & WTG	Monopile, 2 per day & Monopile, 2 per day	Proximal (min. spacing 2 WTG mono positions)
Concurrent	WTG & WTG	Monopile, 2 per day & Monopile, 2 per day	Distal
Concurrent	WTG & OCS-DC	Monopile, 2 per day & Jacket pin pile, 4 per day	Proximal (min. spacing 2 WTG mono positions)

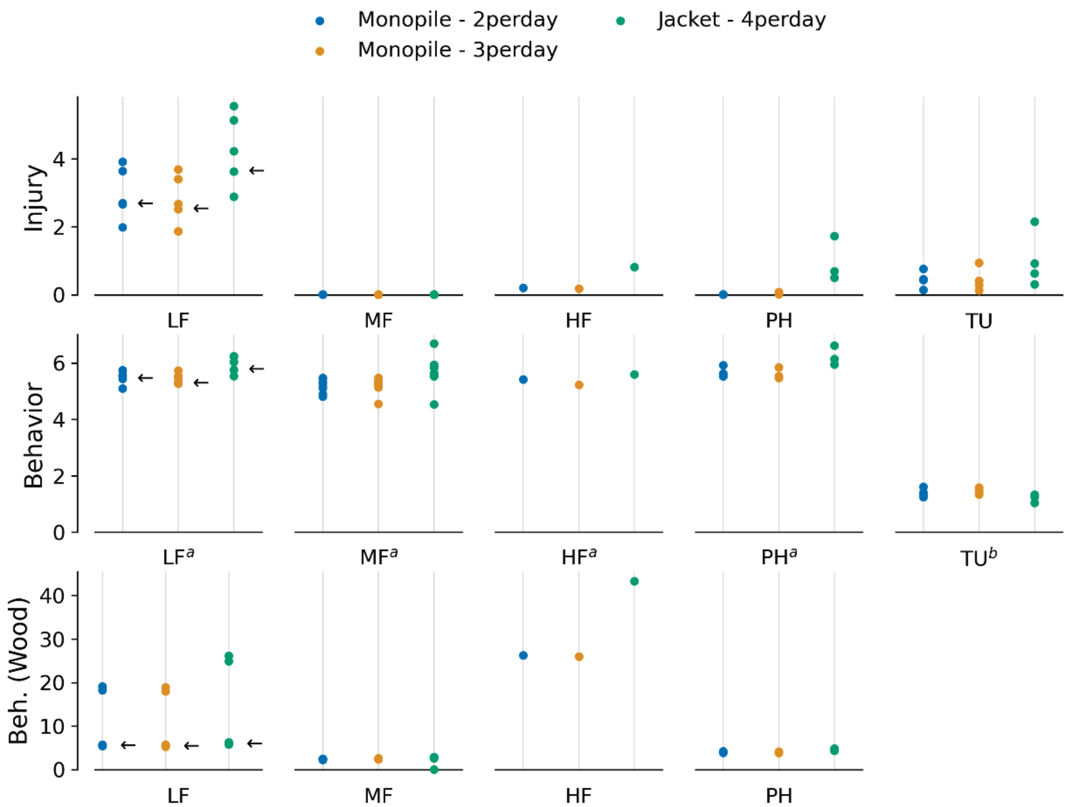

Figure 4.5-1. Maximum exposure ranges ($ER_{95\%}$, km) for sequential operations for injury and behavior thresholds, shown for each hearing group, assuming an attenuation of 10 dB and an average summer sound speed profile. The middle row represents ranges to Level B unweighted SPL acoustic thresholds (a = NOAA 2005; b = Finneran et al. 2017), and the bottom row represents ranges to Level B frequency-weighted SPL acoustic thresholds (Wood et al. 2012). Each dot represents a species within the indicated hearing group (LF = low frequency cetaceans, MF = mid frequency cetaceans, HF = high frequency cetaceans, PW = pinnipeds in water, TU = sea turtles, and arrows indicate NARW), and dot color represents a combination of foundation type and installation schedule (number of piles installed per day). Note the different y-axis scales between the rows.

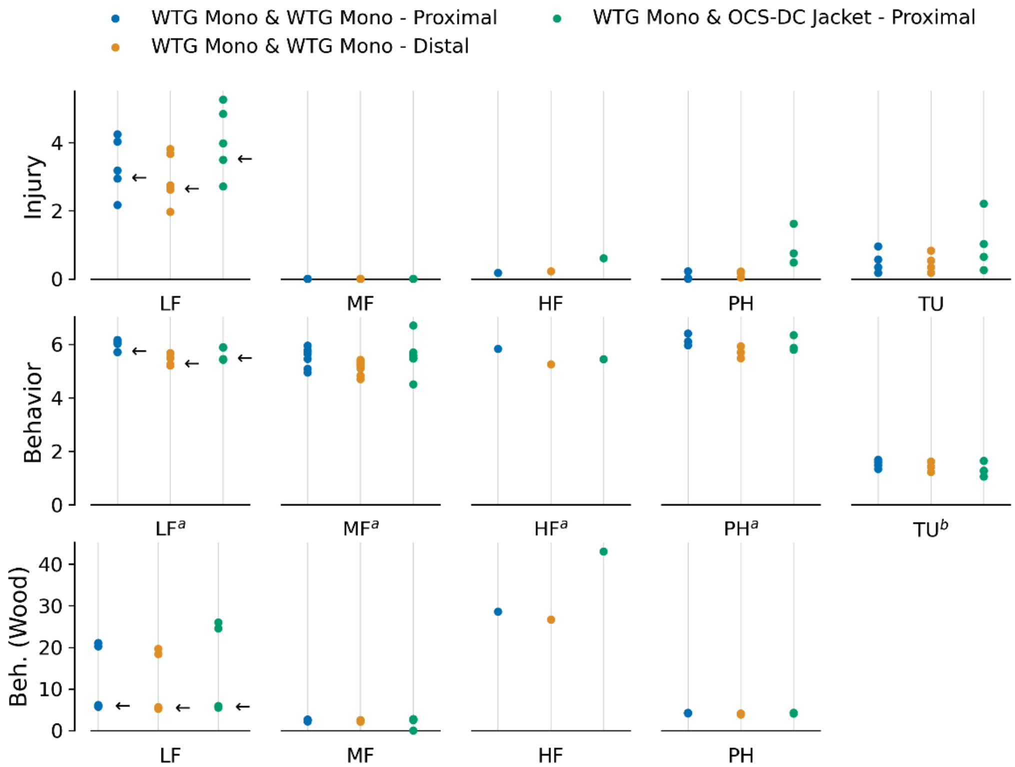

Figure 4.5-2. Maximum exposure ranges ($ER_{95\%}$, km) for concurrent operations for injury and behavior thresholds, shown for each hearing group, assuming an attenuation of 10 dB and an average summer sound speed profile. The middle row represents ranges to Level B unweighted SPL acoustic thresholds (a = NOAA 2005; b = Finneran et al. 2017), and the bottom row represents ranges to Level B frequency-weighted SPL acoustic thresholds (Wood et al. 2012). Each dot represents a species within the indicated hearing group (LF = low frequency cetaceans, MF = mid frequency cetaceans, HF = high frequency cetaceans, PW = pinnipeds in water, TU = sea turtles, and arrows indicate NARW), and dot color represents a combination of foundation type and installation schedule (number of piles installed per day). Note the different y-axis scales between the rows.

4.5.1. Marine Mammals

4.5.1.1. Sequential Operations

The exposure ranges, $ER_{95\%}$, to injury and behavior thresholds are summarized in Tables 4.5-2 and 4.5-3 for monopile and jacket foundations, respectively, assuming 10 dB broadband attenuation and a summer average sound speed profile and no concurrent operations. Exposure ranges are reported for both two and three piles per day for monopile foundations, and for four pin piles per day for jacket foundations. Results for different seasons and different attenuation levels can be found in Appendix I.2.3.2. Single-strike ranges to various isopleths from acoustic modeling can be found in Appendix G, along with per pile SEL acoustic ranges to isopleths for the hearing groups assuming no movement of animals during pile driving.

Table 4.5-2. Monopile foundation (7/12 m diameter) in summer: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with 10 dB attenuation and an average summer sound speed profile.

Species		Two piles per day				Three piles per day			
		Injury		Behavior		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]	L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	3.91	<0.01	5.74	5.70	3.68	<0.01	5.73	5.73
	Minke whale (migrating)	1.98	0	5.09	18.22	1.86	0	5.30	17.96
	Humpback whale	3.63	0	5.57	5.61	3.40	<0.01	5.52	5.51
	North Atlantic right whale[c]	2.66	0	5.43	5.41	2.51	0	5.26	5.25
	Sei whale[c] (migrating)	2.69	<0.01	5.53	19.08	2.67	<0.01	5.46	18.90
MF	Atlantic white sided dolphin	0	0	5.10	2.45	0	0	5.13	2.39
	Atlantic spotted dolphin	0	0	4.89	2.23	0	0	5.28	2.42
	Short-beaked common dolphin	0	0	5.16	2.44	0	0	5.33	2.49
	Bottlenose dolphin, offshore	0	0	4.80	2.41	0	0	4.54	2.34
	Risso’s dolphin	0	0	5.46	2.44	0	0	5.32	2.59
	Long-finned pilot whale	0	0	5.26	2.39	0	0	5.22	2.55
	Short-finned pilot whale	0	0	5.31	2.41	0	0	5.35	2.45
	Sperm whale[c]	0	0	5.44	2.46	0	0	5.47	2.46
HF	Harbor porpoise	0	0.20	5.42	26.24	0	0.18	5.22	26.00
PW	Gray seal	0	0	5.91	4.19	<0.01	0	5.84	4.13
	Harbor seal	<0.01	<0.01	5.52	3.85	0.03	<0.01	5.47	3.88
	Harp seal	0	0	5.62	3.99	0.08	0	5.53	3.82

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

Table 4.5-3. Jacket foundation (4 m diameter) in summer: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with 10 dB attenuation and an average summer sound speed profile.

Species		Four pin piles per day			
		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	5.55	<0.01	6.23	6.24
	Minke whale (migrating)	2.88	<0.01	5.53	24.87
	Humpback whale	5.13	0	6.23	6.24
	North Atlantic right whale[c]	3.62	<0.01	5.75	5.77
	Sei whale[c] (migrating)	4.22	<0.01	6.03	26.13
MF	Atlantic white sided dolphin	0	0	5.52	2.75
	Atlantic spotted dolphin	0	0	6.68	0
	Short-beaked common dolphin	0	0	5.54	2.85
	Bottlenose dolphin, offshore	0	0	4.53	2.58
	Risso's dolphin	0	0	5.83	2.86
	Long-finned pilot whale	0	0	5.59	2.82
	Short-finned pilot whale	0	0	5.63	2.80
	Sperm whale[c]	0	0	5.93	2.84
HF	Harbor porpoise	0.81	0.22	5.59	43.29
PW	Gray seal	1.72	0	6.61	4.84
	Harbor seal	0.69	<0.01	5.94	4.32
	Harp seal	0.49	0	6.13	4.56

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

4.5.1.2. Concurrent Operations

The exposure ranges, $ER_{95\%}$, to injury and behavior thresholds are summarized in Table 4.5-4 through Table 4.5-6 for monopile and jacket foundations, respectively, assuming 10 dB broadband attenuation and a summer average sound speed profile for concurrent operations. Exposure ranges are reported for all three concurrent installation scenarios as described in Table 1.2-13, Table 1.2-14, and Table 1.2-15. Results for different seasons and different attenuation levels can be found in Appendix I.2.3.2. Single-strike ranges to various isopleths from acoustic modeling can be found in Appendix G, along with per pile SEL acoustic ranges to isopleths for the hearing groups assuming no movement of animals during pile driving.

Table 4.5-4. Proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with 10 dB attenuation and an average summer sound speed profile.

Species		Four monopiles per day			
		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	4.23	<0.01	6.16	6.14
	Minke whale (migrating)	2.17	<0.01	5.71	20.23
	Humpback whale	4.02	<0.01	6.02	6.01
	North Atlantic right whale[c]	2.94	0	5.71	5.71
	Sei whale[c] (migrating)	3.18	<0.01	6.10	21.04
MF	Atlantic white sided dolphin	0	0	5.45	2.60
	Atlantic spotted dolphin	0	0	5.08	2.18
	Short-beaked common dolphin	0	0	5.64	2.38
	Bottlenose dolphin, offshore	0	0	4.94	2.41
	Risso's dolphin	0	0	5.77	2.62
	Long-finned pilot whale	0	0	5.69	2.56
	Short-finned pilot whale	0	0	5.74	2.60
	Sperm whale[c]	0	0	5.95	2.64
HF	Harbor porpoise	0	0.18	5.83	28.67
PW	Gray seal	0	0	6.40	4.26
	Harbor seal	0.22	<0.01	5.96	4.13
	Harp seal	0.02	0	6.10	4.22

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

Table 4.5-5. Distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations: Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with 10 dB attenuation and an average summer sound speed profile.

Species		Four monopiles per day			
		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	3.80	<0.01	5.65	5.65
	Minke whale (migrating)	1.96	<0.01	5.20	18.38
	Humpback whale	3.66	<0.01	5.67	5.57
	North Atlantic right whale[c]	2.61	<0.01	5.24	5.24
	Sei whale[c] (migrating)	2.74	<0.01	5.48	19.64
MF	Atlantic white sided dolphin	0	0	5.09	2.34
	Atlantic spotted dolphin	0	0	4.83	2.13
	Short-beaked common dolphin	0	0	5.19	2.32
	Bottlenose dolphin, offshore	0	0	4.70	2.35
	Risso's dolphin	0	0	5.36	2.53
	Long-finned pilot whale	0	0	5.26	2.42
	Short-finned pilot whale	0	0	5.29	2.43
	Sperm whale[c]	0	0	5.42	2.46
HF	Harbor porpoise	0	0.23	5.26	26.68
PW	Gray seal	0.17	0	5.92	4.10
	Harbor seal	0.22	<0.01	5.48	3.85
	Harp seal	0.04	0	5.70	4.04

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

Table 4.5-6. Concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day): Exposure ranges ($ER_{95\%}$) in km to marine mammal threshold criteria with 10 dB attenuation and an average summer sound speed profile.

Species		Two monopiles and four pin piles per day			
		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
LF	Fin whale[c]	5.25	0	5.88	5.83
	Minke whale (migrating)	2.71	<0.01	5.42	24.53
	Humpback whale	4.83	0	5.89	5.91
	North Atlantic right whale[c]	3.49	<0.01	5.45	5.52
	Sei whale[c] (migrating)	3.97	<0.01	5.89	25.97
MF	Atlantic white sided dolphin	0	0	5.50	2.76
	Atlantic spotted dolphin	0	0	6.70	0
	Short-beaked common dolphin	0	0	5.46	2.74
	Bottlenose dolphin, offshore	0	0	4.50	2.50
	Risso's dolphin	0	0	5.70	2.75
	Long-finned pilot whale	0	0	5.47	2.67
	Short-finned pilot whale	0	0	5.60	2.67
	Sperm whale[c]	0	0	5.56	2.71
HF	Harbor porpoise	0.61	0.25	5.45	43.07
PW	Gray seal	1.62	0	6.34	4.28
	Harbor seal	0.75	<0.01	5.79	4.08
	Harp seal	0.48	<0.01	5.87	4.25

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

4.5.2. Sea Turtles

4.5.2.1. Sequential Operations

Similar to the results presented for marine mammals (Section 4.5.1), the exposure ranges ($ER_{95\%}$) for sea turtles are summarized in Tables 4.5-7 and 4.5-8 for monopile and jacket foundations, respectively, assuming 10 dB broadband attenuation and a summer acoustic propagation environment. Results for different seasons and at different attenuation levels can be found in Appendix I.2.3. Single-strike ranges to various isopleths from acoustic modeling can be found in Appendix G, along with per pile SEL distances to isopleths for the hearing groups assuming no movement of animals during pile driving.

Table 4.5-7. Monopile foundation (7/12 m diameter) in summer: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with 10 dB attenuation and an average summer sound speed profile.

Species	Two piles per day			Three piles per day		
	Injury		Behavior	Injury		Behavior
	L_E	L_{pk}	L_p	L_E	L_{pk}	L_p
Kemp's ridley turtle[a]	0.43	0	1.40	0.28	0	1.43
Leatherback turtle[a]	0.76	0	1.60	0.93	0	1.58
Loggerhead turtle	0.14	0	1.24	0.12	0	1.33
Green turtle	0.45	0	1.35	0.41	0	1.47

[a] Listed as Endangered under the ESA.

Table 4.5-8. Jacket foundation (4 m diameter) in summer: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with 10 dB attenuation and an average summer sound speed profile.

Species	Four pin piles per day		
	Injury		Behavior
	L_E	L_{pk}	L_p
Kemp's ridley turtle[a]	0.62	0	1.26
Leatherback turtle[a]	2.15	0	1.33
Loggerhead turtle	0.30	0	1.03
Green turtle	0.92	0	1.25

[a] Listed as Endangered under the ESA.

4.5.2.2. Concurrent Operations

Similar to the results presented for marine mammals (Section 4.5.1), the exposure ranges ($ER_{95\%}$) for sea turtles are summarized in Table 4.5-9 through Table 4.5-11 for monopile and jacket foundations, respectively, assuming 10 dB broadband attenuation and a summer acoustic propagation environment. Results for different seasons and at different attenuation levels can be found in Appendix I.2.5. Single-strike ranges to various isopleths from acoustic modeling can be found inAppendix G, along with per pile SEL distances to isopleths for the hearing groups assuming no movement of animals during pile driving.

Table 4.5-9. Proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with 10 dB attenuation and an average summer sound speed profile.

Species	Four piles per day		
	Injury		Behavior
	L_E	L_{pk}	L_p
Kemp's ridley turtle[a]	0.34	0	1.59
Leatherback turtle[a]	0.95	0	1.68
Loggerhead turtle	0.18	0	1.33
Green turtle	0.57	0	1.47

[a] Listed as Endangered under the ESA.

Table 4.5-10. Distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with 10 dB attenuation and an average summer sound speed profile.

Species	Four piles per day		
	Injury		Behavior
	L_E	L_{pk}	L_p
Kemp's ridley turtle[a]	0.34	0	1.42
Leatherback turtle[a]	0.83	0	1.62
Loggerhead turtle	0.18	0	1.22
Green turtle	0.53	0	1.42

[a] Listed as Endangered under the ESA.

Table 4.5-11. Proximal assumptions for concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day): Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria with 10 dB attenuation and an average summer sound speed profile.

Species	Two monopiles and four pin piles per day		
	Injury		Behavior
	L_E	L_{pk}	L_p
Kemp's ridley turtle[a]	0.65	0	1.27
Leatherback turtle[a]	2.20	0	1.64
Loggerhead turtle	0.26	0	1.05
Green turtle	1.02	0	1.27

[a] Listed as Endangered under the ESA.

5. Summary

This study predicted underwater sound levels associated with the installation of piles supporting WTG and OCS-DC foundations. Sounds fields produced during impact pile driving for installation of 7/12 m tapered monopile foundations, 4 m jacket foundation piles, and casing pipes were found by a three-step process: First, the force applied by the impact hammer at the top of the pile was computed. Second, JASCO's PDSM was used to model the vibration of the pile and to obtain a point-source array representation of the sound radiating from the pile due to such vibrations. Third, JASCO's FWRAM model was used to propagate this sound field into the environment. For monopiles, a comparison of the modeled sound levels was made with a forecasting, empirical model (ITAP) that predicts pile driving sound levels at 750 m from the pile (see Appendix H).

Sounds fields produced during vibratory pile driving of goal post sheet piles were predicted by propagating measured spectra as a noise-radiating point source in the middle of the water column using JASCO's MONM-BELLHOP model.

Acoustic ranges to injury and behavioral thresholds were calculated for the 7/12 m monopile foundation, 4 m jacket foundation piles, casing pipe, and goal post installation (see Section 4.3 and Appendix G). Due to the high number of hammer strikes needed to install the casing pipes, the distances to PTS onset for low- and high-frequency cetaceans are greater than the distance to behavioral disturbance; however, low-frequency baleen whales are not expected to occur in the nearshore waters of the casing pipe installation area, nor is it expected that animals would remain in the ensonified zone of auditory injury for the entire duration of piling in any given day.

Animal movement modeling was used to sample sound fields produced during impact pile driving of 7/12 m monopile foundations. The resulting exposure histories were used to determine if simulated marine mammal and sea turtle animals (animats) exceeded regulatory thresholds. For those animats that exceeded thresholds, the closest point of approach to the source was found for each animat and the range encompassing 95% of those closest points of approach was reported as the exposure range, $ER_{95\%}$. The species-specific $ER_{95\%}$ ranges (see tables in Section 4 and Appendices I.2.4 and I.2.5) were determined for different broadband sound attenuation levels (0, 6, 10, 15 and 20 dB) to simulate the use of noise reduction systems, such as bubble curtains. $ER_{95\%}$ can be used for mitigation purposes, such as establishing monitoring or exclusion areas. Fish were considered to be static receivers, so exposure ranges were not calculated. Instead, the acoustic ranges to their regulatory thresholds were determined and reported for each broadband attenuation level (see tables in Section 4).

5.1. Construction Schedules

Exposure estimates and exposure ranges for monopile and jacket foundation installation were calculated for five different construction schedules. Construction schedules 1 and 2 represent traditional, sequential operations with one pile driving vessel (operating one hammer). Construction schedule 1 assumes two monopiles are driven each day and construction schedule 2 assumes three monopiles are driven each day. Construction schedules 3, 4, and 5 represent potential concurrent operation of two pile driving vessels (each operating one hammer). Construction schedule 3 assumes two concurrently operating monopile installation vessels, each installing two piles per day, and that they are operating near each other (i.e., a separation distance of two foundation locations). Construction schedule 4 is similar to 3 except that the vessels are operating at a greater distance from each other (i.e., on the opposite ends of the lease area). Construction schedule 5 assumes installation of the jacket foundation while another vessel is concurrently installing monopile foundations.

Figure 5.1-1 compares the estimated number of individuals that may exceed the injury threshold among the different construction schedules, and Figure 5.1-2 compares the estimated number of individuals that may exceed the behavioral thresholds across the different construction schedules. While weak trends may exist, the stochastic nature of the modeling approach likely accounts for the majority of difference between the different construction schedules. Section 5.1.1 summarizes exposure estimates. Section 5.1.2 summarizes exposure range comparisons among the construction schedules, based on results in Section 4.5, and Section 5.1.3 focuses on interpreting the NARW results as an example.

5.1.1. Exposure Estimates

Injury Exposures

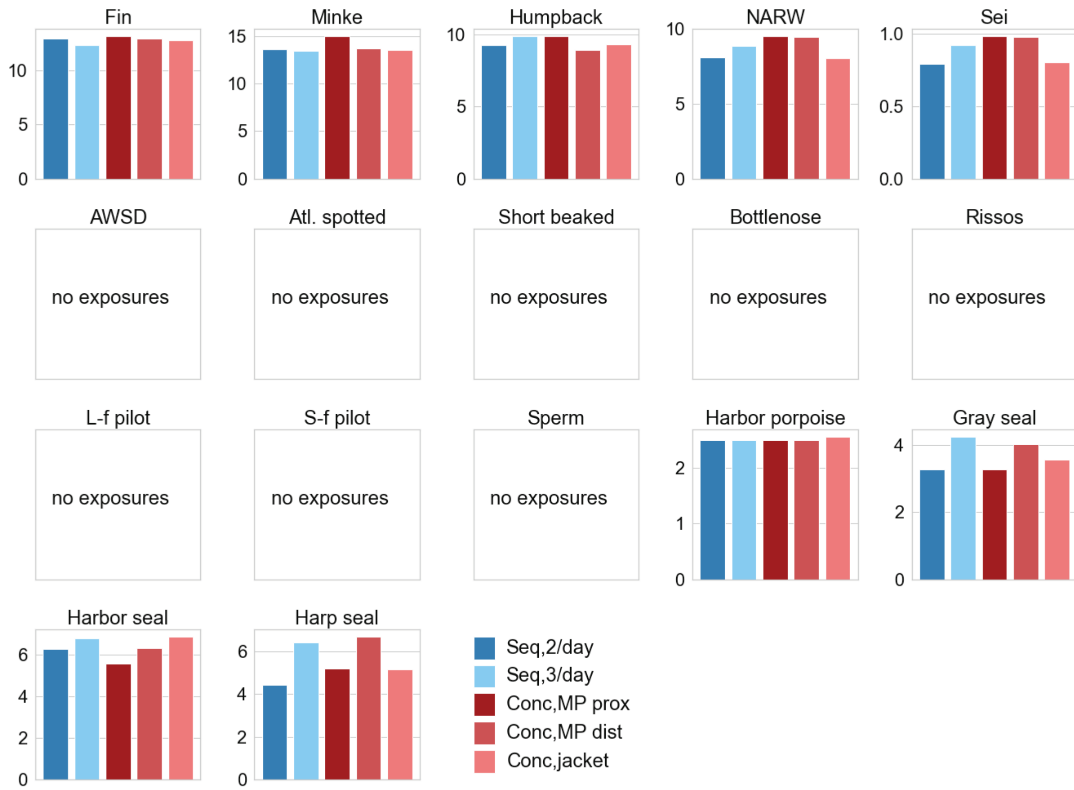

Figure 5.1-1. Summary of injury exposures for each species, colored by construction schedule.Construction schedules in each plot are ordered 1-5 from left to right. There is no strong trend in terms of piles per day for sequential operations. Sometimes there are more predicted exposures for 2 per day monopile installation, and sometimes more for 3 per day monopile installation, depending on species. This is due to the stochasticity of the modeling approach and indicates installations of piles are effectively independent events in terms of potential impacts.

- For LF cetaceans, concurrent proximal monopile installations (i.e., Construction Schedule 3) tends to be slightly more impactful than sequential operations or other types of concurrent operations.
- For MF cetaceans, there are no SEL injury exposures at any attenuation level. With 0dB attenuation, there are a small number of exposures above the PK threshold. Of these, the highest is consistently short-beaked common dolphin because of their higher densities.
- Harbor porpoise (HF) exposures are consistent regardless of schedule.
- For seals, Construction Schedule 3 tends to be the least impactful of all the schedules.
- For all species, Construction Schedule 5 has similar results to Construction Schedule 1. These two schedules are almost identical except that the 2 days of sequential operations in Construction Schedule 1 are replaced by 2 days of concurrent operations in Construction Schedule 5, while the remaining 28 days of operations remain the same.

Behavioral Exposures

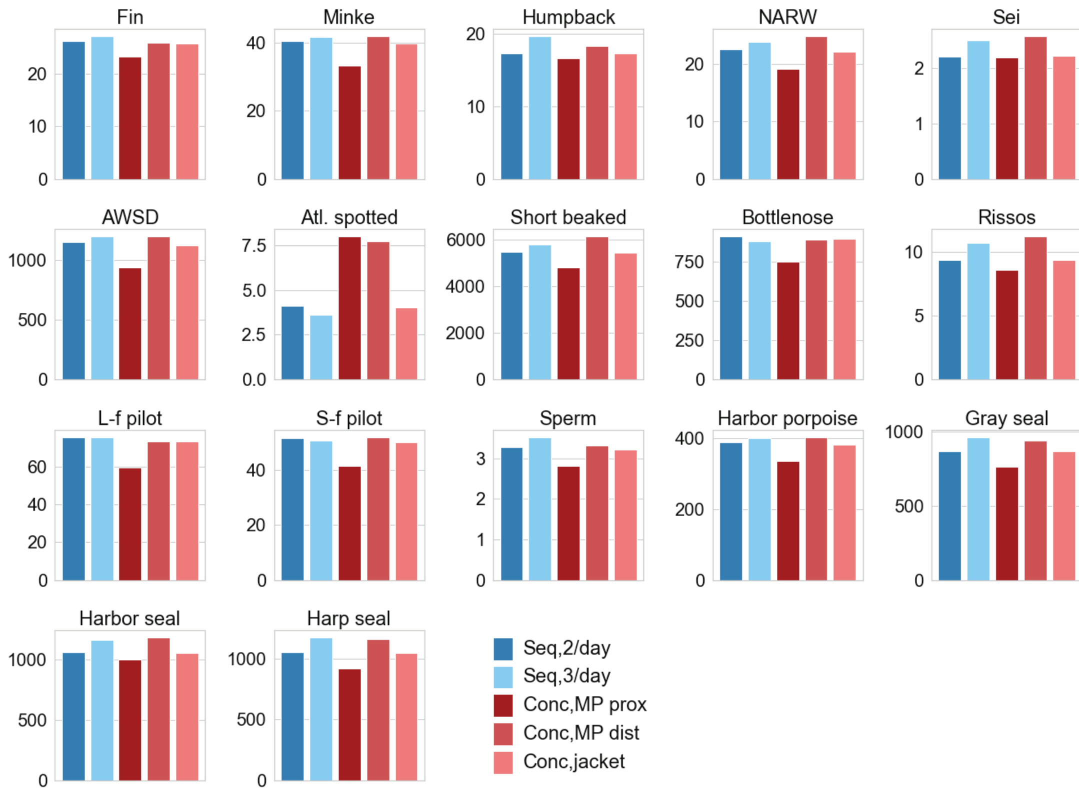

Figure 5.1-2. Summary of behavioral exposures for each species, colored by construction schedule. Construction schedules in each plot are ordered 1-5 from left to right.

- In almost every case, the Construction Schedule 3 results in the least behavioral impacts, since many of the same animats tend to be exposed to two overlapping sources, rather than more animats being exposed to spatially separated sources.
- As with injury exposures, Construction Schedules 1 and 5 yield very similar results.

5.1.2. Exposure ranges

Injury Exposure Ranges

- For injury exposure ranges, there is no consistent trend across all species between 2 per day and 3 per day monopile sequential operations.
- Jacket foundation installation tends to show larger exposure ranges for SEL injury since there are many more strikes per day to install 4 pin piles (~17,000 strikes per pile) versus either 2 or 3 monopiles (~10,000 strikes per pile).
- Exposure ranges for proximal monopile operations are consistently slightly higher than for distal operations.
- Exposure ranges for proximal jacket and monopile operations are higher than for the concurrent monopile-only operations, mainly due to the cumulative impact of jacket foundation installation.

Behavioral Exposure Ranges

- Behavioral exposure ranges for the proximal monopile installation are consistently slightly higher for the proximal monopile installation than for the distal monopile installation.

- For behavior, the largest exposure ranges result from the installation of jacket foundations, for either sequential or concurrent operations.

5.1.3. NARW

As an example, the NARW exposure ranges and exposure estimates for the different scenarios are summarized in Table 5.1-1 and Table 5.1-2, respectively. Table 5.1-1 shows that concurrent, proximal installation of monopiles may increase exposure ranges, indicating that there is some synergistic increase of effects from nearby concurrent pile driving. That is, some animals that exceed the SEL threshold may receive meaningful sound energy from multiple piles. Little difference, however, was found in predicted injury among the different construction schedules. The potential mean number of NARW predicted to exceed the injury threshold is 8.08 for construction schedule 1 and 8.84 for construction schedule 2. The mean number of NARW predicted to exceed the injury threshold is about 9.5 for construction schedules 3 and 4, when multiple vessels are installing monopile foundations. This increase with concurrent operations is partially due to additive effects of concurrent operations as more piles are driven each day, and because a greater number of piles are installed in the highest NARW density month. If the monopile foundations in construction schedules 1 and 2 were installed assuming the highest density, the mean number of NARW predicted to exceed the injury threshold would be 8.37 and 8.98, respectively. In construction schedule 5, the mean NARW predicted to exceed the injury threshold is 8.03, which is similar to construction schedules 1 and 2 indicating little or no synergistic effects of installing a jacket foundation while monopiles are installed.

Conversely, a reduction in the mean number of NARW estimated to exceed the behavioral disruption thresholds is predicted for concurrent, proximal pile driving (Table 5.1-2). It is likely that this reduction is due to a shortened piling campaign because concurrent pile driving allows the project to be completed in less time, and because there is some overlap in the proximal sound fields. Although a similar number of exposures above threshold may occur in each of the construction schedules, individuals exceeding thresholds are only counted once per 24 hours regardless of how many times they receive sound levels above threshold during that period.

The NARW example does point to differences in exposure estimates and exposure ranges for the different construction schedules, but the differences are small. The difference in exposure estimates for sequentially driving two piles per day versus three piles per day is within the sampling variance of the probabilistic modeling approach. This is seen by noting that the SEL injury estimates for Fin and Minke whale increase from two piles per day to three piles per day while Humpback, NARW, and Sei whale decrease. Differences this small indicate that each sequential pile is effectively a singular event.

Table 5.1-1. Exposure ranges predicted for North Atlantic Right Whales for the evaluated daily foundation installation scenarios, with 10 dB attenuation and an average summer sound speed profile.

Daily foundation installations		Injury		Behavior	
		L_E	L_{pk}	L_p [a]	L_p [b]
Sequential	2 piles /day	2.66	0	5.43	5.41
	3 piles /day	2.51	0	5.26	5.25
	4 pin piles /day	3.62	<0.01	5.75	5.77
Concurrent	4 MP /day (proximal)	2.94	0	5.71	5.71
	4 MP /day (distal)	2.61	<0.01	5.24	5.24
	4 pin piles /day + 2 MP /day	3.49	<0.01	5.45	5.52

Table 5.1-2. Mean number of North Atlantic Right Whales predicted to receive sound levels above exposure criteria with 10 dB attenuation for the five construction schedules.

Construction schedule	Injury		Behavior	
	L_E	L_{pk}	L_p [a]	L_p [b]
1	8.08	<0.01	22.49	24.82
2	8.84	<0.01	23.85	22.71
3	9.53	<0.01	19.10	17.97
4	9.47	0.01	24.84	23.00
5	8.03	<0.01	22.09	23.88

[a] NOAA (2005). [b] Wood et al. (2012).

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Glossary

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

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

A-weighting
Frequency-selective weighting for human hearing in air that is derived from the inverse of the idealized 40-phon equal loudness hearing function across frequencies.

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

ambient noise
All-encompassing sound at a given place, usually a composite of sound from many sources near and far (ANSI S1.1-1994 (R2004)), e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity. attenuation

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

auditory frequency weighting (auditory weighting function, frequency-weighting function)
The process of band-pass filtering sounds to reduce the importance of inaudible or less-audible frequencies for individual species or groups of species of aquatic mammals (ISO 2017). One example is M-weighting introduced by Southall et al. (2007) to describe “Generalized frequency weightings for various functional hearing groups of marine mammals, allowing for their functional bandwidths and appropriate in characterizing auditory effects of strong sounds”.

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 and ASA S1.13-2005 (R2010)).

boxcar averaging
A signal smoothing technique that returns the averages of consecutive segments of a specified width.

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

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

cetacean
Any animal in the order Cetacea. These are aquatic, mostly marine mammals and include whales, dolphins, and porpoises.

continuous sound
A sound whose sound pressure level remains above ambient sound during the observation period (ANSI and ASA S1.13-2005 (R2010)). A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

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

delphinid
Family of oceanic dolphins, or Delphinidae, composed of approximately thirty extant species, including dolphins, porpoises, and killer whales.

ensonified
Exposed to sound.

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

geoacoustic
Relating to the acoustic properties of the seabed.

hearing group
Groups of marine mammal species with similar hearing ranges. Commonly defined functional hearing groups include low-, mid-, and high-frequency cetaceans, pinnipeds in water, and pinnipeds in air.

hearing threshold
The sound pressure level for any frequency of the hearing group that is barely audible for a given individual in the absence of significant background noise during a specific percentage of experimental trials.

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

high-frequency (HF) cetacean
The functional cetacean hearing group that represents those odontocetes (toothed whales) specialized for hearing high frequencies.

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

low-frequency (LF) cetacean
The functional cetacean hearing group that represents mysticetes (baleen whales) specialized for hearing low frequencies.

mid-frequency (MF) cetacean
The functional cetacean hearing group that represents those odontocetes (toothed whales) specialized for mid-frequency hearing.

Monte Carlo simulation
The method of investigating the distribution of a non-linear multi-variate function by random sampling of all of its input variable distributions.

mysticete
Mysticeti, a suborder of cetaceans, use their baleen plates, rather than teeth, to filter food from water. They are not known to echolocate, but they use sound for communication. Members of this group include rorquals (Balaenopteridae), right whales (Balaenidae), and grey whales (*Eschrichtius robustus*).

non-impulsive sound
Sound that is broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically does not have a high peak pressure with rapid rise time (typically only small fluctuations in decibel level) that impulsive signals have (ANSI S3.20-1995 (R2008)). For example, marine vessels, aircraft, machinery, construction, and vibratory pile driving (NIOSH 1998, NOAA 2015).

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.

odontocete
The presence of teeth, rather than baleen, characterizes these whales. Members of the Odontoceti are a suborder of cetaceans, a group comprised of whales, dolphins, and porpoises. The skulls of toothed whales are mostly asymmetric, an adaptation for their echolocation. This group includes sperm whales, killer whales, belugas, narwhals, dolphins, and porpoises.

otariid
A common term used to describe members of the Otariidae, eared seals, commonly called sea lions and fur seals. Otariids are adapted to a semi-aquatic life; they use their large fore flippers for propulsion. Their ears distinguish them from phocids. Otariids are one of the three main groups in the superfamily Pinnipedia; the other two groups

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

particle acceleration
The rate of change of particle velocity. Unit: meter per second squared (m/s^2). Symbol: *a*.

particle velocity
The physical speed of a particle in a material moving back and forth in the direction of the pressure wave. Unit: meter per second (m/s). Symbol: *v*.

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

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

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

phocid
A common term used to describe all members of the family Phocidae. These true/earless seals are more adapted to in-water life than are otariids, which have more terrestrial adaptations. Phocids use their hind flippers to propel themselves. Phocids are one of the three main groups in the superfamily Pinnipedia; the other two groups are otariids and walrus.

pinniped
A common term used to describe all three groups that form the superfamily Pinnipedia: phocids (true seals or earless seals), otariids (eared seals or fur seals and sea lions), and walrus.

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

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

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

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

received level
The sound level measured at a receiver.

rms
root-mean-square.

rms sound pressure level (L_p)
The root-mean-square average of the instantaneous sound pressure as measured over some specified time interval. For continuous sound, the time interval is one second. See also sound pressure level (L_p) and 90% rms SPL.

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

signature
Pressure signal generated by a source.

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

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

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

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

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

For sound in water, the reference sound pressure is one micropascal (p_0 = 1 μPa) and the unit for SPL is dB re 1 μPa^2:

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

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

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

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

spectral density level
The decibel level ($10\cdot\log_{10}$) of the spectral density of a given parameter such as SPL or SEL, for which the units are dB re 1 μPa^2/Hz and dB re 1 μPa^2·s/Hz, respectively.

spectrum
An acoustic signal represented in terms of its power, energy, mean-square sound pressure, or sound exposure distribution with frequency.

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

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

Appendix A. 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 and driving pressure. Maximum sound levels from pile installation usually occur during the last stage of driving (Betke 2008). The representative make and model of impact and vibratory hammers, and the hammering energy schedule, were provided by the manufacturers.

A.1. Monopile Foundations – Impact Pile Driving

Sunrise Wind is expected to construct WTG monopile foundations consisting of single, tapered piles (Table 1.2-1). For monopile foundation models, piles are assumed to be vertical and driven to a penetration depth of 50 m. While pile penetrations across the SRWF will vary, this value was chosen as the maximum penetration depth. The estimated number of strikes required to install piles to completion were obtained from Sunrise Wind in consultation with potential hammer suppliers. All acoustic evaluation was performed assuming that only one pile is driven at a time. Modeling input, assumptions, and methods are listed in Table A-1. Sound from the piling barge was not included in the model.

Table A-1. Details of model inputs, assumptions, and methods for the expected 7/12 m monopile installation.

Parameter	Description
Monopile 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	4000 kJ
Ram weight	1977.15 kN
Helmet weight	2746.8 kN
Strike rate (min^{-1})	50
Estimated number of strikes to drive pile	10,398 (see Table 1.2-7)
Expected penetration	50 m
Modeled seabed penetration	14, 24, 34, 43, 48 m (see Table 1.2-4)
Pile length	129.68 m
Pile diameter	7 m (top) to 12 m (bottom)
Pile wall thickness	8.1–13.5 mm
Environmental parameters for all pile types	
Sound speed profile	GDEM data averaged over region
Bathymetry	SRTM data
Geoacoustics	Elastic seabed properties based on client-supplied description of surficial sediment samples
Propagation model for all pile types	
Modeling method	FWRAM full-waveform parabolic equation propagation with 22.5° azimuthal resolution
Source representation	Vertical line array
Frequency range	10–25,000 Hz
Synthetic trace length	1000 ms
Maximum modeled range	89 km

A.2. Jacket Foundation Piles – Impact Pile Driving

Sunrise Wind is expected to construct jacket foundations consisting of 8 pin piles, 4 m in diameter. Although a single foundation requires 8 piles, it is expected that a maximum of only 4 piles will be installed within any 24 h period. Jacket foundation piles are assumed to be vertical and driven to a penetration depth of 90 m. While pile penetrations across the SRWF will vary, this value was chosen as the maximum penetration depth. The estimated number of strikes required to install piles to completion were obtained from Sunrise Wind in consultation with potential hammer suppliers. All acoustic evaluation was performed assuming that only one pile is driven at a time. Modeling input, assumptions, and methods are listed in Table A-2. Sound from the piling barge was not included in the model.

Table A-2. Details of model inputs, assumptions, and methods for the expected 4 m jacket foundation pile installation.

Parameter	Description
Jacket foundation 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	4000 kJ
Ram weight	1977.15 kN
Helmet weight	2746.8 kN
Strike rate (min^{-1})	32
Estimated number of strikes to drive pile	17,088 (see Table 1.2-7)
Expected penetration	90 m
Modeled seabed penetration	12, 25, 43, 63, 80,90 m (see Table 1.2-4)
Pile length	110 m
Pile diameter	4 m
Pile wall thickness	7.5 mm
Environmental parameters for all pile types	
Sound speed profile	GDEM data averaged over region
Bathymetry	SRTM data
Geoacoustics	Elastic seabed properties based on client-supplied description of surficial sediment samples
Propagation model for all pile types	
Modeling method	FWRAM full-waveform parabolic equation propagation with 22.5° azimuthal resolution
Source representation	Vertical line array
Frequency range	10–25,000 Hz
Synthetic trace length	1000 ms
Maximum modeled range	89 km

A.3. Casing Pipe – Impact Pile Driving

Sunrise Wind is expected to install a temporary casing pipe at two HDD exit pit locations for the SRWEC. For casing pipe models, piles are assumed to be angled and driven to a maximum penetration depth of 10 m. The estimated number of strikes required to install piles to completion were obtained through coordination with potential hammer suppliers. All acoustic evaluation was performed assuming that only one pile is driven at a time. Modeling input, assumptions, and methods are listed in Table A-3. Sound from the piling barge was not included in the model.

Table A-3. Details of model inputs, assumptions, and methods for the expected casing pipe installation.

Parameter	Description
Casing pipe pile driving source model	
Impact hammer energy	18 kJ
Hammer type	Grundoram pneumatic hammer
Strike rate (min^{-1})	180
Strikes per pile	64,800
Strikes per day	32,400
Total number of casing pipes	2
Maximum piles installed per day	0.5
Angle of installation	11–12 degrees (relative to horizontal)
Expected penetration	10 m
Pile length	137.16 m
Pile diameter	1.2 m
Pile wall thickness	25.4 millimter (mm)

A.4. Goal Posts – Vibratory Pile Driving

Sunrise Wind is expected to install temporary goal posts to support casing pipe installation at the HDD exit pits. For goal post models, piles are assumed to be vertical and driven to a maximum penetration depth of 10 m. The estimated duration required to install a single sheet pile to completion was obtained through coordination with potential hammer suppliers. All acoustic evaluation was performed assuming that only one pile is driven at a time. Modeling input, assumptions, and methods are listed in Table A-4. Sound from the piling barge was not included in the model.

Table A-4. Details of model inputs, assumptions, and methods for the expected installation of goal posts.

Parameter	Description
Goal posts pile driving source model	
Pile type	Sheet piles
Hammer type	APE Model 300 (vibratory hammer)
Estimated duration to drive a single pile	2 h
Expected penetration	10 m
Single pile installation duration	2 h
Maximum piles installed per day	4
Total number of piles	44
Pile length	30 m
Pile width	600 mm
Pile wall thickness	25 mm

Appendix B. Underwater Acoustics

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

B.1. Acoustic Metrics

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa in water and p_0 = 20 μPa in air. Because the perceived loudness of sound, especially impulsive noise 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 noise and its effects on marine life. Here we provide specific definitions of relevant metrics used in the accompanying report. Where possible, we follow ISO standard definitions and symbols for sound metrics (e.g., ISO 2017).

The zero-to-peak sound pressure level, or peak sound pressure level (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, $p(t)$:

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

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 a noise 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:

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

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 L_p 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 L_p ($L_{p,\mathrm{fast}}$) 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 $L_{p,\mathrm{boxcar\ 125ms}}$. Another approach, historically used to evaluate L_p of impulsive signals underwater, defines $g(t)$ as a boxcar function with edges set to the times corresponding to 5% and 95% of the cumulative square pressure function encompassing the duration of an impulsive acoustic event. This calculation is applied individually to each impulse signal, and the results have been referred to as 90% SPL ($L_{p,90\%}$).

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

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

where T_0 is a reference time interval of 1 s. L_E 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 in terms of relevance for 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 impulsive sounds, SEL can be calculated by summing the SEL of the *N* individual pulses. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the *N* individual events:

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

B.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 decidecade bands, which are approximately one-tenth of a decade wide and often referred to as 1/3-octave-bands. Each octave represents a doubling in sound frequency. The center frequency of the *i*th band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{\frac{i}{10}} \text{ kHz} \qquad \text{(B-5)}$$

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

$$f_c(i) = 10^{\frac{i}{10}} \text{ kHz} \qquad \text{(B-6)}$$

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

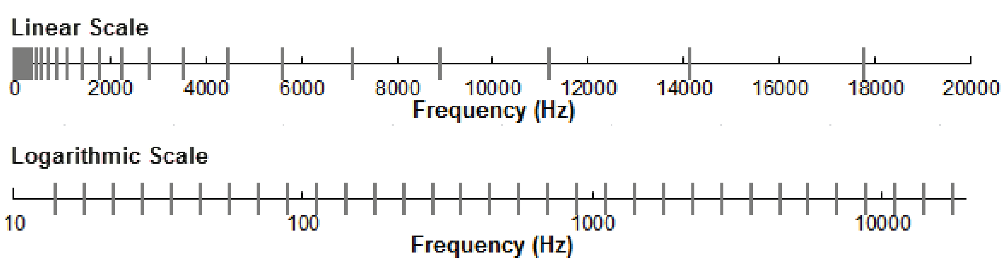


Figure B-1. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and on a logarithmic scale.

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

$$L_{p,i} = 10\log_{10} \int_{f_{lo,i}}^{f_{hi,i}} S(f)\, df \qquad \text{(B-7)}$$

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

$$\text{Broadband SPL} = 10\log_{10}\sum_{i} 10^{\frac{L_{p,i}}{10}} \quad \text{(B-8)}$$

Figure B-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 require less computation time than 1 Hz bands and still resolves the frequency-dependence of the sound source and the propagation environment.

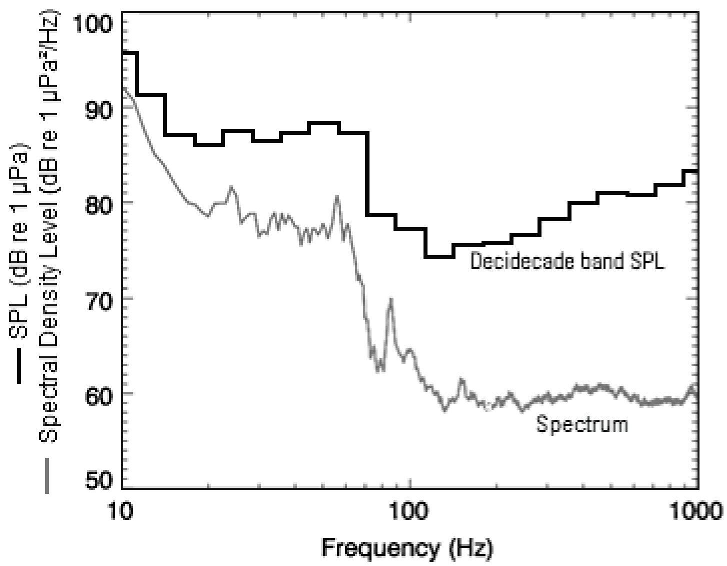


Figure B-2. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.

Appendix C. Auditory (Frequency) Weighting Functions

Weighting functions are applied to the sound spectra under consideration to weight the importance of received sound levels at particular frequencies in a manner reflective of an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007). Southall et al. (2007) were first to suggest weighting functions and functional hearing groups for marine mammals. The Technical Guidance issued by NOAA (NMFS, 2018) includes weighting functions and associated thresholds, and is used here for determining the ranges for potential Level A harassment to marine mammals.

C.1. Frequency Weighting Functions – Technical Guidance (NMFS 2018)

In 2015, a US Navy technical report by Finneran (2015) recommended new auditory weighting functions. The overall shape of the auditory weighting functions is similar to human A-weighting functions, which follows the sensitivity of the human ear at low sound levels. This frequency-weighting function is expressed as:

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

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid-, and high-frequency cetaceans, 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 noise impacts on marine mammals (NMFS, 2018). Table C-1 lists the frequency-weighting parameters for each hearing group; Figure C-1 shows the resulting frequency-weighting curves.

Table C-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	8,800	110,000	1.20
High-frequency cetaceans	1.8	2	12,000	140,000	1.36
Phocid pinnipeds in water	1.0	2	1,900	30,000	0.75
Otariid pinnipeds in water	2.0	2	940	25,000	0.64

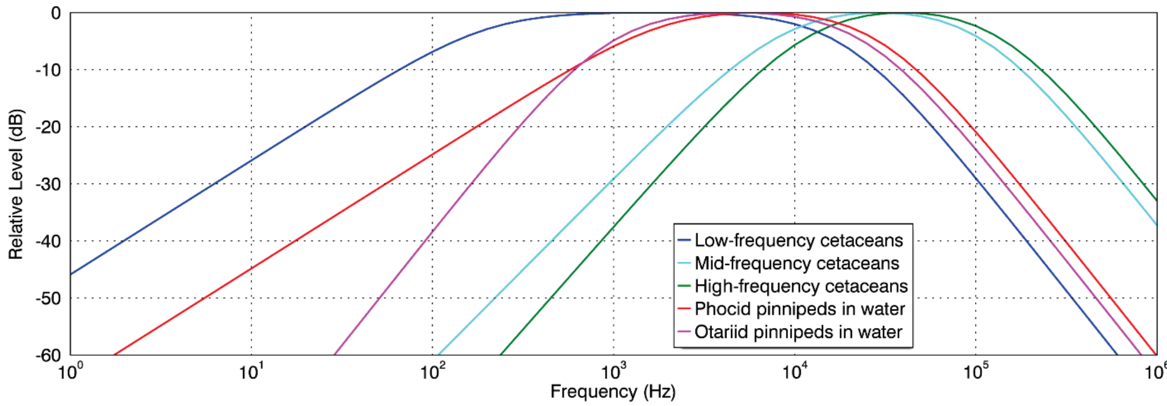


Figure C-1. Auditory weighting functions for functional marine mammal hearing groups included in NMFS (2018).

C.2. Frequency Weighting Functions – Southall et al. (2007)

Auditory weighting functions for marine mammals were proposed by Southall et al. (2007). These so-called 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:

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

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 C-2). Figure C-1 shows the auditory weighting functions.

Table C-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

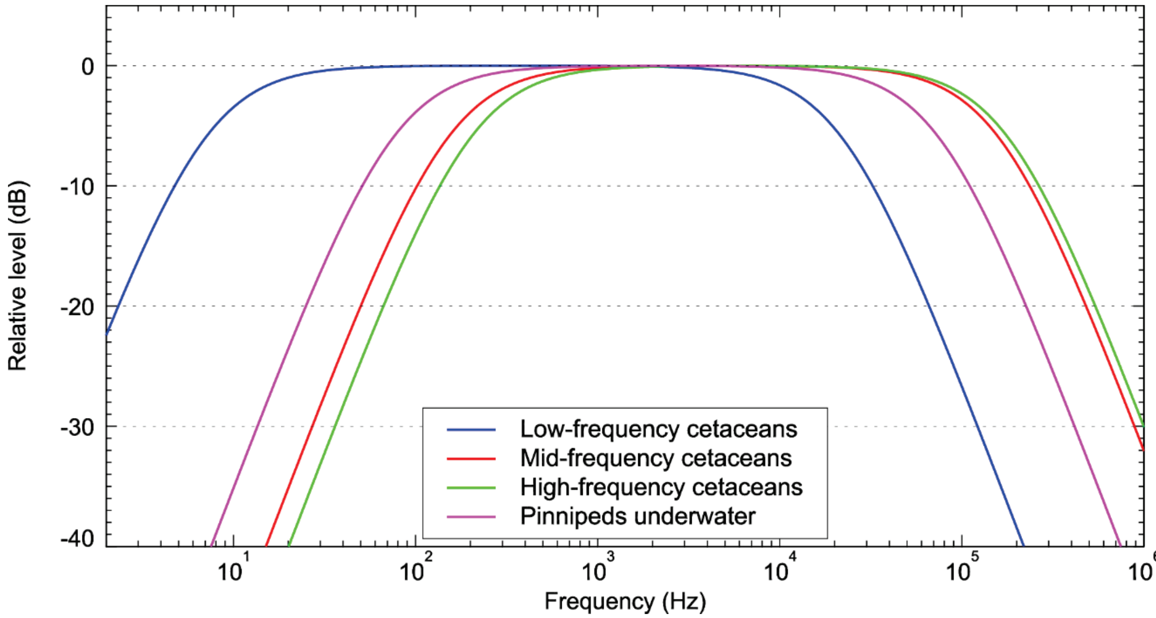


Figure C-2. Auditory weighting functions for the functional marine mammal hearing groups as recommended by Southall et al. (2007).

Appendix D. Source Models

D.1. Pile Driving Source Model (PDSM)

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

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

The sound radiating from the pile itself is simulated using a vertical array of discrete point sources. The point sources are centered on the pile axis. Their amplitudes are derived using an inverse technique, such that their collective particle velocity, calculated using a near-field wave-number integration model, matches the particle velocity in the water at the pile wall. The sound field propagating away from the vertical source array is then calculated using a time-domain acoustic propagation model (see Appendix E.3). MacGillivray (2014) describes the theory behind the physical model in more detail.

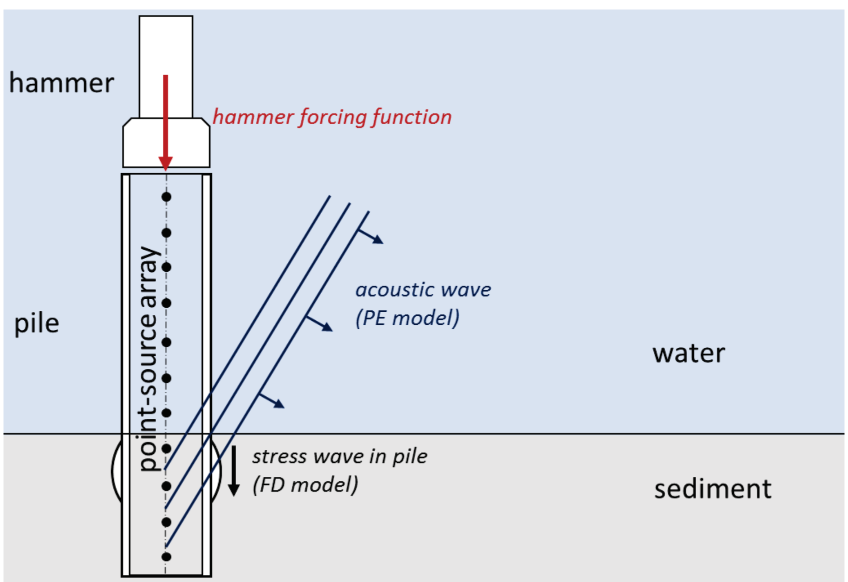


Figure D-1. Physical model geometry for impact driving of a cylindrical pile (vertical cross-section). The hammer forcing function is used with the finite difference (FD) model to compute the stress wave vibration in the pile. A vertical array of point sources is used with the parabolic equation (PE)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

Appendix E. Sound Propagation Modeling Methodology

E.1. Environmental Parameters

E.1.1. Bathymetry

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

E.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 Sunrise Wind. The dominant soil type is expected to be sand. Table E-1 shows the sediment layer geoacoustic property profile based on the sediment type and generic porosity-depth profile using a sediment grain-shearing model (Buckingham 2005).

Table E-1. Estimated geoacoustic properties used for modeling, as a function of depth. 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)
0–2.5	Sand	2.136–2.139	1,764–1,767	0.88–0.879	300	3.65
2.5–5		2.139–2.143	1,767–1,770	0.879–0.879		
5–7.5		2.143–2.146	1,770–1,773	0.879–0.878		
7.5–10		2.146–2.15	1,773–1,777	0.878–0.877		
10–55		2.15–2.209	1,777–1,833	0.877–0.862		
55–100		2.209–2.266	1,833–1,887	0.862–0.845		
100–233		2.266–2.425	1,887–2,031	0.845–0.785		
233–366		2.425–2.565	2,031–2,155	0.785–0.718		
366–500		2.565–2.684	2,155–2,263	0.718–0.652		
>500		2.684	2,263	0.652		

E.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 US Navy's Generalized Digital Environmental Model (GDEM; NAVO 2003). Considering the greater area around the proposed construction area and deep waters, the shape of the sound speed profiles do not change much in summer months (Figure E-1). The mean sound speed profile for spring months also did not differ much from the summer mean profile; therefore, the summer average was used for the acoustic modeling. Water depths in the SRWF are less than 60 m mean lower low water. An average profile, obtained by calculating the mean of all summer profiles shown in Figure E-1, was assumed to be representative of the entire area for modeling purposes.

For impact piling of monopiles and jacket foundation piles, modelling was also conducted for a representative winter sound speed profile (Figure E-2), obtained by calculating the mean of the profiles corresponding to December, January, and February.

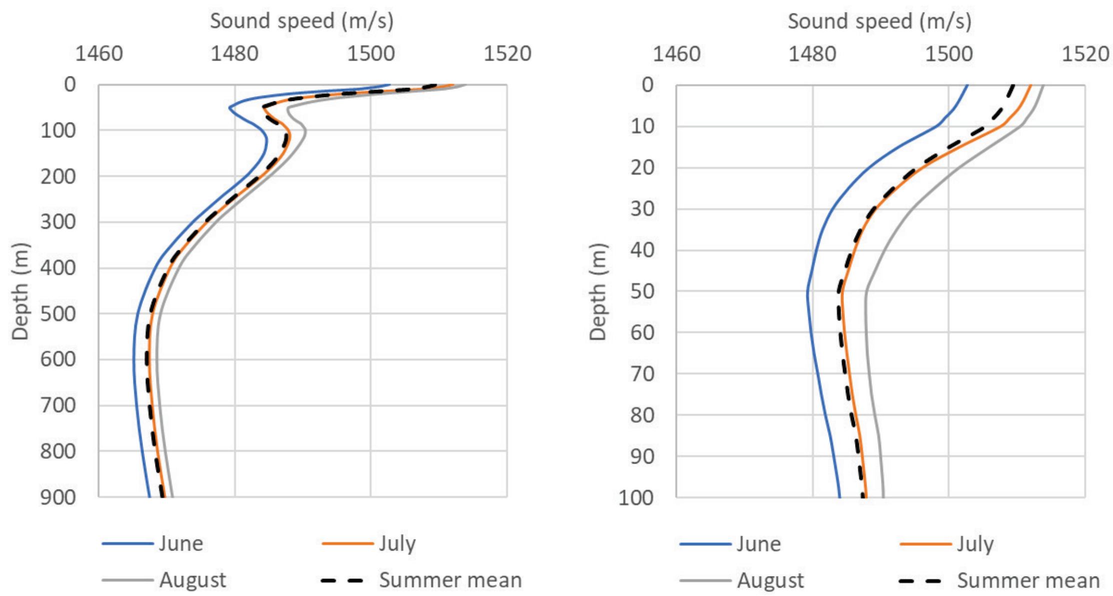


Figure E-1. Sound speed profiles for the summer months of June through August for Sunrise Wind Farm and the mean profile used in the modeling and obtained by taking the average of all profiles: (left) profile up to 900 m and (right) profile up to 100 m.

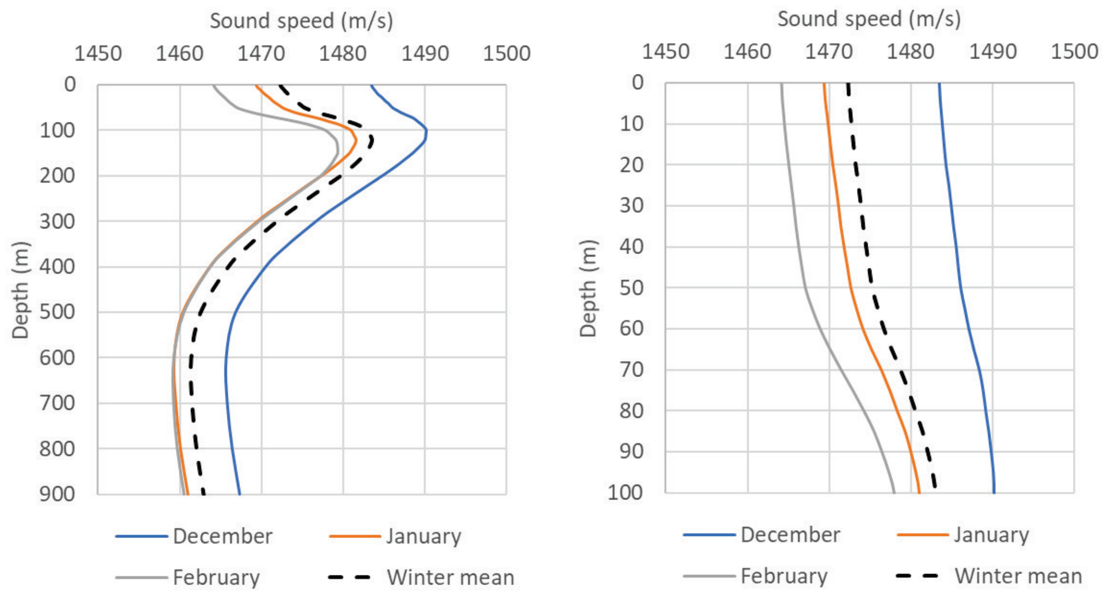


Figure E-2. Sound speed profiles for the winter months of December through February for Sunrise Wind Farm and the mean profile used in the modeling and obtained by taking the average of all profiles: (left) profile up to 900 m and (right) profile up to 100 m.

E.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 energy source level ($L_{S,E}$), expressed in dB re 1 µPa²m²s, and energy propagation loss ($N_{PL,E}$), in units of dB, at a given frequency are known, then the received level ($L_{E,p}$) at a receiver location can be calculated in dB re 1 µPa²s by:

$$L_{E,p}(\theta, r) = L_{S,E}(\theta) - N_{PL,E}(\theta, r), \quad \text{(E-1)}$$

where θ defines the specific direction, and r is the range of the receiver from the source.

E.3. Sound Propagation with MONM

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

MONM treats frequency dependence by computing acoustic transmission loss at the center frequencies of 1/3-octave-bands. At each center frequency, the transmission loss is modeled as a function of depth and range from the source. Composite broadband received SEL are then computed by summing the received 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 E.4). It is the total sound energy transmission loss that is calculated. For our purposes, that is equivalent to propagating the L_E acoustic metric. For continuous, steady-state signals SPL is readily obtained from the SEL.

Acoustic fields in three dimensions are generated by modeling propagation loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as N×2-D (Figure E-3). These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding N = 360°/$\Delta\theta$ planes.

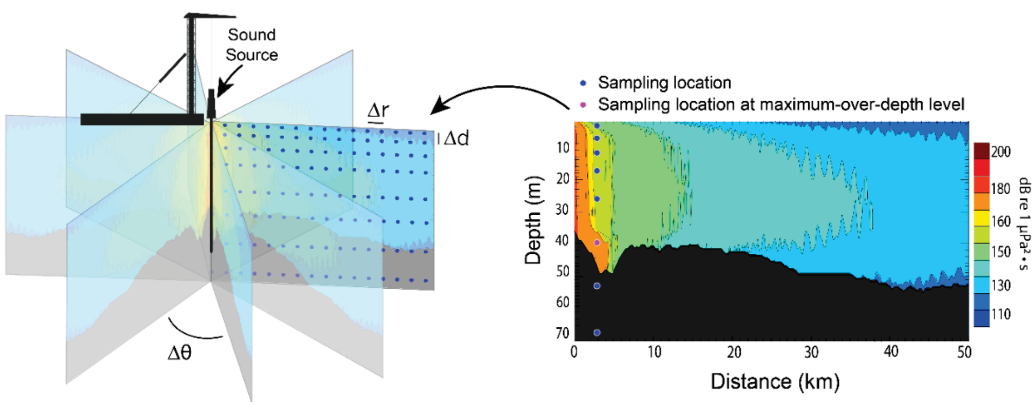


Figure E-3. Modeled three-dimensional sound field (N×2-D method) and maximum-over-depth modeling approach. Sampling locations are shown as blue dots on both figures. On the right panel, the pink dot represents the sampling location where the sound level is maximum over the water column. This maximum-over-depth level is used in calculating distances to sound level thresholds for some marine animals.

E.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 E-4). The synthetic pressure waveforms were post-processed, after applying a travel time correction, to calculate standard SPL and SEL metrics versus range and depth from the source.

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

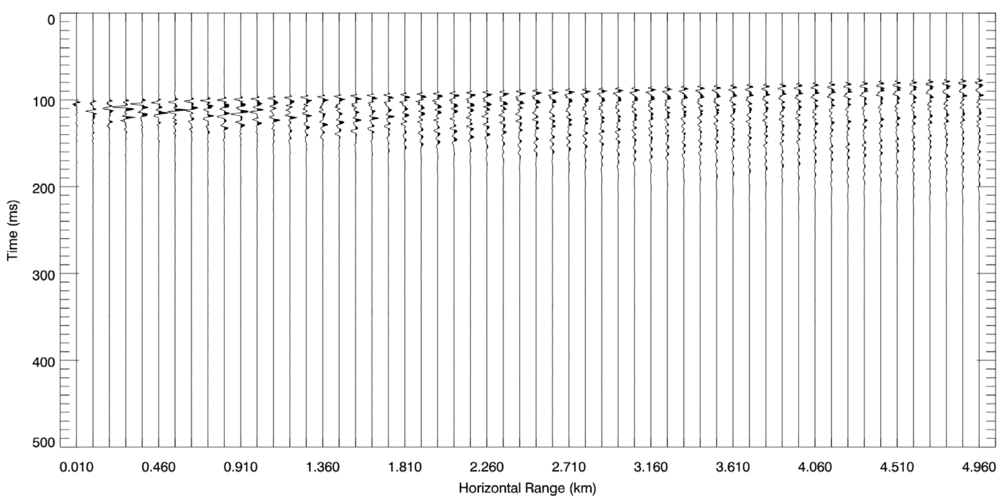
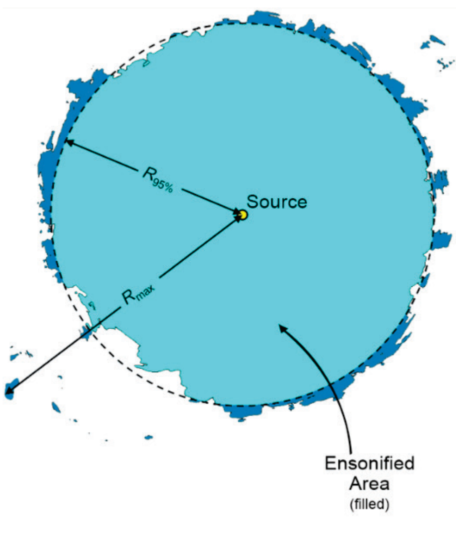


Figure E-4. Example of synthetic pressure waveforms computed by FWRAM at multiple range offsets. Receiver depth is 35 m and the amplitudes of the pressure traces have been normalised for display purposes.

E.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 E-5 shows an example of an area with sound levels above threshold and two methods of reporting the injury or behavioral disruption range: (1) R_{max}, the maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field, and (2) $R_{95\%}$, the maximum range at which the sound level was encountered after the 5% farthest such points were excluded. $R_{95\%}$ is used because, regardless of the shape of the maximum-over-depth footprint, the predicted range encompasses at least 95% of the horizontal area that would be exposed to sound at or above the specified level. The difference between R_{max} and $R_{95\%}$ depends on the source directivity and the heterogeneity of the acoustic environment. $R_{95\%}$ excludes ends of protruding areas or small isolated acoustic foci not representative of the nominal ensonification zone.



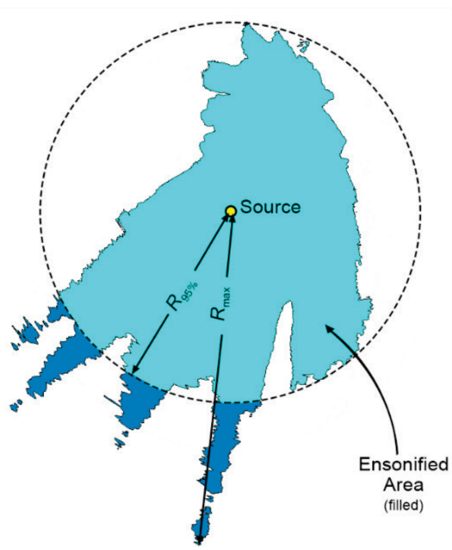


Figure E-5. Sample areas ensonified to an arbitrary sound level with R_{max} and $R_{95\%}$ ranges shown for two different scenarios. (a) Largely symmetric sound level contour with small protrusions. (b) Strongly asymmetric sound level contour with long protrusions. Light blue indicates the ensonified areas bounded by $R_{95\%}$; darker blue indicates the areas outside this boundary which determine R_{max}.

E.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 F. Effects from Secondary Sound Sources in the Project Area

The primary sources of underwater sound generated during the Project are associated with installation of monopile and jacket pile foundations. These primary sound sources are the focus of the quantitative analysis presented in the main text. The objective of this Appendix is to provide a qualitative description and evaluation of other underwater sound sources associated with Project construction and operation, collectively referred to as 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 F-1), 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.

F.1. Vessels

All vessels emit sound from propulsion systems while in transit, and engines and machinery emit noise through the hull while in use. The emitted sounds are typically broadband, non-impulsive, continuous, low-frequency noise. A vessel's acoustic signature depends on the vessel type (e.g., tanker, bulk carrier, tug, container ship, recreational vessel) and vessel characteristics (e.g., engine specifications, propeller dimensions and number, length, draft, hull shape, gross tonnage, speed). Large shipping vessels and tankers produce lower frequency sounds with primary acoustic energy ~40 Hz and apparent underwater source levels (SLs) of SPL 177 to 188 dB re 1 µPa (McKenna et al. 2012). Dynamically positioned (DP) vessels use thrusters to maneuver and maintain station, and generate substantial underwater noise with apparent SLs ranging from SPL 150 to 180 dB re 1 µPa depending on operations and thruster use (BOEM 2014). Smaller, high-speed vessels may produce higher-frequency sound (1,000 to 5,000 Hz) with apparent SLs between SPL 150 and 180 dB re 1 µPa (Kipple 2002, Kipple and Gabriele 2003).

Marine mammals, sea turtles, fish and invertebrates in many locations are regularly subjected to vessel activity and may be habituated to vessel noise as a result of frequent or prolonged exposure (BOEM 2014). Non-Project vessel traffic in the vicinity of the Project may include recreational vessels, fishing vessels, cargo vessels, tankers, passenger vessels, and others. Vessels associated with the Project during construction and operation will not contribute considerably more vessel traffic above baseline conditions and therefore the potential risk of impact from Project vessel noise is low to very low.

F.1.1. Potential Impacts to Marine Fauna

F.1.1.1. Marine Mammals

The vessel sounds emitted by ship engines, propellers, thrusters, and hulls are within the (assumed) best hearing frequency ranges of low-frequency cetaceans and are audible by all marine mammals (NMFS 2018). Vessel activities in the Project Area will add to the existing ambient vessel sound level of regular vessel traffic in the area, which could cause behavioral impacts to marine mammals (Kraus et al. 2005, Southall 2005, Clark et al. 2009, Geo-Marine 2010). As with other anthropogenic sound, the potential effects from vessel noise depends on factors such as the marine mammal species, the marine mammal's location and activity, the novelty of the sound, habitat, and oceanographic conditions.

Marine mammals exposed to vessel sounds have reported variable behavioral responses. Analyses of observations made during the Behavioral Response of Australian Humpback whales (*Megaptera novaeangliae*) to Seismic Surveys (BRAHSS) study, Dunlop et al. (2015, 2016a, 2016b, 2017a, 2017b, 2018) found only minor and temporary changes in the migratory behavior of humpback whales in response to exposure to vessel and seismic airgun sounds. Increased proximity of vessels, however, led to aversive reactions (Dunlop et al. 2017b) and to reduced social interactions between migrating humpback whales (Dunlop et al. 2020). In other studies of humpback whales, most individuals did not respond to sonar vessels with the sonar turned off (Sivle et al. 2016, Wensveen et al. 2017), and Tsujii et al. (2018) found that humpback whales moved away from large vessels, while others noted temporary changes in respiratory behavior (Baker and Herman 1989, Frankel and Clark 2002)) or temporary cessation of foraging activities (Blair et al. 2016). Researchers have also

reported a temporary change in the distribution and behavior of marine mammals in areas experiencing increased vessel traffic, particularly associated with whale watching, likely due to increases in ambient noise from concentrated vessel activity (Erbe 2002, Nowacek et al. 2004). The large number of studies on humpback whales and the resulting variety of documented responses clearly demonstrate how context affects behavior.

Marine mammals in the Project Area are regularly subjected to commercial shipping traffic and other vessel noise and could potentially be habituated to vessel noise (BOEM 2014). Hatch et al. (2012) estimated that calling North Atlantic right whales (*Eubalaena glacialis*) (NARWs) may have lost 63 to 67% of their communication “space” due to shipping noise. Although received levels of sound may, at times, be above the non-impulsive sound threshold for Level B harassment (120 dB SPL), NARWs have been known to continue to feed in Cape Cod Bay, Massachusetts despite disturbance from passing vessels (Brown et al. 2000). In another study, NARWs showed no behavioral response to ship sounds at all, or at least not to received levels of 132 to 142 dB re 1 µPa from large ships passing within 1 nm (1.9 km) distance, nor to received levels of 129 to 139 dB re 1 µPa (main energy between 50 and 500 Hz) to artificial playback of ship noise (Nowacek et al. 2004).

Studies of responses by mid-frequency cetaceans to vessel sounds, conducted in various parts of the world and with a variety of species, have also shown mixed results. Groups of Pacific humpback dolphins (*Sousa chinensis*) in eastern Australia that included mother-calf pairs, increased their rate of whistling after a vessel transited the area (Van Parijs and Corkeron 2001). The authors postulated that vessel sounds disrupted group cohesion, especially between mother-calf pairs, requiring re-establishment of vocal contact after vessel noise temporarily masked their communication. Lesage et al. (1999) revealed that beluga whales (*Delphinapterus leucas*) reduced their overall call rate in the presence of vessels but increased the emission and repetition of specific calls and shifted to higher frequency bands. In response to high levels of vessel traffic, killer whales increased the duration (Foote et al. 2004) or the amplitude (Holt et al. 2009) of their calls. Other studies of killer whales (*Orcinus orca)* showed temporary changes in behavior in response to vessel noise including less foraging and increased surface-active behavior), respiration, swim speed, and direction occurred at received levels above 130 dB re 1 µPa (0.01 to 50 kHz) (Williams et al. 2002, Lusseau et al. 2009, Noren et al. 2009, Williams et al. 2014). Marley et al. (2017) found that Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Fremantle Inner Harbor, Australia significantly increased their average movement speed in the presence of high vessel densities during resting behavior. Behavioral budgets also changed in the presence of vessels, with animals spending more time traveling and less time resting or socializing.

Mid-frequency Cuvier’s beaked whales (*Ziphius cavirostris*) responded to ship sounds by decreasing their vocalizations when they attempted to catch prey (Aguilar Soto et al. 2006), and foraging changes were observed in Blainville’s beaked whales (*Mesoplodon densirostris*) when they were exposed to vessel noise (Pirotta et al. 2012). Harbor porpoises (*Phocoena phocoena*) tend to swim away from approaching vessels emitting high frequency noise in the Bay of Fundy, Canada (Polacheck and Thorpe 1990) and have been observed to move rapidly out of the path of a survey vessel within 1 km on the western coast of North America (Barlow 1988). Both harbor porpoises and beaked whale species are known to avoid relatively low levels of anthropogenic sound, and are generally recognized as behaviorally sensitive species (Wood et al. 2012 criteria).

In response to vessel noise, a tagged seal changed its diving behavior, switching quickly from a dive ascent to descent (Mikkelsen et al. 2019). This observation agrees with descriptions of changes in diving reported from juvenile northern elephant seals (*Mirounga angustirostris*) (Fletcher et al. 1996, Burgess et al. 1998). The tagging study also found that harbor seals (*Phoca vitulina*) and grey seals (Halichoerus grypus) are routinely exposed to vessel noise 2.2 to 20.5% of their time at sea (Mikkelsen et al. 2019).

Sound levels and the presence of vessels associated with the Project may result in behavioral responses by marine mammals, but within the context of an already highly trafficked region, the intermittent nature of vessel activity suggests that the impacts due to Project vessels are likely to be low.

F.1.1.2. Potential Impacts to Sea Turtles

Most of the underwater sound produced by ships is low frequency (~20–500 Hz) and overlaps with the known or assumed best hearing frequency range of all sea turtles. The broadband (20–1,000 Hz) apparent source level of a modern commercial ship (54,000 gross ton container ship traveling at 21.7 knots) is up to 188 dB re 1µPa (McKenna et al. 2012). This source level is below the non-impulsive acoustic injury threshold of 200 dB re 1 µPa for sea turtles (Finneran et al. (2017), meaning that only behavioral responses could be expected from sea turtles exposed to Project related vessel noise. Underwater noise that is detectable by sea turtles can mask signal detection, and influence behavior, but the consequences of masking and attendant behavioral changes on the survival of sea turtles are not known (Popper et al. 2014).

Many of the proposed Project-related vessels are significantly smaller than cargo ships and most will transit at slower speeds than cargo ships. The apparent source levels of smaller, slower vessels may be below the behavioral response thresholds of sea turtles or limited to the area immediately adjacent to the vessel. As with marine mammals, sea turtles are regularly subjected to commercial shipping traffic and other vessel noise and may be habituated to vessel noise as a result of this exposure (BOEM 2014). Given the lower sound levels associated with vessel transit and operation and the limited ensonified area produced by this source, the risk of impact to sea turtles is expected to be very low to low.

F.1.1.3. Potential Impacts to Fish

Vessel noise may interfere with feeding and breeding, alter schooling behaviors and migration patterns (Buerkle 1973, Olsen et al. 1983, Schwarz and Greer 1984, Soria et al. 1996, Vabø et al. 2002, Mitson and Knudsen 2003, Ona et al. 2007, Sarà et al. 2007), mask important environmental auditory cues (CBD 2012, Barber 2017), and induce endocrine stress response (Wysocki et al. 2006). Fish communication is mainly in the low-frequency (<1000 Hz) range (Ladich and Myrberg 2006, Myrberg and Lugli 2006) so masking is a particular concern because many fish species have unique vocalizations that allow for inter- and intra-species identification, and because fish vocalizations are generally not loud, usually ~120 dB SPL with the loudest sounds reaching 160 dB SPL (Normandeau Associates 2012). Behavioral responses in fishes differ depending on species and life stage, with younger, less mobile age classes being the most vulnerable to vessel noise impacts (Popper and Hastings 2009, Gedamke et al. 2016).

Underwater sound from vessels can cause avoidance behavior, which has been observed for Atlantic herring (*Clupea harengus*) and Atlantic cod (*Gadus morhua*), and is a likely behavior of other species as well (Vabø et al. 2002, Handegard et al. 2003). Fish may respond to approaching vessels by diving towards the seafloor or by moving horizontally out of the vessel's path, with reactions often initiated well before the vessel reaches the fish (Ona et al. 2007, Berthe and Lecchini 2016). The avoidance of vessels by fish has been linked to high levels of infrasonic and low-frequency sound (~10 to 1,000 Hz) emitted by vessels. Accordingly, it was thought that quieter vessels would result in less avoidance (and consequently quieter vessels would have a higher chance of encountering fish) (De Robertis et al. 2010). By comparing the effects of a quieted and conventional research vessel on schooling herring, it was found that the avoidance reaction initiated by the quieter vessel was stronger and more prolonged than the one initiated by the conventional vessel (Ona et al. 2007). In a comment to this publication, Sand et al. (2008) pointed out that fish are sensitive to particle acceleration and that the cue in this case may have been low-frequency particle acceleration caused by displacement of water by the moving hull. This could explain the stronger response to the larger, noise-reduced vessel in the study by Ona et al. (2007), which would have displaced more water as it approached.

Nedelec et al. (2016) investigated the response of reef-associated fish by exposing them in their natural environment to playback of vessel engine sounds. They found that juvenile fish increased hiding and ventilation rate after a short-term vessel sound playback, but responses diminished after long-term playback, indicating habituation to sound exposure over longer durations. These results were corroborated by Holmes et al. (2017) who also observed short-term behavioral changes in juvenile reef fish after exposure to vessel noise as well as desensitization over longer exposure periods.

While sounds emitted by vessel activity are unlikely to injure fish, vessel sound has been documented to cause temporary behavioral responses (Holmes et al. 2017). Fish in the area are already exposed to vessels sounds in this high-traffic area, and Project-related vessel noise will be intermittent and of short duration, so the overall impacts to fish are expected to be low.

F.1.1.4. Potential Impacts to Invertebrates

Although the study of effects of sound on invertebrates (e.g., crustaceans, cephalopods, and bivalves) is in its nascency, it is evident that invertebrates are sensitive to particle motion (as opposed to pressure) (Popper and Hawkins 2018) and that they can detect vibrations in the sea bed (Roberts et al. 2015, Roberts and Breithaupt 2016, Roberts and Elliott 2017). While there are currently no agreed upon metrics or clearly defined levels (in terms of sound pressure or particle motion) for assessing the effects or impacts of sound on invertebrates (Hawkins and Popper 2017), recent experiments have measured sound pressure levels and particle motion associated with trauma in cuttlefish (*Sepia officinalis*) (Solé et al. 2017) and longfin squid (*Doryteuthis pealeii*) (Mooney et al. 2016, Jones et al. 2020, Jones et al. 2021). And, some studies have found potential behavioral effects (e.g., flight or retraction) or physiological (e.g., stress) responses in invertebrates. For example, shore crabs (*Carcinus maenas*) in the presence of vessel noise ceased feeding and were slower to retreat to shelter (Wale et al. 2013b). The common prawn (*Palaemon serratus*) had fewer intra-specific interactions and spent more time outside of their shelters where the sound pressure levels were lower (Filiciotto et al. 2016). Lobsters (*Nephrops norvegicus*) reduced locomotor activity and clams (*Ruditapes philippinarum*) exhibited behaviors that ultimately prevented feeding (Solan et al. 2016).

Shore crabs exposed to playbacks of vessel noise demonstrated an increase in oxygen consumption that was presumed to indicate a higher metabolic rate and/or stress (Wale et al. 2013a). A similar response was observed in the blue mussel (*Mytilus edulis*), which not only increased oxygen consumption but also had more fragmentation of cellular DNA (Wale et al. 2016). In Pacific oysters (*Magallana gigas*), chronic exposure to vessel noise was shown to depress activity and food uptake, ultimately limiting growth (Charifi et al. 2018). Evidence from a field experiment with sea hares (*Stylocheilus striatus*) demonstrated a significant increase in the likelihood of developmental failure at the embryonic stage and mortality at the free-swimming stage, when exposed to play-backs of vessel noise (Nedelec et al. 2014).

Overall, while there are preliminary indications of potential impacts of vessel noise on some invertebrates, most research has been conducted in a laboratory setting, where tank boundaries may affect the acoustic field and observed behavioral response (Rogers et al. 2016, Popper and Hawkins 2018). Further, nearly all studies measured sound pressure rather than particle motion (Jesus et al. (2020). Although high-intensity noise may produce high sound pressure levels and high levels of particle motion concurrently, it is impossible to determine this relationship without proper measurements (Popper and Hawkins 2018). It is unlikely, however, that these stimuli have more than short-term consequences. For example, the shore crabs that showed an increase in oxygen consumption did not respond after repeated exposures to vessel noise (Wale et al. 2013a). Thus, overall risks of impacts to invertebrates associated with vessel noise are expected to be low.

F.1.2. Monitoring and Mitigation

Sound levels associated with vessels vary with vessel class, speed, and activity. High speeds and the use of thrusters increase noise levels significantly (Richardson et al. 1995) though marine fauna are regularly subjected to commercial shipping traffic and other vessel noise and are likely habituated to vessel noise as a result of this regular exposure (BOEM 2014). Many of the proposed Project-related vessels are much smaller than cargo ships that frequently transit the area and, for mitigation purposes, will typically transit at slower speeds.

F.2. Aircraft

Aircraft, both fixed wing and helicopter, may be used during Project construction and operation for crew transfers and biological monitoring activities. The evaluation of aircraft sound on marine fauna differs from other underwater sound sources in that sound generated by aircraft is produced within the air, transmitted through the water surface, and propagated underwater. Most sound energy from aircraft reflects off the air-water interface; only sound radiated downward within a 26-degree cone penetrates below the water surface (Urick 1972).

In general, underwater sound levels produced by fixed wing aircraft and helicopters are typically low frequency (16–500 Hz) and range between 84–159 dB re 1 µPa (Richardson et al. 1995, Patenaude et al. 2002, Erbe et al. 2018). (Patenaude et al. 2002) recorded the transmission of sound into water from two types of aircraft: a

Twin Otter fixed-wing airplane and a Bell 212 helicopter. Sound levels were measured at 3 m and 18 m below the water surface while the aircraft flew at various airspeeds and four altitudes overhead. Maximum received levels in the 10 to 500 Hz frequency band at 18 m water depth were approximately 120 dB re 1 μPa for both the Twin Otter and Bell 212 (Patenaude et al. 2002). Received PK sound levels were generally higher at 3 m depth than 18 m depth by an average of 2.5 dB but varied considerably with both the altitude and speed of the aircraft (Patenaude et al. 2002). Because underwater sound from aircraft depends on height, angle, speed, and sound propagation in different environmental conditions (temperature, humidity in air, and salinity in water) (Hubbard 1991, Erbe et al. 2018), underwater sound levels from aircraft are highly variable.

There is limited research on the impacts of aircraft sounds to marine fauna, however, sound emitted by aircraft that propagations underwater has the potential to cause behavioral responses in marine mammal, sea turtle, and fish (McCauley et al. 2000a, Popper et al. 2014, Todd et al. 2015, Finneran et al. 2017, NMFS 2018). Further information is required to determine the potential underwater effects of aircraft in invertebrates (Hawkins et al. 2015). Given that the majority of sound emitted by aircraft is reflected off the surface of the water, impacts to marine fauna are expected to be very low to low.

F.2.1. Potential Impacts to Marine Fauna

F.2.1.1. Marine Mammals

Aircraft noise is typically low- to mid-frequency, overlapping with cetacean calls and with the potential to cause temporary changes in behavior and localized displacement of marine mammals when transmitted from air through the water surface (Richardson et al. 1985a, Richardson and Würsig 1997, Nowacek et al. 2007). Marine mammals react to aircraft noise more often when the aircraft is lower in altitude, closer in lateral distance, and flying over shallow water (Richardson et al. 1985b, Patenaude et al. 2002). Temporary reactions displayed by marine mammals include short surfacing, hasty dives, aversion from the aircraft, or dispersal from the incoming aircraft (Bel'kovich 1960, Kleĭnenberg et al. 1964, Richardson et al. 1985a, Richardson et al. 1985b, Luksenburg and Parsons 2009). The response of cetaceans to aircraft noise largely depends on the species as well as the animals' behavioral state at the time of exposure (e.g., migrating, resting, foraging, socializing) (Würsig et al. 1998).

Cetaceans within the low frequency hearing group showed varied behavioral response when exposed to aircraft noise. Bowhead whales (*Balaena mysticetus*) displayed frequent behavioral reactions to fixed-wing aircraft and helicopter sounds at altitudes <305 m (Dahlheim 1981, Richardson et al. 1985b, Koski et al. 1988, Richardson and Malme 1993). However, Patenaude et al. (2002) noted that only 17% of observed bowhead whales showed behavioral response to passing helicopters, even at the lower altitudes (150 m) and lateral distances of 250 m. Behavioral changes were also seen in gray whales (*Eschrichtius robustus*) in response to the sound from a Bell 212 helicopter (Malme et al. 1984).

Variable behavioral reactions to aircraft sound were also observed in mid-frequency cetaceans. In the Gulf of Mexico, beaked whales, pygmy and dwarf sperm whales (*Kogia spp*.), and various delphinids (pantropical spotted [*Stenella attenuate*], Clymene [*Stenella clymene*], striped [*Stenella coeruleoalba*] and spinner [*Stenella longirostris*] dolphins) showed a strong behavioral response to an approaching fixed-winged aircraft by quickly diving (Würsig et al. 1998). Several studies reported defensive behavioral responses to approaching aircraft in sperm whales (Würsig et al. 1998, Richter et al. 2003, Richter et al. 2006, Smultea et al. 2008). In contrast, only 3.2% (or 24 of 760) of beluga whales responded to fixed wing aircraft at heights above the water ranging from 182 to 427 m (Patenaude et al. 2002). Given that recorded SPL at 18 m was approximately equivalent (~120 dB SPL) to the regulatory defined acoustic behavioral response threshold level for marine mammals, the lack of response is unsurprising in this study (Patenaude et al. 2002).

The sound emitted by aircraft has the potential to elicit temporary behavioral responses in marine mammals and Project-related aircraft can be at low altitude, but due to the intermittent nature and the small ensonified area of this sound source, the risks of aircraft impact to marine mammals are expected to be low.

F.2.1.2. Sea Turtles

Although aircraft sounds can be within the hearing frequency range of turtles, very few studies have analyzed the impacts of aircraft noise on sea turtles. The only documented behavioral responses were from nesting sea turtles near (1.7 km) a military jet airfield in which the turtles exhibited postnatal behavioral reactions to in-air aircraft noise (Balazs and Ross 1974).

Given the frequency range and sound levels produced by aircraft, sea turtles may have adverse behavioral responses to this source. However, the intermittent nature and the small area of ensonification produced by aircraft is unlikely to impact sea turtles. Risk of impact are therefore expected to be very low.

F.2.1.3. Fish

Because documented sound levels in water from aircraft can be higher than the regulatory-defined non-impulsive behavioral acoustic thresholds for fish (Andersson et al. 2007, Wysocki et al. 2007, Mueller-Blenkle et al. 2010, Purser and Radford 2011), it can be inferred that aircraft may cause behavioral responses in fish. It is unlikely, however, that the underwater sound from aircraft associated with the Project will have much impact on fish because the sound produced by these aircraft is intermittent and has a small ensonified area. The risks of impacts to fish from aircraft sound are expected to be very low.

F.2.1.4. Invertebrates

Aircraft may produce low-frequency sounds within the hearing range of marine invertebrates but there are currently no data available on the potential impacts of this underwater sound on marine invertebrates. As with fish, the risks of impacts to invertebrates from aircraft sound propagated underwater are expected to be very low due to the small ensonified area and intermittent nature of the source.

F.2.2. Monitoring and Mitigation

To mitigate potential impacts to marine fauna from aircraft noise during aerial surveys, uncrewed aerial systems (drones) equipped with a camera system may be used for real time monitoring of marine mammals. With uncrewed aerial systems, Protected Species Observers (PSOs) monitor high-definition drone camera footage in real time from shore or a vessel. This monitoring approach minimizes traditional, more intrusive methods to detect marine mammals and limits sound from fixed-wing aircraft that is typically used in marine mammal and sea turtle aerial surveys. The underwater sound levels recorded from drones (<100 dB re 1 µPa) is well below underwater noise regulatory thresholds (Erbe et al. 2017). Helicopter and fixed-wing aircraft used during the Project construction and operation phase will be in operation intermittently and primarily maintain safe altitudes (150 to 300 m) above sea level. At these heights, and with the use of drones for aerial surveys, overall aircraft noise may elicit only short-term behavioral response in marine mammals such that the impact risk is very low.

F.3. High Resolution Geophysical (HRG) Surveys

High resolution geophysical (HRG) surveys are required to characterize the seafloor and inform the Project design. Seafloor mapping and bottom-penetrating imaging systems differ primarily in the frequency range that the various sources produce. Higher frequencies resolve smaller features, so seafloor mapping is conducted using high-frequency sources while lower frequencies are used to characterize conditions below the seabed.

Acoustic signals produced by HRG sources are impulsive, tonal, or frequency-modulated (FM) chirp pulses (short duration signals that sweep through a band of frequencies) (Halvorsen and Heaney 2018). Impulsive signals are produced by a variety of sources such as airguns, boomers, and sparkers using a variety of mechanisms (e.g., release of compressed air and electrostatic discharge) (Crocker and Fratantonio 2016). Tonal and FM chirp signals are produced by electromechanical sonars. Sub-bottom profilers are electromechanical sources that (typically) produce FM chirp signals at low frequencies able to penetrate the seafloor. Other electromechanical HRG sources such as side-scan and multibeam sonars, and echosounders

produce tonal or FM chirp signals at higher frequencies for seafloor mapping. The source level, beamwidth, pulse duration, and pulse repetition rate of such sources are typically adjustable and selected for the needs of each survey. For regulatory purposes, sound signals are classified as either impulsive or non-impulsive with accompanying thresholds for assessing potential impacts on animals (see Section 2.4). Airguns, boomers, sub-bottom profilers, and sparkers are classified by NMFS as impulsive sound sources, while all electromechanical HRG sources are classified as non-impulsive.

Penetrating HRG systems produce low frequency sounds with high source levels. Mini-airguns emit sounds <5 kHz with source levels of 217–228 re 1 µPa (Crocker and Fratantonio 2016). Sub-bottom profilers produce sounds with primary acoustic energy in frequency bands 2–115 kHz at levels from 178 to 241 dB re 1 µPa and penetrating seismic profilers produce sound at lower frequencies (0.25–15 kHz) with source levels 205–206 dB re 1 µPa range (Crocker and Fratantonio 2016). Many seafloor mapping systems are operated at frequencies >200 kHz, which is above the hearing range of all marine animals and not expected to have any impacts. Some electromechanical systems, however, operate at lower frequencies and are audible to marine mammals. These systems produce sounds within the 0.4–170 kHz frequency range and sound levels from 177–247 dB re 1 µPa (Crocker and Fratantonio 2016). For example, multibeam echosounders produced sounds of ~30 to 70 kHz at source levels up to ~230 dB re 1 µPa. And, though not used for imaging, underwater positioning equipment (e.g., ultra-short baseline, USBL, systems) used during HRG surveys emit sound in the 20–50 kHz band with source levels up to 188–191 dB re 1 µPa.

There is an overall paucity of information on the effects of HRG sounds on marine fauna. Impulsive sources used for imaging below the seabed such as sub-bottom profilers and airguns are likely audible to all marine fauna and their use may result in injury and behavioral disruption. If such sources are used, a quantitative impact analysis following established guidelines should be conducted. Electromechanical HRG sources operating within the established hearing range of marine fauna are classified as non-impulsive by NMFS, eliminating the potential for injury, but do have the potential to cause behavioral disturbance. These sources tend to be highly directive with narrow beams and small ensonified areas, so animals are likely to receive only short-duration exposures. Impacts to marine fauna from HRG sounds are expected to be low.

F.3.1. Potential Impacts to Marine Fauna

F.3.1.1. Marine Mammals

Many HRG sources operate at frequencies (>200 kHz) above the hearing range of marine mammals so are not expected to result in impacts. Research suggests that sound levels produced by HRG sources operating within the hearing range of marine mammals are unlikely to cause injury but could result in temporary behavioral responses.

While Varghese et al. (2020) found no consistent changes in Cuvier's beaked whale foraging behavior during multibeam echosounder surveys, analogous studies assessing mid-frequency active sonar on beaked whale foraging found that individuals would stop echolocating and leave the area. Other studies have focused on the responses of marine mammals exposed to sonar. For example, minke whales (*Balaenoptera acutorostrata*) demonstrated strong avoidance to mid-frequency sonar at 146 dB re 1 µPa (Sivle et al. 2015, Kvadsheim et al. 2017) and Wensveen et al. (2019) showed northern bottlenose whales (*Hyperoodon ampullatus*) had a greater response to (military) sonar signals. Surface-feeding blue whales showed no changes in behavior to mid-frequency sonar, but blue whales (*Balaenoptera musculus*) feeding at deeper depths and non-feeding whales displayed temporary reactions to the source; including cessation of feeding, reduced initiation of deep foraging dives, generalized avoidance responses, and changes to dive behavior (DeRuiter et al. 2013, Goldbogen et al. 2013, Sivle et al. 2015). Several behavioral reactions were seen in beaked whale species in response to mid-frequency sonar sounds (12–400 kHz and 230 dB re 1 µPa) including cessation of clicking, termination of foraging dives, changes in direction to avoid the sound source, slower ascent rates to the surface, longer deep and shallow dive durations, and other atypical dive behavior (Tyack et al. 2011, DeRuiter et al. 2013, Stimpert et al. 2014, Miller et al. 2015, Cholewiak et al. 2017). Exposure to mid-frequency sonar at various sound levels (125–185 dB re 1 µPa) caused behavioral responses in California sea lions (*Zalophus californianus*), including a refusal to participate in trials, hauling out, an increase in respiration rate, and an increase in the time spent submerged (Houser et al. 2013, Houser et al. 2016). Hooded seals (*Cystophora cristata*) showed initial avoidance behavior to 1–7 kHz sonar signals at levels between 160 and 170 dB re 1 µPa, but these animals did adapt to the sound and stopped avoiding the source (Kvadsheim et al. 2010).

Non-impulsive, sonar-type HRG sources operating within the hearing range of marine mammals are unlikely to produce injury but could cause behavioral responses. These sources typically have narrow beams that would expose marine mammals for short time periods and only negligible effects on marine mammal species could be expected. A previous analysis by BOEM (2014) on the potential effects of sound associated with HRG surveys on marine mammals in the Mid- and South-Atlantic wind planning areas concluded that impacts are expected to be minimal with the implementation of mitigation measures for sources operating at or below 200 kHz. With mitigation and monitoring practices, impacts to marine mammals from HRG sound sources are expected to be low.

F.3.1.2. Sea Turtles

HRG surveys that use non-impulsive sources are not expected to impact sea turtles because they operate at frequencies above the sea turtle hearing range (<1 kHz). Low-frequency impulsive HRG equipment may produce sounds within the hearing ranges of sea turtles and impacts should be evaluated using a quantitative approach.

F.3.1.3. Fish

Non-impulsive sounds produced by HRG survey operations are outside of fish hearing range and are not expected to produce injury or behavioral responses in fish (BOEM 2014, Popper et al. 2014, Popper and Hawkins 2019). Potential impacts of low frequency impulsive HRG sources on fish may include behavioral responses, masking of biologically important sounds, temporary hearing loss, and physiological effects (BOEM 2014, Popper et al. 2014, Popper and Hawkins 2019). Given the mobile and therefore intermittent nature of HRG surveys, the short-duration and infrequent surveying of small areas of the seafloor relative to the overall area, and the likelihood that fish will move away from the sound source, the impacts of underwater noise from impulsive HRG source surveys are expected to be low.

F.3.1.4. Invertebrates

As with sea turtles and fish, non-impulsive HRG sound sources are above the hearing range of invertebrates and are not expected to cause impacts, but impulsive sources may be within the hearing range of some invertebrates. For most marine invertebrate species sensitivity to underwater sound and susceptibility to noise-induced effects has not been investigated. Anatomical and experimental evidence suggests that particle motion (not sound pressure) is the primary mode for marine invertebrates perceiving acoustic stimuli. Nearly all studies on noise-induced effects on marine invertebrates, however, have measured sound pressure rather than particle motion reducing the relevance of their findings. There are currently no appropriate metrics or clearly defined levels (sound pressure or particle motion) for assessing the effect of underwater sound on marine invertebrates (Hawkins and Popper 2017). Even though criteria and thresholds are not available for invertebrates, the short-term and infrequent nature of impulsive HRG surveys are expected to be of low risk of impact to invertebrates.

F.3.2. Monitoring and Mitigation

Monitoring and mitigation during HRG surveys can decrease the potential impacts to marine mammals from HRG sound exposure by reducing the zone of influence and therefore the likelihood of sound exposures exceeding regulatory thresholds. NOAA and BOEM have advised that HRG sources that operate at and below 200 kilohertz (kHz) have the potential to cause acoustic harassment to marine species, including marine mammals, and therefore require the establishment and monitoring of exclusion zones (BOEM 2014). Standard mitigation employed during HRG surveys includes the use of PSOs, time of year restrictions, protective zones, ramp-up of active sound sources and shut down of sources should marine mammals or sea turtles enter the established exclusion zones.

F.4. Drilling

Project construction activities will likely include drilling for geotechnical surveys and horizontal directional drilling (HDD). Geotechnical studies are conducted using drill rigs or other excavating tools to characterize the subsurface conditions in locations where foundational structures are expected to be installed (Shell Gulf of Mexico Inc. 2015). In some areas, such as the export cable landfall location, an HDD rig may be needed to create a conduit for the cable to be pulled through.

For both activities, a drill head produces vibrations that propagate as sound through the sediment and water column (Hall and Francine 1991, Nguyen 1996, Willis et al. 2010). Geotechnical drilling operations can emit sound both from the drill at the seabed and from the machinery on the barge (Gales 1982). HDD emits sound at the mouth of the borehole and the drill head. Unlike offshore drill rigs used for geotechnical drilling that are acoustically connected to the water column via drillships (floating rigs) or drill rigs (bottomed rigs), HDD rigs are installed on shore and the sound they produce that enters the water is often negligible (Hall and Francine 1991, Nguyen 1996, Willis et al. 2010).

Most measurements of offshore drilling sounds have been made for oil exploration and production drilling. The sound levels associated with those drilling operations have been documented to be within the hearing range of many marine species and above the recommended marine mammal, sea turtle, and fish injury and behavioral thresholds (Greene 1987, NOAA 2005, Popper et al. 2014, Finneran et al. 2017, NMFS 2018). The underwater sounds from those drilling activities are non-impulsive, low frequency (20–1000 Hz), and of varying levels ranging from an SPL of 117 to 184 dB re 1 µPa (Greene 1987, Blackwell et al. 2004a, Dow Piniak et al. 2012). However, the types of drilling likely to be used during Project construction are of a smaller scale and are unlikely to produce the maximum sounds reported for oil drilling. Schlesinger et al. (2016) estimated a broadband source level of 170.7 dB re 1 µPa for offshore rock socket drilling in British Columbia. The modeled maximum distance to an SPL of 120 dB re 1 µPa was 5.8 km for that drilling activity. Only two papers have measured sounds from geotechnical drilling. Erbe and McPherson (2017) measured broadband (30 Hz to 2 kHz) sound source levels of 142 and 145 dB re 1 µPa for small-core drilling from a jack-up rig at two locations off western Australia. The sound levels were up to 35 dB above ambient sound levels at some frequencies, and thus audible to marine fauna, but much less than oil production drilling sounds and below levels used in marine noise regulations. Willis et al. (2010) recorded a peak sound level of 107 dB re 1 $\mu Pa_{0\text{-}pk}$ at 7.5 m from hard-rock drilling.

Underwater sound emitted by Project construction drilling activities is not expected to produce injury to marine fauna but is likely to be audible and could elicit temporary behavioral responses. Impacts associated with this activity are expected to be low.

F.4.1. Potential Impacts to Marine Fauna

F.4.1.1. Marine Mammals

Impacts to marine mammals from underwater sound from drilling depend on the species, distance from the source, and type of drilling activity (Awbrey and Stewart 1983, Richardson et al. 1990a, Richardson et al. 1990b, Miller et al. 2005, Blackwell et al. 2017). Observed responses can include changes in migratory pathways, avoidance, changes in calling behavior, and altered diving and feeding patterns . For prolonged, large, drilling activities, acoustic masking may be a concern for marine mammals if the sounds interfere with their ability to detect or recognize important biological acoustic signals (Richardson et al. 1999, Houser and Cross 2014).

While underwater drilling sounds can have a negative effect on some marine mammals (bowhead and beluga whales), others (ringed seals and harbor porpoises) have been documented to be far more tolerant to drilling activities (Moulton et al. 2003, Todd et al. 2009). Received sound levels of drilling from construction operations were within the hearing range of phocid seals (<100 Hz); however, no aversion to sound was observed for ringed seals (Blackwell et al. 2004b). In the North Sea, high frequency odontocete species, such as harbor porpoises, have been found feeding around offshore drilling rigs and platforms during routine drilling and production operations at relatively low sound pressure levels (120 dB re 1 µPa) (Todd et al. 2009). The lack of behavioral response from harbor porpoises to drilling sounds could cause acoustic masking; however, this impact was not discussed within this study (Todd et al. 2009).

The potential impacts on marine mammals from underwater sound exposure produced by drilling operations may be behavioral disruption, acoustic masking, and physiological responses (i.e. stress) (Richardson et al. 1999, Miller et al. 2005, Blackwell et al. 2017). These responses are expected when underwater sounds associated with drilling activities are above marine mammal behavioral thresholds (NOAA 2005). However, past research suggests not all marine mammals respond negatively to drilling operations and any reactions to this source are short-term (Blackwell et al. 2004b, Todd et al. 2009). In addition, most behavioral reactions have been reported in response to oil production drilling, whereas drilling operations associated with wind farm construction activities would be of a much smaller magnitude. Sounds emitted by offshore drilling activities for wind farm development are non-impulsive and intermittent, which makes this activity unlikely to cause prolonged behavioral responses or acoustic masking. Given the short-duration and non-impulsive nature of this source, behavioral responses to underwater marine drilling sounds during the construction phase are expected to be minor.

F.4.1.2. Sea Turtles

There is insufficient information on the impacts of underwater drilling sounds to sea turtles. However, sea turtle hearing sensitivity is within the frequency range (100–1000 Hz) of sound produced by low-frequency sources such as marine drilling (for a summary, see Popper et al. 2014). Sound levels emitted by construction drilling operations are likely to be audible to sea turtles. However, it is unlikely that the sound from construction drilling operations will reach behavioral thresholds, and even more unlikely that the sound will reach injury thresholds, unless the sea turtle is within close proximity to the drilling activity (McCauley et al. 2000b, Dow Piniak et al. 2012, Finneran et al. 2017). Risks of impact are expected to be low, but further research is required to understand the potential effects of marine drilling noise during wind turbine installation to sea turtles.

F.4.1.3. Fish

It is unclear whether or not the sound emitted by marine drilling activities impacts fish. The available literature suggests that noise effects on fish produced by continuous drilling operations may mask acoustic signals conveying important environmental information (McCauley 1994, Popper et al. 2014). Masking may arise when sounds exceed the hearing thresholds of fish and it is probable that, within close proximity to drilling operations, sounds would reach above the recommend thresholds. McCauley (1998) determined that any noise effects to fish from marine drilling activity would likely be temporary behavioral changes within a few hundred meters of the source. For instance, measured source levels during drilling operations reached 120 dB at 3–5 km, which may have caused fish avoidance (McCauley 1998). Recordings of planktivorous fish choruses were still active during drilling operations off the coast of the Timor Sea; however, it is likely that partial masking of their calls would have occurred (McCauley 1998). The sounds emitted by marine drilling operations for wind farm construction are expected to be short-term and intermittent. It is therefore unlikely that the acoustic characteristics of this source will cause prolonged acoustic masking to fish and the risk of impact from this activity is expected to be low.

F.4.1.4. Invertebrates

There are no data on the effect of sound from drilling on marine invertebrates. However, evidence from research on the levels of particle motion associated with behavioral responses in blue mussels indicates that the threshold of sensitivity in this species falls within vibration levels measured near blasting, pile driving, and impact drilling (Roberts et al. 2015). Only a small number of studies have indicated reception of vibration in bivalves and an associated behavioral response, which included closing syphons and, in more active mollusks, moving away from the substrate (Mosher 1972, Ellers 1995, Kastelein 2008). Anticipated drilling for the Project is typically short duration and intermittent, so it is unlikely that drilling has more than short-term consequences. Risk of impact to invertebrates from sounds emitted by marine drilling are expected to be low.

F.4.2. Monitoring and Mitigation

Recorded drilling operation source levels were highly variable, ranging from 123 dB to 184 dB SPL for oil production drilling (Greene 1987, Blackwell et al. 2004a, Dow Piniak et al. 2012). While received sound levels could exceed behavioral response thresholds for some marine fauna, the limited area of ensonification and intermittent nature of drilling operations mean the noise impacts from this activity are expected to be very low to low. Currently, no monitoring or mitigation practices are used for sound produced by underwater drilling.

F.5. Dredging

Dredging is most often used to create or maintain depth in channels or harbors by removing materials from the seafloor, but other uses for dredging include contaminated sediment removal, flood/storm protection, extraction of mineral resources, and fishing benthic species. As it pertains to offshore wind, dredging may be used to remove materials from the seafloor in preparation of offshore foundation and export cable locations.

There are two fundamental types of dredge that could be used by the Project – mechanical and hydraulic. Mechanical dredging refers to crane-operated buckets, grabs (clamshell), or backhoes used to remove seafloor material. Hydraulic (suction) dredging and controlled flow excavation dredging involve the use of a suction to either remove sediment from the seabed or relocate sediment from a particular location on the seafloor. There are a variety of hydraulic and controlled flow excavation dredge types including trailing suction, cutter-suction, auger suction, jet-lift, and air-lift. The sound produced by hydraulic dredging results from the combination of sounds generated by the impact and abrasion of the sediment passing through the draghead, suction pipe, and pump. The frequency of the sounds produced range from ~1 to 2 kHz, with reported sound levels from 172 to 190 dB re 1 µPa for suction dredges (Robinson et al. 2011, Todd et al. 2015, McQueen 2019).

There is limited research on the impacts of underwater noise related to dredging activity on marine fauna. It is unlikely that dredging operations will exceed the marine mammal, sea turtle, and fish injury thresholds unless animals are within the immediate vicinity of the operating equipment (McCauley et al. 2000a, Popper et al. 2014, Todd et al. 2015, Finneran et al. 2017, NMFS 2018). Further information is required to determine the effects of dredging activity to underwater invertebrates (Hawkins et al. 2015). Overall, the impacts of dredging are expected to be expected to be very low to low.

F.5.1. Potential Impacts to Marine Fauna

F.5.1.1. Marine Mammals

Few studies have investigated the direct effects of sound of dredging on marine mammals. The topic is further confounded by the difficulty of separating the effects of dredging from other anthropogenic activity (such as vessel noise). Most marine mammals would not be expected to exceed PTS (injury) thresholds, but as dredging occurs in one area for relatively long periods, they may experience TTS and behavioral responses (Todd et al. 2015, NMFS 2018). A case study by McQueen et al. (2020) on the expected effects of underwater dredging noise concluded that although harbor porpoises may experience TTS within 74 m from the sound source there was no evidence of significant behavioral avoidance. However, the modeling scenario was based on relatively simple sound exposure estimates, there was uncertainty about sound propagation in the environment, and uncertainty in the exposure-response relationship in the behavior of the animals, leading the authors to conclude that the impacts may be underestimated (McQueen et al. 2020).

Although most research cannot isolate the acoustic impacts of dredging from other anthropogenic activity, there is evidence to suggest that it at least contributes to the negative effects observed on some marine mammals, including displacement in bowhead whales(Richardson et al. (1990b), grey whales Bryant et al. (1984), minke whales, Anderwald et al. (2013), and grey seals (*Halichoerus grypus*, Anderwald et al. (2013)). Diederichs et al. (2010) found short-term avoidance in harbor porpoises at ranges of 600 m from a dredger operating in the North Sea. However, the most compelling evidence for potential impacts of dredging is from research that used models to differentiate the observed impacts of dredging from the vessel traffic in a busy Scotland harbor (Pirotta et al. 2013). Despite a documented tolerance of high vessel presence, bottlenose dolphins spent less time in the area during periods of high-intensity dredging (Pirotta et al. 2013).

The few existing studies suggest that acoustic exposure from dredging operations may elicit behavioral responses or cause TTS to marine mammals close to the source. With the short-duration and intermittent sounds produced by dredging activities, risks to marine mammals are expected to be low.

F.5.1.2. Sea Turtles

While the acoustic impacts of dredging to sea turtles are expected to be similar to other secondary sound sources, the response thresholds for sea turtles are not well researched and are poorly understood relative to marine mammals. There are no thresholds suggested for sea turtles exposed to non-impulsive noise but suction dredging may produce sounds up to 190 dB re 1 µPa (Robinson et al. 2011, Todd et al. 2015), which exceeds the impulsive threshold of 175 dB re 1 µPa for behavioral disruption suggested by Finneran et al. (2017) (based on impulsive sounds studied by (McCauley et al. 2000b). Accumulated sound energy will not exceed the recommended sea turtle cumulative sound exposure threshold for TTS or PTS (SEL: 189 and 204 dB re 1 µPa, respectively) (Popper et al. 2014, Finneran et al. 2017).

There is currently no information on the direct effects of dredging noise on sea turtles (Popper et al. 2014). There is evidence, however, of potentially positive impacts of dredging to breeding flatback turtles (*Natator depressus*), which increased their use of a dredging area and made longer and deeper resting dives during dredging operations (Whittock et al. 2017). The most likely driver for the observed behavioral response was speculated to be the absence of predators which were displaced by the noise from dredging operations. In general, sound emitted by dredging operations is intermittent and typically short-term. The impacts of noise from dredging operations are likely to be very low to low.

F.5.1.3. Fish

Sound generated by dredging operations is assumed to be primarily relevant to fish that are sensitive to sound pressure (i.e., have swim bladders) (McQueen et al. 2020). However, underwater sound from activities such as dredging can cause avoidance behavior, which has been observed in Atlantic herring and Atlantic cod (Vabø et al. 2002, Handegard et al. 2003). It is unlikely that fish would be exposed to noise levels from dredging that would result in impairment or injury, but behavioral effects, such as auditory masking, could result from exposure to dredging noise (Popper et al. 2014, McQueen et al. 2020). Given that dredging operations are short-term and localized, the impacts from underwater noise to fish from are expected to be low.

F.5.1.4. Invertebrates

There is no available research on the effect of sound from dredging on invertebrates. Contact of the draghead with the seabed may result in substrate-borne vibration, which is likely to be of greater concern to benthic invertebrates than sound pressure (Roberts et al. 2015, Roberts and Breithaupt 2016, Roberts and Elliott 2017). Only a small number of studies have indicated reception of vibration in bivalves and an associated behavioral response, which included closing syphons and, in more active mollusks, moving away from the substrate (Mosher 1972, Ellers 1995, Kastelein 2008). Nevertheless, to date, there is no convincing evidence for any significant effects induced by non-impulsive noise in benthic invertebrates. It is unlikely that these stimuli have more than short-term consequences so the potential impacts of dredging sounds to invertebrates are expected to be very low.

F.6. Wind Turbine Generator Operations

Sound is generated by operating wind turbine generators (WTGs) due to pressure differentials across the airfoils of moving turbine blades and from mechanical noise of bearings and the generator converting kinetic energy to electricity. Sound generated by the airfoils, like aircraft, is produced in air and enters the water through the air water interface. Mechanical noise associated with the operating WTG is transmitted into the water as vibration through the foundation and subsea cable. There is also a known particle motion component to noise from wind turbines (Sigray and Andersson 2012). Both airfoil sound and mechanical vibration may result in continuous underwater noise.

Underwater sound radiated from operating WTGs is low-frequency and low level (Nedwell and Edwards 2004). At distances of 14 to 20 m from operational WTGs in Europe, underwater sound pressure levels ranged from 109 dB to 127 dB re 1µPa (Tougaard et al. 2009). Pangerc et al. (2016) recorded sound levels at ~50 m from two individual 3.6 megawatt (MW) WTGs monopile foundations over a 21-day operating period. The sound pressure level increased with wind speed up to an average value of 128 dB re 1 µPa at a wind speed of ~10 m/s, and then showed a general decrease in sound levels with increasing wind speed as the turbine blades were feathered. Miller and Potty (2017) measured an SPL of 100 dB re 1 µPa within 50 m of five General Electric Haliade 150–6 MW wind turbines with a peak signal frequency of 72 Hz. At the Block Island Wind Farm off of Rhode Island, sound levels were found to be 112–120 dB re 1 µPa near the WTG when wind speeds were 2–12 m/s and the WTG sound levels declined to ambient within 1 km from the WTG (Elliott et al. 2019). Tougaard et al. (2009) found that sound level from three different WTG types in European waters was only measurable above ambient sound levels at frequencies below 500 Hz, and Thomsen et al. (2016) suggest that at approximately 500 m from operating WTGs, sound levels are expected to approach ambient levels.

WTG foundation design was found to influence sound levels in the water as a function of distance. Sound levels measured at 150 m from a steel monopile WTG foundation were 133 dB re 1µPa with peak frequencies between 50–140 Hz, while measurements at 150 m from a jacket WTG foundation were 122 dB re 1µPa with a peak frequency of 50 Hz and secondary peaks at 150, 400, 500, and 1,200 Hz. However, at 40 m the sound pressure levels were comparable between the steel monopile (135 dB) and jacket foundation types (137 dB) (Thomsen et al. 2016).

Two recent meta-papers (Tougaard et al. 2020, Stöber and Thomsen 2021) assessed WTG operational sounds by extracting sound levels measured at various distances from operating WTGs from currently available reports. Tougaard et al. (2020) used a linear model to fit sound levels as a function of turbine size, wind speed, and distance. Their model suggested that sound from multiple WTGs would be detectable out to a few km in areas with very low ambient noise levels but would be below ambient unless "very close" to individual WTGs in areas with high ambient noise from shipping or wind. Notably, the available data were from lower-power WTGs than are currently being planned for the U.S. east coast, and primarily from geared, rather than direct drive, WTGs. Stöber and Thomsen (2021) attempted to fill this knowledge gap by extracting a strictly defined subset of the data used by Tougaard et al. (2020) to extrapolate sound levels to larger turbine sizes and to direct drive turbines. However, the small size of their data subset greatly increases the already considerable uncertainty of the modeling results. Additionally, their model assumed that SPL increases linearly with WTG capacity, which contrasts with what is known of typical mechanical systems. Both studies found sounds to generally be higher for higher powered WTGs, and thus distances to a given sound threshold are likely to be greater for higher powered WTGs. However, as Stöber and Thomsen (2021) point out, direct drive technology could reduce these distances substantially. Importantly, no measurements exist for these larger turbine sizes and few measurements have been made for direct drive turbines so the uncertainty in these estimates is large.

The frequency and sound level generated from operating WTGs depend on WTG size, wind speed and rotation, foundation type, water depth, seafloor characteristics, and wave conditions (Cheesman 2016, Elliott et al. 2019). Operational noise from WTGs is low frequency (60–300 Hz) and at relatively low sound pressure levels near the foundation (100–151 dB re 1 µPa) and decreases to ambient within 1 km (Tougaard et al. 2009, Lindeboom et al. 2011, Dow Piniak et al. 2012). Underwater sounds emitted by WTGs are audible to marine mammals, sea turtles, fish, and invertebrates but are lower than the regulatory injury and typically lower than the behavioral thresholds for marine fauna, and often are lower than the ambient sound levels that these animals typically experience. It is unlikely that WTG operations will cause injury or behavioral responses to marine fauna, so the risk is of impact is expected to be low.

F.6.1. Potential Impacts to Marine Fauna

F.6.1.1. Marine Mammals

While underwater noise from WTGs has been measured within the hearing frequency range of marine mammals, impacts at the anticipated noise levels are limited to behavioral response and auditory masking (Bergström et al. 2014). Behavioral responses may include changes in foraging, socialization, or movement, including avoidance of the area. For example, there is evidence that harbor porpoises avoided WTGs during construction and initial operation (Teilmann and Carstensen 2012). However, they appeared to slowly increase their use of the WTG area during continued operation, demonstrating potential long-term habituation. This result also suggests that noise impacts are greater during construction than operation (Madsen et al. 2006). Harbor seals also show avoidance behavior when exposed to simulated sound from WTGs, however this response was limited to distances of less than 500m to the source (Hastie et al. 2018). Finally, research into both harbor porpoises and harbor seals demonstrated fewer surfacings when exposed to playbacks of noise from WTGs, but this response was limited to 200m from the source (Koschinski et al. 2003)

Auditory masking could also impact marine mammals, potentially affecting foraging, social interactions, and predator avoidance (Weilgart 2007, Erbe et al. 2016b). The potential for masking is highly dependent on the species in question, and those with low-frequency hearing will be more susceptible due to the overlap with the frequency range of WTG underwater noise.

Research with captive harbor porpoises indicated the potential for auditory masking from simulated WTG underwater noise. As with behavioral responses, the area of impact was predicted to be relatively close to the source (10–20m) (Lucke et al. 2007).Therefore, the potential for auditory masking is likely limited to short ranges from the WTG.

Tougaard et al. (2020) estimated that WTG sounds would drop below the 120-dB re 1 µPa U.S. regulatory threshold for marine mammal behavioral impacts from continuous sounds (NMFS 2005) within approximately 50–100 m of the WTG, using currently available sound measurements taken at various distances from operational WTGs. These WTGs all had a lower capacity than those planned for installation off the US east coast and most were from geared-drive WTGs. Thus, Stöber and Thomsen (2021) extrapolated sound levels to larger WTG sizes, and found the distance to the behavioral threshold could extend out to several kilometers. However, the small size of their dataset and choice of modeling methods make these predicted distances unreliable. Additionally, those authors suggest that this distance could be reduced substantially (almost fivefold) for newer direct drive WTGs. The authors also noted that larger sized wind farms, for which data are nonexistent, might only have limited impacts related to behavioral response in marine mammals.

Overall, noise generated from WTG operation is minor and does not cause injury or lead to permanent avoidance at distances greater than 0.5 nm (1 km) for the species studied (e.g., harbor porpoise, seals, and fish) (Wahlberg and Westerberg 2005, Stenberg et al. 2015), with potential to have minimal effects at much closer distances up to within a few meters of the WTG (Bergström et al. 2013). Underwater noise impact to marine mammals associated with WTG operation is expected to be very low to low.

F.6.1.2. Sea Turtles

Low-frequency sound emitted by WTG is of concern for sea turtles. Their most sensitive hearing range is confined to low frequencies (Ridgway et al. 1969, Bartol et al. 1999), and sea turtles have shown behavioral avoidance to low frequency sound (O'Hara and Wilcox 1990, Dow Piniak et al. 2012). Operational WTG underwater noise may be slightly higher than ambient sound however, WTG sound levels decline to ambient levels within 1 km from the turbine (Kraus et al. 2016, Elliott et al. 2019). Because of these lower sound levels, sea turtles are unlikely to detect sounds generated by WTGs at large distances away from the Project in the presences of ambient sound. Therefore, sea turtles are at very low risk from exposure due to WTG noise. Any behavioral changes caused by exposure to WTG underwater sounds are expected to be short-term and localized to areas near the WTGs.

F.6.1.3. Fish

Underwater sound generated by operating WTGs is in the best hearing frequency range of fish but is of low intensity (Madsen et al. 2006). The measured sound levels are well below existing non-impulsive acoustic thresholds for injury or behavioral response in fish (McCauley et al. 2000a, Popper et al. 2014, Finneran et al. 2017). While the underwater sound levels are related to WTG power and wind speed, with increased wind speeds creating increased underwater sound levels, even at high wind speeds Wahlberg and Westerberg (2005) estimated permanent avoidance by fish would only occur within four meters of a WTG foundation. Stöber and Thomsen (2021) extrapolated measured sound levels to larger WTG sizes and found larger distances to a given sound threshold but noted that impacts might be limited to behavioral responses in fishes that could be offset by benefits from lower fishing effort and the creation of artificial reefs at wind farm sites.

In a study on fish near the Svante wind farm in Sweden, Atlantic cod, and roach (*Rutilus rutilus*) catch rates were significantly higher near turbines when the rotors were stopped, which could indicate fish attraction to turbine structure and avoidance to noise when operational (Westerberg 2000 as cited in Thomsen et al. 2006). In another study, no avoidance behavior was observed as fish densities increased around turbine foundations of the Lillgrund offshore wind farm in Sweden (Bergström et al. 2014). It is important to note that ambient sound levels can influence how fish detect other sounds and a change in background noise could alter how fish perceive and react to biological stimuli (Popper and Fay 1993). Current understanding is that underwater noise generated by WTG operation is of minor significance for fish (Wahlberg and Westerberg 2005, Stenberg et al. 2015). Underwater noise risks to fish associated with WTG operation is expected to be low.

F.6.1.4. Invertebrates

There is limited data on the effects of underwater sound from operating WTGs on invertebrates. Pine et al. (2012) found potential impacts on the median time to metamorphosis of estuarine crabs (*Austrohelice crassa* and *Hemigrapsus crenulatus*), although this experiment only measured the sound pressure level, not particle motion. Invertebrates may be susceptible to detecting particle motion produced by operational WTGs at the seabed, which could cause a behavioral response (Roberts et al. 2015, Roberts and Breithaupt 2016, Roberts and Elliott 2017). However, there is a paucity of data regarding responses of invertebrates to acoustic exposure, and no studies of noise-induced hearing effects. Overall, risks are expected to be very low.

F.6.2. Monitoring and Mitigation

Noise generated by operating WTGs is typically below regulatory thresholds for injury and behavioral disruption, and does not lead to permanent avoidance at distances >1 km for the species studied (e.g., harbor porpoise, seals, and fish) (Wahlberg and Westerberg 2005, Stenberg et al. 2015). Although there are potential behavioral impacts within a few meters of an operational WTG (Bergström et al. 2013), the risks are very low to low and no mitigation or monitoring is used for underwater sound produced by WTG operations.

F.7. Impact Risk Definitions

Risk rankings of secondary sound sources are very low, low, moderate, or high based on the probability of marine fauna exposure and the vulnerability of the marine species to a particular development stressor (Table F-1). Marine species occurrence and their relationships to the established criteria were evaluated using: existing literature on marine mammal, sea turtle, fish distribution and presence/use of Lease Area OCS-A 0487, information on the potential impacts of offshore wind farm construction and operations in both the US and globally, and studies that provide a general understanding of hearing, response to anthropogenic sound, and other factors that influence the potential underwater noise impacts of offshore wind construction, operations, and decommissioning activities on marine fauna.

Table F-1. 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.

Appendix G. Acoustic Range Results

The following subsections contain tables of ranges to injury and behavior thresholds described in Sections 2.5 and 2.6, as well as maps and tables of ranges to various isopleths, for reference.

G.1. Impact Pile Driving Single-Strike PK Ranges

G.1.1. Location ID-97

Table G-1. Distance R_{max} and $R_{95\%}$ (km) to the single-strike unweighted peak pressure level (PK) for a 7/12 m monopile at location ID-97 using an IHC S-4000 at each hammer energy.

Level (L_{pk})	Summer												Winter											
	Hammer energy (kJ)												Hammer energy (kJ)											
	1000		1500		2000		2500		3200		4000		1000		1500		2000		2500		3200		4000	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
230	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
219	<0.01	<0.01	0.05	0.05	0.08	0.08	0.09	0.09	0.10	0.10	0.11	0.11	<0.01	<0.01	0.03	0.03	0.08	0.08	0.09	0.09	0.10	0.10	0.11	0.11
218	0.01	0.01	0.07	0.06	0.09	0.09	0.10	0.10	0.11	0.11	0.12	0.12	0.01	0.01	0.06	0.06	0.09	0.09	0.10	0.10	0.11	0.11	0.12	0.12
216	0.06	0.06	0.09	0.09	0.11	0.11	0.12	0.12	0.14	0.13	0.14	0.14	0.05	0.05	0.09	0.09	0.11	0.11	0.12	0.12	0.14	0.13	0.14	0.14
213	0.09	0.09	0.12	0.11	0.14	0.14	0.16	0.15	0.16	0.16	0.23	0.22	0.09	0.09	0.12	0.12	0.14	0.14	0.16	0.15	0.17	0.17	0.18	0.17
210	0.12	0.12	0.14	0.14	0.23	0.22	0.27	0.26	0.29	0.28	0.31	0.30	0.12	0.12	0.15	0.14	0.22	0.21	0.26	0.25	0.29	0.28	0.31	0.30
207	0.15	0.14	0.25	0.24	0.30	0.29	0.37	0.36	0.41	0.40	0.46	0.44	0.15	0.15	0.24	0.24	0.30	0.29	0.40	0.38	0.44	0.43	0.47	0.46
202	0.32	0.31	0.42	0.41	0.65	0.61	0.74	0.70	0.80	0.77	0.88	0.82	0.32	0.31	0.46	0.44	0.65	0.61	0.76	0.73	0.83	0.79	0.88	0.84
200	0.40	0.39	0.56	0.53	0.78	0.75	0.90	0.85	0.97	0.93	1.04	0.99	0.42	0.40	0.57	0.53	0.82	0.77	0.90	0.85	0.94	0.90	0.99	0.94
190	1.20	1.14	1.75	1.66	2.18	2.03	2.14	2.00	2.38	2.25	2.60	2.45	1.24	1.16	1.80	1.70	2.22	2.07	2.26	2.11	2.54	2.38	2.74	2.58
180	2.86	2.66	3.89	3.58	4.61	4.25	4.76	4.33	5.33	4.90	5.75	5.24	2.92	2.75	4.08	3.77	4.99	4.53	5.16	4.71	5.69	5.20	6.18	5.66

Dashes indicate that the acoustic threshold was not reached.
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.

G.1.2. Location ID-259

Table G-2. Distance R_{max} and $R_{95\%}$ (km) to the single-strike unweighted peak pressure level (PK) for a 7/12 m monopile at location ID-259 using an IHC S-4000 at each hammer energy.

Level (L_{pk})	Summer												Winter											
	Hammer energy (kJ)												Hammer energy (kJ)											
	1000		1500		2000		2500		3200		4000		1000		1500		2000		2500		3200		4000	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
230	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
219	-	-	0.05	0.05	0.09	0.09	0.10	0.09	0.11	0.11	0.13	0.13	-	-	0.04	0.04	0.08	0.08	0.10	0.09	0.11	0.11	0.13	0.13
218	0.02	0.02	0.09	0.09	0.10	0.10	0.11	0.11	0.13	0.13	0.14	0.14	0.02	0.02	0.08	0.08	0.10	0.09	0.11	0.11	0.13	0.13	0.14	0.14
216	0.08	0.08	0.11	0.11	0.13	0.13	0.14	0.13	0.15	0.15	0.16	0.16	0.06	0.06	0.11	0.11	0.13	0.13	0.14	0.14	0.16	0.15	0.17	0.17
213	0.12	0.12	0.15	0.14	0.17	0.17	0.17	0.17	0.18	0.18	0.29	0.29	0.12	0.12	0.15	0.15	0.17	0.17	0.18	0.17	0.19	0.19	0.20	0.20
210	0.15	0.15	0.18	0.17	0.28	0.27	0.32	0.31	0.35	0.34	0.37	0.36	0.15	0.15	0.18	0.18	0.21	0.20	0.31	0.30	0.34	0.34	0.37	0.36
207	0.18	0.17	0.33	0.32	0.37	0.36	0.39	0.38	0.49	0.47	0.54	0.52	0.18	0.18	0.32	0.31	0.37	0.36	0.39	0.38	0.54	0.51	0.58	0.57
202	0.46	0.44	0.60	0.57	0.68	0.65	0.82	0.74	0.96	0.90	1.05	1.00	0.48	0.47	0.63	0.61	0.68	0.66	0.84	0.78	0.94	0.90	1.03	0.98
200	0.56	0.54	0.78	0.72	0.97	0.93	1.02	0.97	1.16	1.11	1.27	1.20	0.58	0.57	0.78	0.73	0.96	0.91	1.01	0.96	1.13	1.08	1.25	1.18
190	1.48	1.42	1.98	1.88	2.52	2.42	2.49	2.36	2.77	2.61	2.97	2.81	1.60	1.50	2.02	1.91	2.56	2.44	2.55	2.42	2.81	2.64	3.09	2.90
180	3.60	3.35	4.74	4.44	5.58	5.17	5.24	4.90	5.62	5.25	6.08	5.67	3.74	3.53	5.05	4.73	5.70	5.31	5.58	5.17	5.97	5.64	6.64	6.24

Dashes indicate that the acoustic threshold was not reached.
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.

G.1.3. Location ID-200

Table G-3. Distance R_{max} (km) to the single-strike unweighted peak pressure level (PK) for a jacket foundation pile at location ID-200 using an IHC S-4000 at each hammer energy.

Level (L_{pk})	Summer												Winter											
	Hammer energy (kJ)												Hammer energy (kJ)											
	300		750		1000		2000		3000		4000		300		750		1000		2000		3000		4000	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
230	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
219	-	-	0.02	0.02	0.06	0.06	0.10	0.09	0.08	0.08	0.06	0.06	-	-	0.02	0.02	0.05	0.05	0.10	0.09	0.09	0.09	0.06	0.06
218	-	-	0.04	0.04	0.09	0.09	0.11	0.11	0.09	0.09	0.07	0.07	-	-	0.04	0.04	0.09	0.09	0.11	0.11	0.09	0.09	0.08	0.07
216	-	-	0.09	0.09	0.10	0.10	0.13	0.13	0.11	0.11	0.09	0.09	-	-	0.09	0.09	0.11	0.11	0.13	0.13	0.11	0.11	0.09	0.09
213	0.07	0.07	0.12	0.12	0.13	0.13	0.16	0.15	0.13	0.13	0.13	0.12	0.06	0.06	0.13	0.13	0.14	0.14	0.16	0.16	0.14	0.13	0.13	0.13
210	0.11	0.11	0.15	0.15	0.16	0.16	0.31	0.30	0.27	0.27	0.29	0.28	0.11	0.11	0.16	0.15	0.17	0.17	0.30	0.29	0.32	0.26	0.29	0.28
207	0.13	0.13	0.27	0.27	0.30	0.29	0.47	0.45	0.44	0.43	0.39	0.37	0.14	0.14	0.26	0.26	0.29	0.28	0.46	0.45	0.44	0.42	0.39	0.37
202	0.29	0.28	0.47	0.45	0.58	0.56	0.81	0.78	0.68	0.65	0.60	0.57	0.28	0.27	0.48	0.47	0.65	0.57	0.85	0.82	0.74	0.70	0.60	0.56
200	0.42	0.40	0.72	0.68	0.80	0.76	1.00	0.94	0.89	0.84	0.74	0.70	0.43	0.42	0.72	0.68	0.81	0.78	1.02	0.96	0.97	0.91	0.78	0.75
190	1.10	1.02	1.68	1.59	2.04	1.92	2.50	2.35	2.45	2.31	2.35	2.24	1.10	1.05	1.70	1.62	1.98	1.89	2.54	2.40	2.45	2.31	2.12	1.99
180	2.45	2.33	3.43	3.21	4.26	3.98	4.64	4.37	5.24	4.97	6.72	6.32	2.62	2.48	3.85	3.58	4.46	4.18	5.16	4.85	5.50	5.15	5.95	5.68

Dashes indicate that the acoustic threshold was not reached.
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.

G.2. Impact Pile Driving Single-Strike SEL Ranges

G.2.1. Location ID-97: Hammer Energy Level

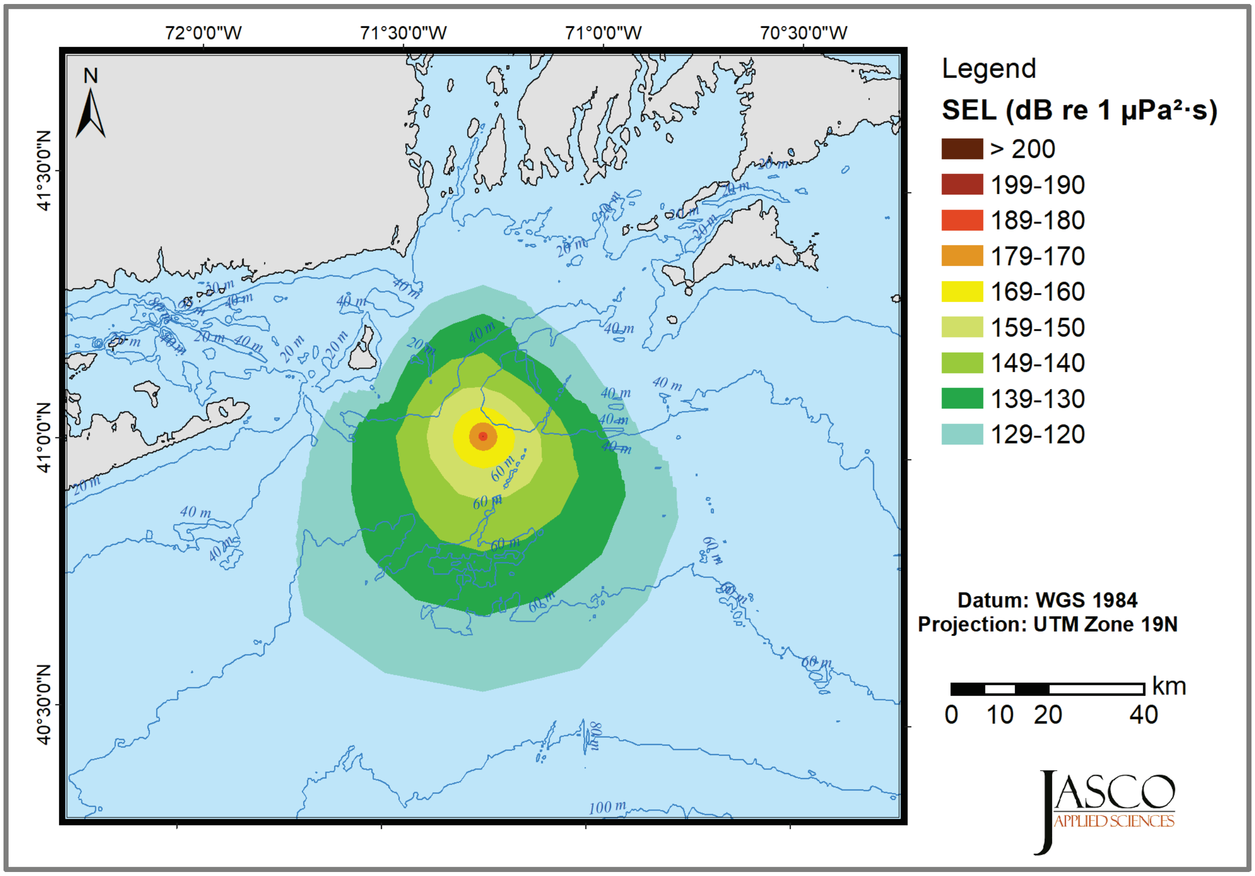


Figure G-1. Location L097, summer: Unweighted single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 3200 kJ.

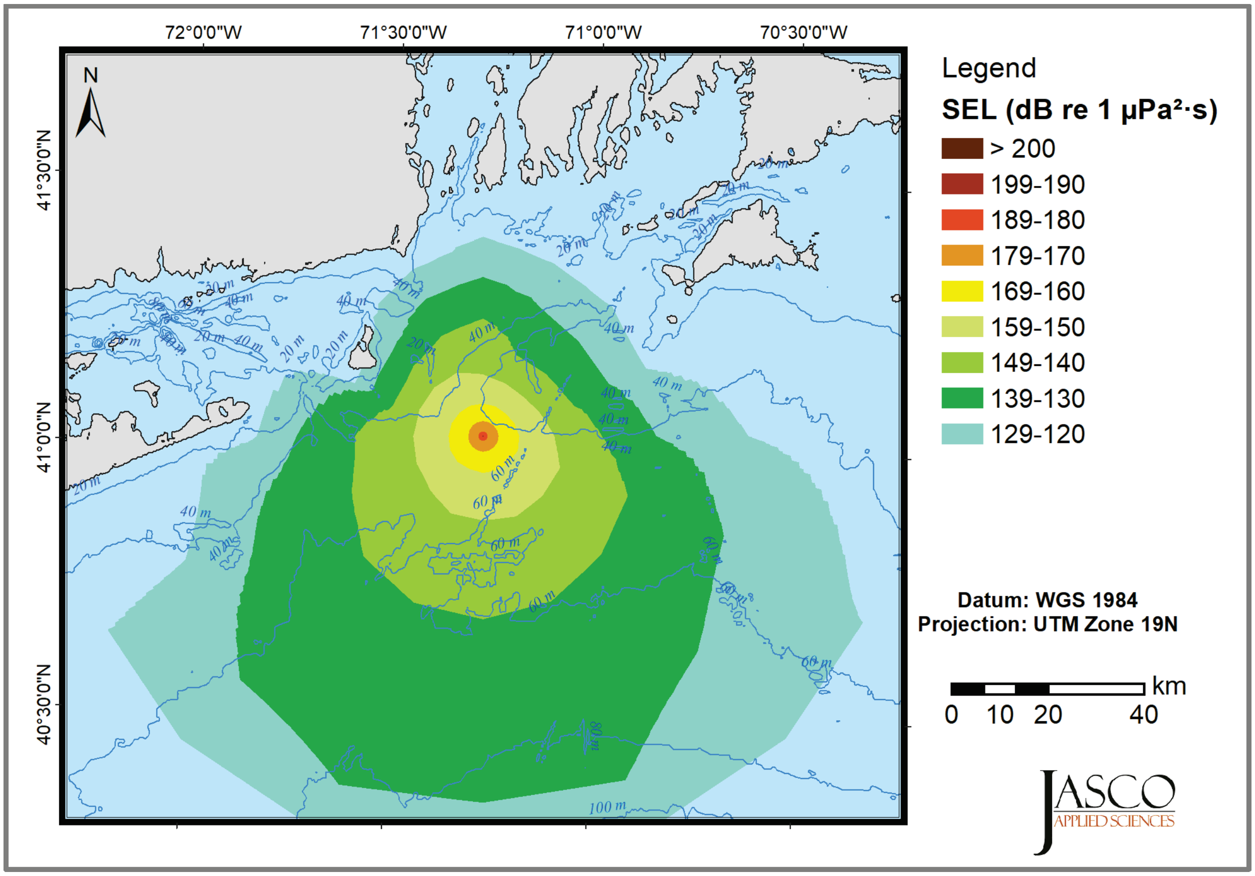


Figure G-2. Location ID-97, winter: Unweighted single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 3200 kJ.

Table G-4. Location ID-97, 1000 kJ: Distance (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 1000 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190	0.09	0.08	0.00	0.00	-	-	-	-	-	-	0.07	0.07	0.09	0.09	0.00	0.00	-	-	-	-	-	-	0.07	0.06
180	0.40	0.38	0.12	0.11	-	-	-	-	-	-	0.27	0.26	0.40	0.39	0.12	0.11	-	-	-	-	-	-	0.27	0.26
170	1.45	1.38	0.49	0.46	-	-	-	-	0.01	0.01	1.15	1.10	1.52	1.46	0.50	0.49	-	-	-	-	0.01	0.01	1.21	1.15
160	3.93	3.63	1.85	1.76	-	-	-	-	0.14	0.13	3.27	3.01	4.21	3.90	1.95	1.86	-	-	-	-	0.14	0.14	3.55	3.28
150	7.98	7.23	4.70	4.32	-	-	-	-	0.71	0.68	7.01	6.36	9.06	8.22	5.09	4.67	-	-	-	-	0.75	0.72	7.88	7.13
140	14.99	13.51	9.14	8.25	-	-	-	-	2.39	2.24	13.66	12.18	18.70	16.93	10.46	9.35	-	-	-	-	2.54	2.39	16.91	15.11
130	25.58	22.50	16.83	15.10	0.09	0.09	-	-	5.51	5.03	23.54	20.64	36.14	32.38	22.23	19.86	0.09	0.09	-	-	6.01	5.48	33.60	30.20
120	37.96	33.65	28.70	25.28	0.29	0.28	0.07	0.07	10.38	9.26	36.38	32.14	63.98	58.30	42.74	39.23	0.35	0.34	0.06	0.06	12.52	11.27	60.89	55.54

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-5. Location ID-97, 1500 kJ: Distance (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 1500 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190	0.12	0.11	0.01	0.01	-	-	-	-	-	-	0.09	0.09	0.12	0.11	0.01	0.01	-	-	-	-	-	-	0.10	0.09
180	0.47	0.46	0.14	0.14	-	-	-	-	-	-	0.38	0.37	0.49	0.47	0.14	0.14	-	-	-	-	-	-	0.40	0.38
170	1.90	1.81	0.76	0.72	-	-	-	-	0.03	0.03	1.58	1.50	1.99	1.88	0.80	0.76	-	-	-	-	0.03	0.03	1.65	1.57
160	4.82	4.42	2.49	2.35	-	-	-	-	0.24	0.23	4.16	3.83	5.21	4.79	2.62	2.47	-	-	-	-	0.23	0.22	4.44	4.09
150	9.40	8.56	5.64	5.13	-	-	-	-	1.01	0.96	8.27	7.51	11.67	10.41	6.16	5.62	-	-	-	-	1.03	0.98	9.65	8.75
140	17.19	15.56	10.82	9.65	-	-	-	-	2.97	2.80	15.81	14.20	24.20	21.71	14.12	12.50	-	-	-	-	3.21	2.97	21.83	19.37
130	28.64	25.56	19.35	17.56	0.11	0.11	-	-	6.51	5.91	26.92	24.19	45.69	41.76	30.53	27.41	0.12	0.11	-	-	7.25	6.55	43.64	39.86
120	41.82	37.97	32.80	29.52	0.47	0.46	0.09	0.09	12.71	11.41	40.58	36.84	>89.00	82.76	59.57	54.06	0.49	0.47	0.10	0.09	16.83	14.79	>89.00	82.34

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-6. Location ID-97, 2000 kJ: Distance (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 2000 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.00	0.00	-	-	-	-	-	-	-	-	-	-	0.00	0.00	-	-	-	-	-	-	-	-	-	-
190	0.14	0.13	0.02	0.02	-	-	-	-	-	-	0.12	0.11	0.14	0.13	0.02	0.02	-	-	-	-	-	-	0.12	0.12
180	0.70	0.68	0.24	0.24	-	-	-	-	-	-	0.50	0.48	0.73	0.70	0.23	0.22	-	-	-	-	-	-	0.51	0.50
170	2.43	2.29	1.08	1.03	-	-	-	-	0.09	0.08	1.95	1.87	2.56	2.42	1.13	1.08	-	-	-	-	0.08	0.08	2.09	1.98
160	5.69	5.20	3.07	2.87	-	-	-	-	0.31	0.30	4.99	4.58	6.24	5.70	3.35	3.11	-	-	-	-	0.31	0.30	5.47	4.99
150	10.94	9.81	6.77	6.15	-	-	-	-	1.41	1.33	9.66	8.74	13.63	12.24	7.62	6.88	-	-	-	-	1.50	1.44	11.80	10.59
140	19.10	17.32	13.18	11.74	0.01	0.01	-	-	3.91	3.61	17.86	16.17	28.28	25.11	16.54	14.78	0.01	0.01	-	-	4.22	3.90	25.98	23.24
130	32.06	28.37	22.92	20.30	0.14	0.13	0.00	0.00	7.89	7.13	30.62	27.10	51.70	47.49	35.42	31.73	0.14	0.14	0.00	0.00	8.96	8.13	49.40	45.27
120	46.04	41.52	36.72	32.65	0.70	0.67	0.12	0.12	14.87	13.37	44.76	40.30	>89.00	83.73	69.24	63.73	0.74	0.71	0.12	0.12	19.19	17.32	>89.00	83.58

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-7. Location ID-97, 2500 kJ: Distance (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 2500 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.01	0.01	-	-	-	-	-	-	-	-	0.00	0.00	0.01	0.01	-	-	-	-	-	-	-	-	0.00	0.00
190	0.14	0.14	0.04	0.04	-	-	-	-	-	-	0.13	0.13	0.15	0.15	0.03	0.03	-	-	-	-	-	-	0.13	0.13
180	0.78	0.75	0.28	0.26	-	-	-	-	-	-	0.63	0.61	0.84	0.81	0.27	0.26	-	-	-	-	-	-	0.65	0.62
170	2.68	2.54	1.19	1.13	-	-	-	-	0.10	0.09	2.23	2.12	2.82	2.66	1.26	1.21	-	-	-	-	0.10	0.09	2.38	2.26
160	6.17	5.62	3.53	3.25	-	-	-	-	0.39	0.38	5.45	4.98	6.86	6.24	3.80	3.51	-	-	-	-	0.41	0.40	6.03	5.49
150	11.93	10.78	7.43	6.68	-	-	-	-	1.64	1.55	10.52	9.43	15.65	13.97	8.50	7.73	-	-	-	-	1.72	1.63	13.93	12.48
140	20.20	18.31	14.21	12.78	0.01	0.01	-	-	4.36	3.99	19.08	17.31	33.06	29.62	19.55	17.60	0.01	0.01	-	-	4.72	4.33	31.18	27.93
130	33.68	30.21	24.86	22.35	0.16	0.15	0.01	0.01	8.62	7.81	32.28	29.02	64.19	59.12	43.15	39.30	0.16	0.16	0.01	0.01	10.13	9.14	62.55	57.06
120	48.22	44.07	38.60	35.02	0.86	0.82	0.15	0.14	16.28	14.56	47.00	42.94	>89.00	84.31	>89.00	83.35	0.92	0.88	0.16	0.15	24.34	21.94	>89.00	84.29

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-8. Location ID-97, 3200 kJ: Distance (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 3200 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.03	0.03	-	-	-	-	-	-	-	-	0.01	0.01	0.03	0.03	-	-	-	-	-	-	-	-	0.01	0.01
190	0.17	0.16	0.08	0.08	-	-	-	-	-	-	0.14	0.14	0.17	0.17	0.08	0.08	-	-	-	-	-	-	0.15	0.15
180	0.95	0.91	0.31	0.30	-	-	-	-	-	-	0.79	0.76	0.97	0.93	0.32	0.31	-	-	-	-	-	-	0.82	0.79
170	3.04	2.85	1.44	1.37	-	-	-	-	0.11	0.11	2.62	2.47	3.26	3.04	1.54	1.46	-	-	-	-	0.12	0.11	2.74	2.60
160	6.86	6.26	4.03	3.72	-	-	-	-	0.51	0.49	6.07	5.55	7.84	7.13	4.32	3.98	-	-	-	-	0.51	0.49	6.75	6.15
150	13.67	12.31	8.22	7.48	-	-	-	-	1.91	1.83	12.33	11.08	18.06	16.19	9.63	8.77	-	-	-	-	2.02	1.91	16.63	14.74
140	23.96	21.30	16.15	14.53	0.04	0.04	-	-	4.89	4.48	22.08	19.76	38.04	34.28	23.58	21.27	0.04	0.04	0.00	0.00	5.36	4.90	36.22	32.61
130	37.36	33.51	28.42	25.34	0.28	0.27	0.06	0.06	9.55	8.67	36.16	32.41	78.39	70.90	50.05	45.70	0.29	0.28	0.07	0.07	12.39	11.05	74.90	67.87
120	53.26	48.76	42.96	38.90	1.21	1.14	0.29	0.28	18.26	16.55	52.05	47.60	>89.00	84.41	>89.00	83.94	1.28	1.22	0.35	0.34	29.54	26.41	>89.00	84.40

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-9. Location ID-97, 4000 kJ: Distance (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 4000 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.04	0.04	-	-	-	-	-	-	-	-	0.01	0.01	0.04	0.04	-	-	-	-	-	-	-	-	0.01	0.01
190	0.23	0.22	0.09	0.09	-	-	-	-	-	-	0.16	0.15	0.21	0.20	0.09	0.09	-	-	-	-	-	-	0.17	0.16
180	1.17	1.11	0.38	0.35	-	-	-	-	0.00	0.00	0.87	0.84	1.22	1.17	0.41	0.39	-	-	-	-	0.00	0.00	0.90	0.87
170	3.41	3.16	1.66	1.57	-	-	-	-	0.13	0.12	2.83	2.68	3.67	3.40	1.73	1.64	-	-	-	-	0.13	0.13	2.97	2.82
160	7.42	6.74	4.37	4.03	-	-	-	-	0.59	0.57	6.53	5.97	8.49	7.77	4.74	4.36	-	-	-	-	0.63	0.60	7.36	6.68
150	14.62	13.22	8.86	8.07	0.01	0.01	-	-	2.19	2.06	13.45	12.05	19.19	17.34	10.74	9.55	0.05	0.04	0.02	0.02	2.39	2.28	17.84	15.91
140	25.70	22.86	17.24	15.61	0.10	0.09	0.05	0.05	5.31	4.87	24.24	21.51	40.46	36.55	26.04	23.42	0.32	0.31	0.10	0.09	6.25	5.72	38.46	34.68
130	39.26	35.22	30.42	26.98	0.59	0.56	0.20	0.20	10.52	9.45	38.16	34.18	87.01	78.40	55.00	49.99	1.10	1.03	0.47	0.46	16.31	14.47	80.42	72.95
120	55.94	51.33	45.32	41.01	2.24	2.09	0.96	0.93	19.83	17.97	54.72	50.10	>89.00	84.47	>89.00	84.15	4.59	4.07	2.29	2.03	45.29	37.83	>89.00	84.42

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

G.2.2. Location ID-259: Hammer Energy Level

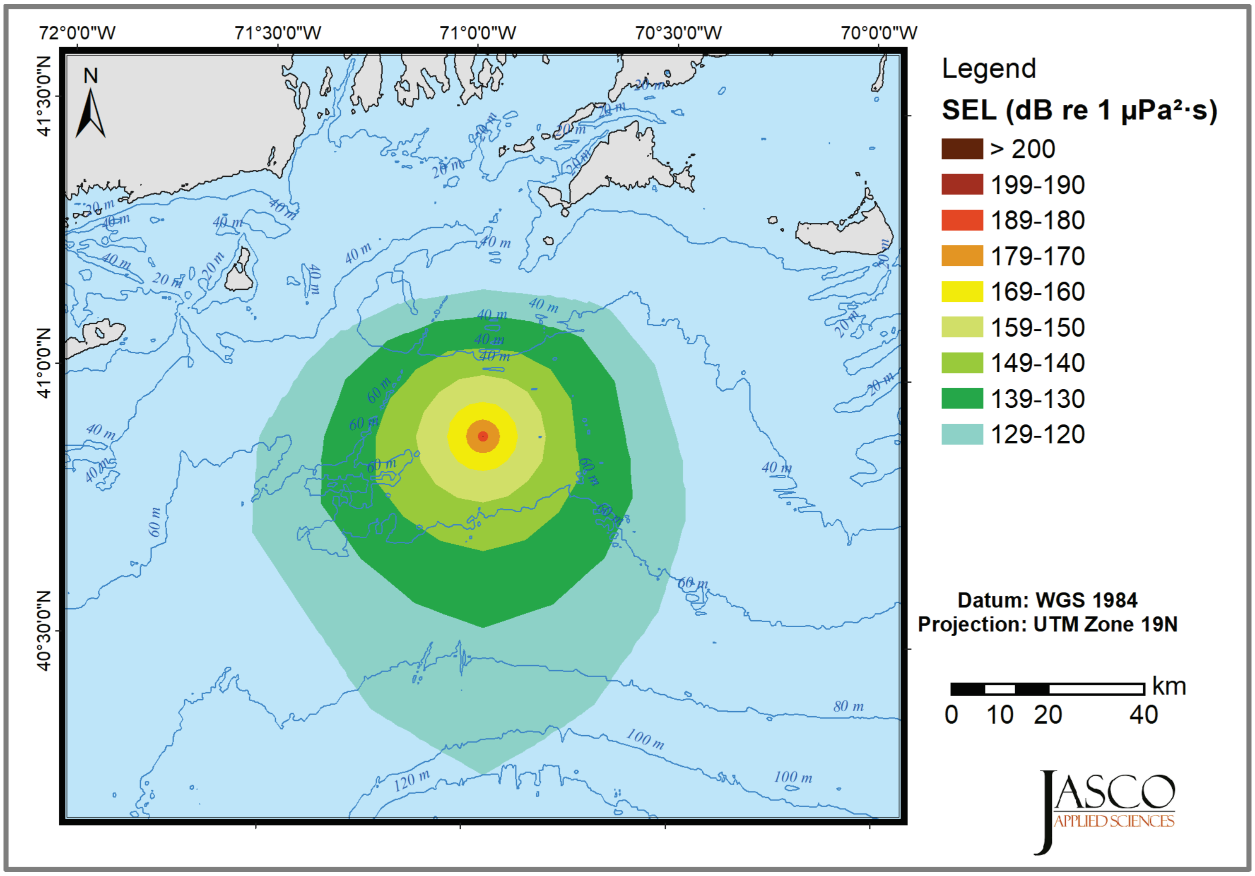


Figure G-3. Location ID-259, summer: Unweighted single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 3200 kJ.

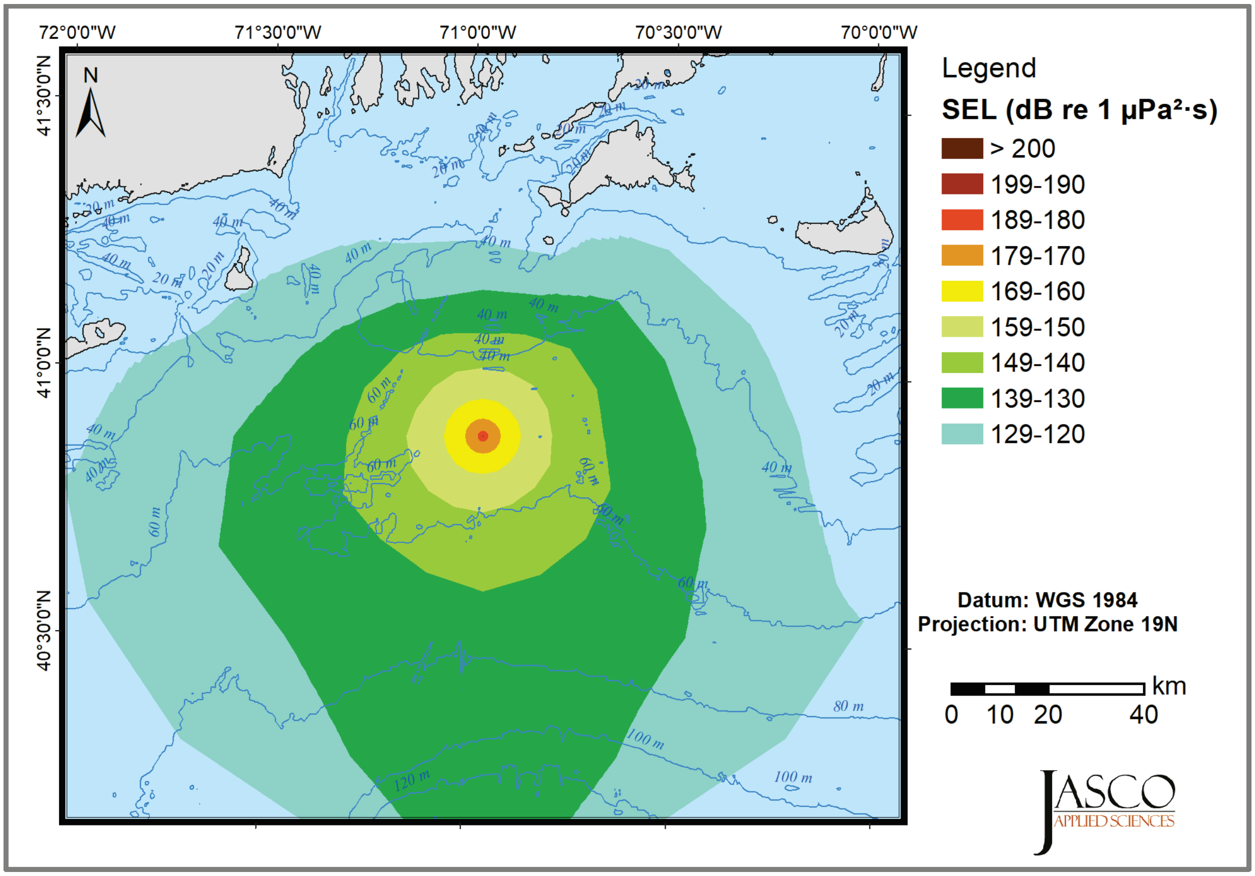


Figure G-4. Location ID-259, winter: Unweighted single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 3200 kJ.

Table G-10. Location ID-259, 1000 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 1000 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190	0.10	0.10	-	-	-	-	-	-	-	-	0.09	0.09	0.10	0.10	-	-	-	-	-	-	-	-	0.06	0.06
180	0.45	0.44	0.14	0.14	-	-	-	-	-	-	0.33	0.32	0.46	0.44	0.14	0.14	-	-	-	-	-	-	0.33	0.32
170	1.78	1.70	0.61	0.59	-	-	-	-	-	-	1.41	1.34	1.87	1.78	0.63	0.60	-	-	-	-	-	-	1.46	1.40
160	4.71	4.47	2.38	2.25	-	-	-	-	0.16	0.16	4.06	3.87	5.00	4.73	2.49	2.38	-	-	-	-	0.17	0.17	4.30	4.09
150	9.24	8.51	5.60	5.26	-	-	-	-	0.85	0.82	8.20	7.55	10.26	9.34	5.98	5.61	-	-	-	-	0.88	0.83	8.98	8.23
140	15.69	14.42	10.26	9.29	-	-	-	-	2.92	2.78	14.04	12.85	19.15	17.47	11.72	10.51	-	-	-	-	3.07	2.92	16.50	15.11
130	25.22	23.01	16.64	15.22	0.10	0.10	-	-	6.50	6.06	22.21	20.04	36.16	31.98	20.76	18.70	0.10	0.10	-	-	6.98	6.51	31.94	28.63
120	38.84	33.88	26.42	24.01	0.45	0.44	0.04	0.04	11.74	10.51	35.28	31.02	>89.00	74.66	43.86	37.88	0.46	0.45	0.04	0.04	13.24	12.03	81.20	64.57

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-11. Location ID-259, 1500 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 1500 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190	0.14	0.13	-	-	-	-	-	-	-	-	0.11	0.11	0.14	0.13	-	-	-	-	-	-	-	-	0.11	0.11
180	0.63	0.61	0.17	0.17	-	-	-	-	-	-	0.46	0.45	0.65	0.63	0.18	0.17	-	-	-	-	-	-	0.47	0.45
170	2.40	2.28	0.96	0.90	-	-	-	-	0.03	0.03	1.92	1.84	2.50	2.39	0.99	0.93	-	-	-	-	0.03	0.03	2.01	1.91
160	5.70	5.38	3.06	2.91	-	-	-	-	0.31	0.30	5.00	4.72	6.13	5.78	3.26	3.11	-	-	-	-	0.30	0.29	5.34	5.03
150	10.88	9.79	6.74	6.29	-	-	-	-	1.32	1.26	9.48	8.73	12.66	11.59	7.38	6.83	-	-	-	-	1.36	1.31	10.86	9.74
140	18.25	16.64	12.24	11.08	-	-	-	-	3.90	3.74	16.21	14.80	24.23	21.85	14.14	12.94	-	-	-	-	4.14	3.95	20.77	18.65
130	29.70	26.74	19.64	17.85	0.14	0.14	-	-	7.84	7.25	27.06	24.58	50.64	42.90	28.88	26.25	0.15	0.14	-	-	8.70	8.01	46.44	39.88
120	47.84	40.62	33.80	29.91	0.64	0.61	0.11	0.11	13.57	12.41	45.14	38.57	>89.00	83.26	>89.00	71.06	0.65	0.63	0.11	0.11	16.25	14.85	>89.00	83.00

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-12. Location ID-259, 2000 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 2000 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190	0.15	0.15	0.02	0.02	-	-	-	-	-	-	0.13	0.13	0.16	0.15	0.02	0.02	-	-	-	-	-	-	0.13	0.13
180	0.71	0.68	0.26	0.26	-	-	-	-	-	-	0.59	0.57	0.72	0.70	0.20	0.20	-	-	-	-	-	-	0.60	0.58
170	2.76	2.65	1.17	1.09	-	-	-	-	0.08	0.08	2.33	2.22	2.88	2.75	1.22	1.16	-	-	-	-	0.05	0.05	2.42	2.30
160	6.48	6.09	3.62	3.46	-	-	-	-	0.36	0.35	5.64	5.32	7.00	6.56	3.85	3.67	-	-	-	-	0.35	0.34	6.10	5.71
150	12.32	11.15	7.66	7.09	-	-	-	-	1.62	1.54	10.80	9.67	14.24	13.09	8.54	7.83	-	-	-	-	1.69	1.61	12.58	11.41
140	19.62	17.99	13.58	12.38	-	-	-	-	4.48	4.26	17.87	16.37	28.52	25.74	16.35	15.02	-	-	-	-	4.78	4.54	25.60	23.26
130	32.50	29.04	21.97	19.83	0.17	0.16	-	-	8.92	8.17	29.88	26.94	72.82	58.96	38.32	33.50	0.17	0.17	-	-	9.86	9.03	65.86	54.23
120	52.74	44.51	36.92	32.54	0.84	0.81	0.15	0.14	15.01	13.76	49.44	41.97	>89.00	84.18	>89.00	82.62	0.79	0.76	0.15	0.15	19.22	17.65	>89.00	84.16

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-13. Location ID-259, 2500 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 2500 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190	0.16	0.16	0.03	0.03	-	-	-	-	-	-	0.15	0.14	0.17	0.17	0.03	0.03	-	-	-	-	-	-	0.15	0.14
180	0.88	0.84	0.32	0.31	-	-	-	-	-	-	0.67	0.64	0.91	0.87	0.30	0.29	-	-	-	-	-	-	0.69	0.66
170	2.97	2.84	1.33	1.26	-	-	-	-	0.10	0.10	2.56	2.44	3.14	2.99	1.40	1.33	-	-	-	-	0.10	0.09	2.66	2.54
160	6.76	6.35	3.96	3.79	-	-	-	-	0.45	0.43	5.94	5.58	7.30	6.82	4.22	4.01	-	-	-	-	0.40	0.38	6.38	5.97
150	12.82	11.78	8.04	7.45	-	-	-	-	1.86	1.77	11.24	10.13	15.00	13.77	8.88	8.16	-	-	-	-	1.95	1.86	12.94	11.82
140	21.62	19.39	14.16	12.96	0.03	0.03	-	-	4.84	4.59	19.31	17.61	30.02	27.02	17.27	15.81	0.03	0.03	-	-	5.24	4.95	26.90	24.43
130	35.80	31.66	24.78	22.45	0.18	0.18	0.06	0.06	9.30	8.55	33.44	29.78	76.08	60.67	39.30	34.27	0.32	0.31	0.06	0.06	10.58	9.53	67.14	54.88
120	60.32	50.41	42.04	36.51	1.18	1.07	0.34	0.33	16.00	14.63	57.26	47.93	>89.00	84.15	>89.00	82.35	1.32	1.24	0.42	0.41	21.28	19.13	>89.00	84.12

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-14. Location ID-259, 3200 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 3200 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.02	0.02	-	-	-	-	-	-	-	-	-	-	0.02	0.02	-	-	-	-	-	-	-	-	-	-
190	0.18	0.18	0.06	0.06	-	-	-	-	-	-	0.17	0.16	0.19	0.19	0.05	0.05	-	-	-	-	-	-	0.17	0.17
180	1.09	1.03	0.37	0.36	-	-	-	-	-	-	0.84	0.81	1.13	1.09	0.37	0.36	-	-	-	-	-	-	0.87	0.83
170	3.54	3.38	1.65	1.58	-	-	-	-	0.13	0.13	2.94	2.80	3.72	3.54	1.79	1.70	-	-	-	-	0.13	0.13	3.08	2.93
160	7.50	6.99	4.52	4.28	-	-	-	-	0.58	0.56	6.60	6.17	8.20	7.61	4.82	4.57	-	-	-	-	0.59	0.57	7.16	6.65
150	14.02	12.90	8.90	8.18	-	-	-	-	2.23	2.12	12.40	11.33	16.19	14.78	9.78	8.98	-	-	-	-	2.43	2.31	14.03	12.85
140	24.14	21.82	15.72	14.39	0.06	0.06	0.02	0.02	5.50	5.18	21.79	19.54	32.30	28.86	18.86	17.13	0.06	0.06	0.02	0.02	5.98	5.62	28.94	26.15
130	39.84	34.76	27.80	25.20	0.58	0.54	0.12	0.12	10.24	9.32	37.70	33.05	>89.00	75.55	45.58	38.93	0.42	0.41	0.15	0.15	12.20	11.01	88.98	69.18
120	70.48	58.17	48.54	41.09	1.76	1.67	0.74	0.70	18.35	16.68	67.04	55.54	>89.00	84.22	>89.00	84.01	1.73	1.62	0.92	0.82	25.16	22.61	>89.00	84.22

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-15. Location ID-259, 4000 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 4000 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.03	0.03	-	-	-	-	-	-	-	-	-	-	0.03	0.03	-	-	-	-	-	-	-	-	-	-
190	0.26	0.25	0.10	0.10	-	-	-	-	-	-	0.18	0.17	0.22	0.21	0.10	0.09	-	-	-	-	-	-	0.18	0.18
180	1.35	1.29	0.44	0.42	-	-	-	-	-	-	0.99	0.95	1.39	1.33	0.42	0.40	-	-	-	-	-	-	1.02	0.98
170	3.90	3.74	1.86	1.77	-	-	-	-	0.15	0.15	3.28	3.12	4.13	3.94	1.94	1.85	-	-	-	-	0.16	0.15	3.50	3.32
160	8.10	7.52	4.92	4.65	-	-	-	-	0.69	0.66	7.10	6.62	8.86	8.17	5.30	4.99	-	-	-	-	0.72	0.69	7.80	7.22
150	14.81	13.60	9.48	8.71	0.02	0.02	0.02	0.02	2.57	2.45	13.14	12.07	17.12	15.59	10.72	9.61	0.04	0.04	0.02	0.02	2.74	2.61	14.98	13.69
140	25.37	23.07	16.71	15.29	0.16	0.16	0.06	0.06	6.04	5.69	23.27	20.98	34.60	30.69	20.30	18.30	0.29	0.28	0.07	0.07	6.76	6.34	30.98	27.82
130	42.08	36.46	29.66	26.68	0.94	0.90	0.63	0.61	11.54	10.31	39.90	34.72	>89.00	80.68	54.06	44.89	1.14	1.08	0.43	0.42	14.49	13.31	>89.00	79.15
120	79.42	63.50	52.32	43.79	3.20	2.96	1.69	1.61	20.13	18.25	73.88	60.11	>89.00	84.25	>89.00	84.09	4.03	3.81	1.88	1.74	36.64	31.67	>89.00	84.26

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

G.2.3. Location ID-200: Hammer Energy Level

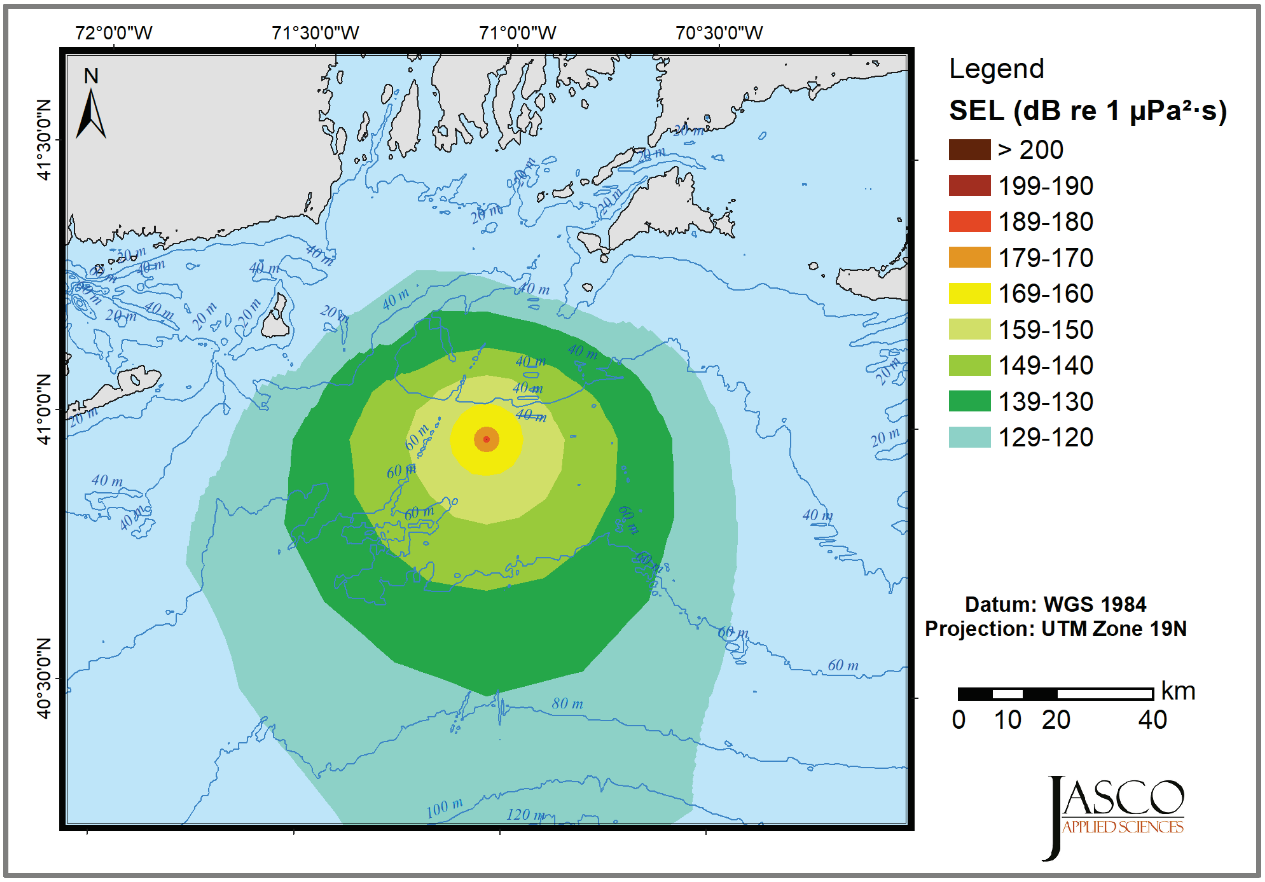


Figure G-5. Location ID-200, summer: Unweighted single-strike sound exposure level (SEL) for a jacket foundation pile using an IHC S-4000 hammer operating at 4000 kJ.

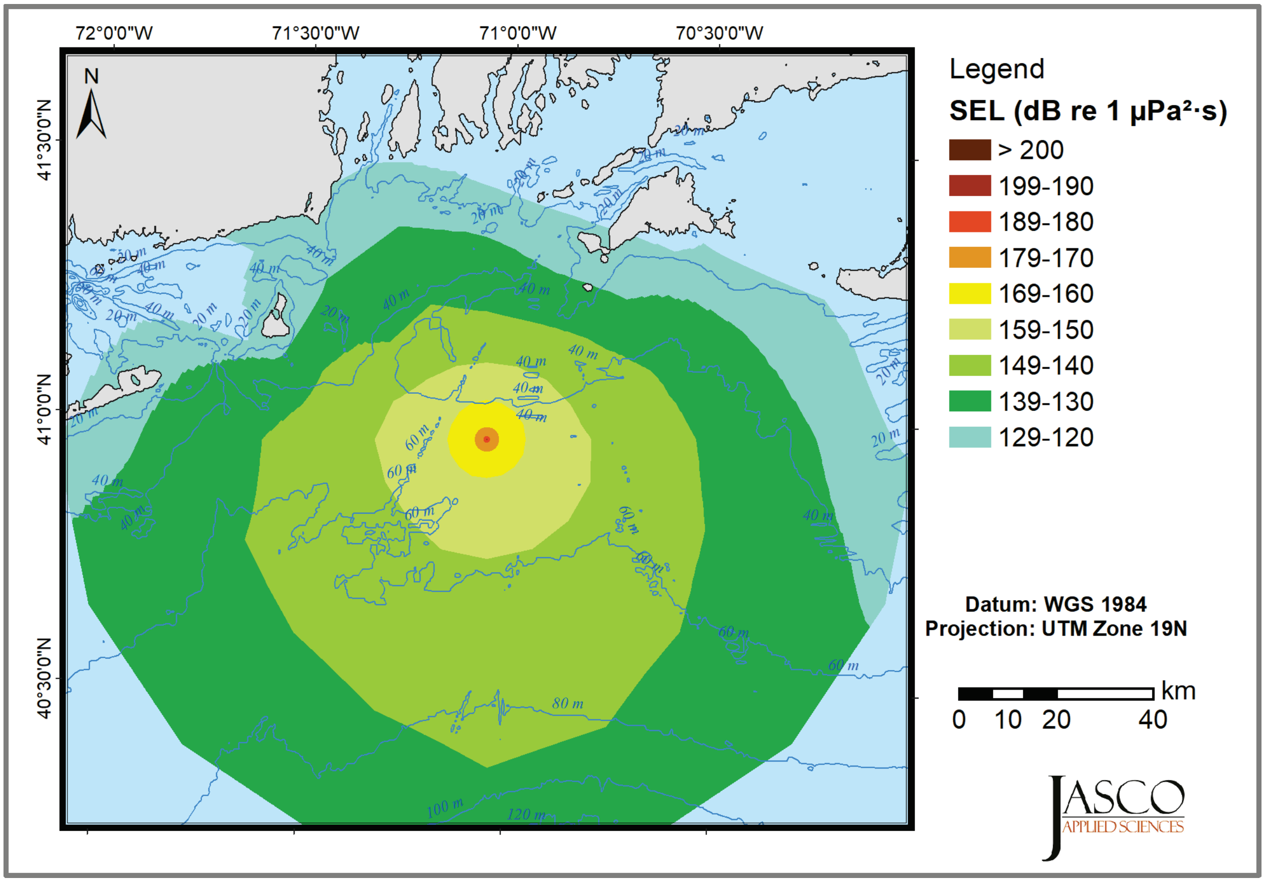


Figure G-6. Location ID-200, winter: Unweighted single-strike sound exposure level (SEL) for a jacket foundation pile using an IHC S-4000 hammer operating at 4000 kJ.

Table G-16. Location ID-200, 300 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a jacket foundation pile using an IHC S-4000 hammer operating at 300 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
180	0.15	0.14	0.10	0.09	-	-	-	-	-	-	0.14	0.13	0.15	0.15	0.10	0.09	-	-	-	-	-	-	0.14	0.14
170	0.80	0.77	0.43	0.41	-	-	-	-	-	-	0.71	0.67	0.83	0.80	0.43	0.42	-	-	-	-	-	-	0.75	0.72
160	2.64	2.52	1.53	1.47	-	-	-	-	0.13	0.13	2.47	2.35	2.77	2.64	1.62	1.54	-	-	-	-	0.14	0.13	2.59	2.47
150	5.68	5.40	4.03	3.80	-	-	-	-	0.60	0.58	5.40	5.13	6.02	5.71	4.26	4.02	-	-	-	-	0.61	0.57	5.72	5.41
140	10.19	9.38	7.34	6.89	-	-	-	-	2.28	2.14	9.64	8.93	11.80	10.74	7.98	7.44	-	-	-	-	2.40	2.28	10.78	9.78
130	17.83	16.29	12.97	11.82	0.13	0.13	-	-	5.02	4.75	16.68	15.22	23.14	20.80	14.84	13.43	0.13	0.13	-	-	5.34	5.04	20.54	18.59
120	29.27	26.34	20.80	18.67	0.54	0.47	0.26	0.25	8.79	8.17	27.80	24.99	45.28	40.94	30.29	27.25	0.50	0.47	0.16	0.16	9.54	8.83	42.58	38.74

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-17. Location ID-200, 750 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a jacket foundation pile using an IHC S-4000 hammer operating at 750 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190	0.09	0.09	-	-	-	-	-	-	-	-	0.09	0.09	0.09	0.09	-	-	-	-	-	-	-	-	0.09	0.09
180	0.40	0.38	0.14	0.14	-	-	-	-	-	-	0.31	0.30	0.41	0.39	0.15	0.15	-	-	-	-	-	-	0.30	0.29
170	1.59	1.52	0.80	0.76	-	-	-	-	0.09	0.09	1.44	1.37	1.64	1.57	0.82	0.80	-	-	-	-	0.04	0.04	1.52	1.45
160	4.10	3.86	2.62	2.48	-	-	-	-	0.29	0.28	3.86	3.63	4.27	4.05	2.74	2.61	-	-	-	-	0.29	0.28	4.05	3.82
150	7.56	7.09	5.52	5.21	-	-	-	-	1.31	1.25	7.15	6.70	8.23	7.68	5.84	5.53	-	-	-	-	1.38	1.30	7.75	7.23
140	13.64	12.45	9.59	8.88	0.03	0.03	-	-	3.58	3.36	12.90	11.76	16.09	14.58	10.83	9.77	0.03	0.03	-	-	3.84	3.60	14.93	13.47
130	23.27	20.64	16.48	15.01	0.29	0.28	0.10	0.09	6.68	6.29	21.83	19.29	32.65	29.26	20.41	18.54	0.27	0.26	0.09	0.09	7.15	6.71	30.89	27.66
120	36.49	32.61	28.35	25.30	1.11	1.03	0.46	0.44	11.65	10.56	35.51	31.62	87.24	72.60	48.54	43.96	1.22	1.11	0.47	0.45	13.38	12.09	81.12	68.37

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-18. Location ID-200, 1000 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a jacket foundation pile using an IHC S-4000 hammer operating at 1000 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190	0.11	0.11	0.02	0.02	-	-	-	-	-	-	0.10	0.10	0.11	0.11	0.02	0.02	-	-	-	-	-	-	0.10	0.10
180	0.49	0.47	0.24	0.24	-	-	-	-	-	-	0.44	0.43	0.50	0.48	0.17	0.17	-	-	-	-	-	-	0.45	0.44
170	1.95	1.87	1.04	0.95	-	-	-	-	0.10	0.10	1.77	1.68	2.00	1.91	1.12	1.04	-	-	-	-	0.10	0.10	1.88	1.80
160	4.70	4.45	3.04	2.87	-	-	-	-	0.44	0.42	4.44	4.19	4.94	4.68	3.25	3.07	-	-	-	-	0.45	0.43	4.66	4.41
150	8.57	7.99	6.14	5.82	-	-	-	-	1.64	1.57	8.13	7.58	9.38	8.68	6.56	6.20	-	-	-	-	1.69	1.62	8.86	8.20
140	15.21	13.79	10.92	9.83	0.10	0.10	-	-	4.13	3.90	14.37	13.03	18.28	16.59	12.51	11.26	0.10	0.09	-	-	4.40	4.14	16.88	15.24
130	25.56	23.04	18.09	16.49	0.47	0.45	0.14	0.14	7.44	6.96	24.29	21.75	36.00	32.71	23.86	21.58	0.47	0.46	0.15	0.15	8.08	7.52	33.89	30.73
120	39.03	35.26	30.69	27.51	1.64	1.51	0.76	0.67	12.97	11.75	37.95	34.10	>89.00	80.73	57.92	50.51	1.69	1.58	0.74	0.65	14.98	13.44	>89.00	79.86

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-19. Location ID-200, 2000 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a jacket foundation pile using an IHC S-4000 hammer operating at 2000 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190	0.14	0.13	0.09	0.09	-	-	-	-	-	-	0.13	0.13	0.14	0.14	0.09	0.09	-	-	-	-	-	-	0.13	0.13
180	0.80	0.77	0.32	0.31	-	-	-	-	-	-	0.68	0.65	0.82	0.79	0.37	0.30	-	-	-	-	-	-	0.70	0.67
170	2.68	2.55	1.54	1.48	-	-	-	-	0.13	0.13	2.47	2.36	2.79	2.65	1.61	1.53	-	-	-	-	0.13	0.13	2.59	2.47
160	5.78	5.46	4.05	3.82	-	-	-	-	0.60	0.57	5.42	5.14	6.14	5.82	4.27	4.04	-	-	-	-	0.64	0.59	5.78	5.46
150	10.18	9.35	7.40	6.94	0.04	0.04	-	-	2.33	2.20	9.62	8.89	11.94	10.86	8.16	7.60	0.04	0.04	-	-	2.44	2.32	10.96	9.93
140	17.36	15.87	13.02	11.83	0.42	0.40	0.13	0.13	5.12	4.85	16.39	14.95	22.71	20.40	15.31	13.84	0.30	0.29	0.13	0.13	5.46	5.16	20.26	18.46
130	28.85	25.84	20.94	18.73	1.15	1.08	0.67	0.64	8.94	8.30	27.73	24.78	50.72	45.26	33.49	30.29	1.20	1.06	0.65	0.62	9.92	9.17	48.28	43.37
120	43.63	39.63	34.90	31.15	3.08	2.88	1.95	1.86	15.00	13.60	42.67	38.60	>89.00	84.21	>89.00	83.42	3.22	2.94	1.95	1.80	19.14	17.49	>89.00	84.20

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-20. Location ID-200, 3000 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a jacket foundation pile using an IHC S-4000 hammer operating at 3000 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.03	0.03	-	-	-	-	-	-	-	-	0.02	0.02	0.03	0.03	-	-	-	-	-	-	-	-	0.02	0.02
190	0.12	0.12	0.07	0.07	-	-	-	-	-	-	0.11	0.11	0.12	0.12	0.07	0.07	-	-	-	-	-	-	0.11	0.11
180	0.78	0.74	0.37	0.35	-	-	-	-	0.03	0.03	0.64	0.61	0.78	0.74	0.39	0.37	-	-	-	-	0.02	0.02	0.65	0.62
170	2.73	2.60	1.54	1.48	-	-	-	-	0.11	0.11	2.47	2.34	2.75	2.63	1.56	1.49	-	-	-	-	0.12	0.12	2.47	2.35
160	6.63	6.30	4.29	4.05	-	-	-	-	0.65	0.63	6.08	5.79	7.82	7.37	4.39	4.18	-	-	-	-	0.71	0.67	6.93	6.59
150	14.53	13.19	9.10	8.50	0.09	0.09	0.06	0.06	2.49	2.34	13.54	12.32	20.83	18.91	12.01	11.03	0.09	0.09	0.06	0.06	2.52	2.37	19.57	17.88
140	25.98	23.62	18.41	16.72	0.46	0.44	0.28	0.27	5.64	5.36	24.98	22.66	51.17	45.92	33.17	30.08	0.45	0.43	0.26	0.25	6.04	5.74	49.38	44.30
130	41.16	37.07	31.73	28.81	1.65	1.57	1.02	0.97	11.74	10.68	40.03	36.12	>89.00	84.17	>89.00	82.99	1.64	1.51	0.93	0.89	16.90	15.41	>89.00	84.15
120	69.88	59.20	52.30	46.03	4.08	3.85	2.75	2.58	21.90	19.70	67.90	57.67	>89.00	84.43	>89.00	84.37	3.94	3.68	2.60	2.41	49.53	44.58	>89.00	84.40

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-21. Location ID-200, 4000 kJ: Distance R_{max} (km) to the single-strike sound exposure level (SEL) for a jacket foundation pile using an IHC S-4000 hammer operating at 4000 kJ in summer and winter.

Level (SEL)	Summer												Winter											
	Flat		LFC		MFC		HFC		PPW		TUW		Flat		LFC		MFC		HFC		PPW		TUW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.03	0.03	-	-	-	-	-	-	-	-	0.03	0.03	0.03	0.03	-	-	-	-	-	-	-	-	0.03	0.03
190	0.11	0.11	0.06	0.06	-	-	-	-	-	-	0.09	0.09	0.11	0.11	0.06	0.06	-	-	-	-	-	-	0.09	0.09
180	0.69	0.66	0.29	0.28	-	-	-	-	0.05	0.05	0.61	0.59	0.69	0.66	0.31	0.30	-	-	-	-	0.05	0.05	0.61	0.58
170	2.67	2.56	1.42	1.34	-	-	-	-	0.10	0.10	2.35	2.24	2.59	2.46	1.42	1.35	-	-	-	-	0.10	0.09	2.29	2.19
160	7.73	7.28	4.59	4.36	0.04	0.04	-	-	0.67	0.63	7.19	6.78	8.18	7.78	4.47	4.24	0.04	0.04	-	-	0.71	0.66	7.58	7.13
150	17.56	16.02	11.85	10.91	0.10	0.09	0.06	0.06	2.47	2.31	17.00	15.51	24.68	22.44	14.44	13.22	0.09	0.09	0.06	0.06	2.47	2.31	23.76	21.55
140	31.60	28.65	24.55	22.24	0.58	0.57	0.27	0.27	6.47	6.15	31.04	28.15	67.82	58.16	41.08	37.35	0.54	0.52	0.37	0.35	6.54	6.21	65.60	56.49
130	53.08	46.61	41.68	37.65	1.87	1.79	1.13	1.07	15.50	14.15	52.20	45.96	>89.00	84.30	>89.00	84.01	1.82	1.67	1.00	0.94	20.64	18.81	>89.00	84.30
120	>89.00	80.79	80.86	67.18	4.46	4.19	2.99	2.82	29.71	26.87	>89.00	80.43	>89.00	84.43	>89.00	84.38	4.23	3.98	2.83	2.64	64.94	56.42	>89.00	84.42

Dashes indicate that the acoustic threshold was not reached.
Flat = unweighted; LFC = low-frequency cetaceans; MFC = mid-frequency cetaceans; HFC = high-frequency cetaceans; PPW = pinnipeds in water; TUW = sea turtles in water.
TUW weighting functions are from the US Navy (Blackstock et al. 2018), the rest are from the Technical Guidance (NMFS 2018).
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

G.3. Impact Pile Driving Single-Strike SPL Ranges

G.3.1. Location ID-97: Hammer Energy Level

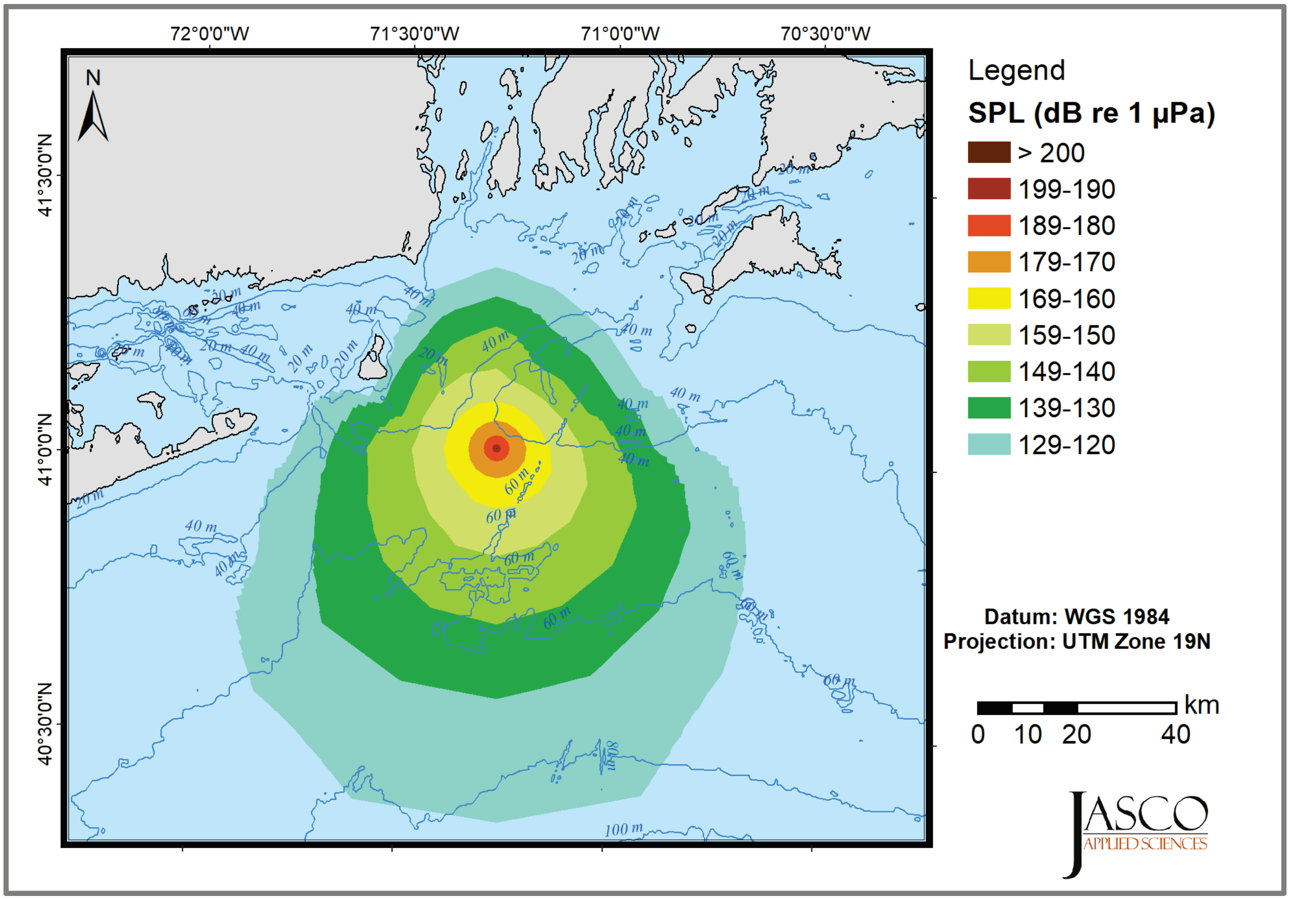


Figure G-7. Location ID-97, summer: Unweighted single-strike sound pressure level (SPL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 3200 kJ.

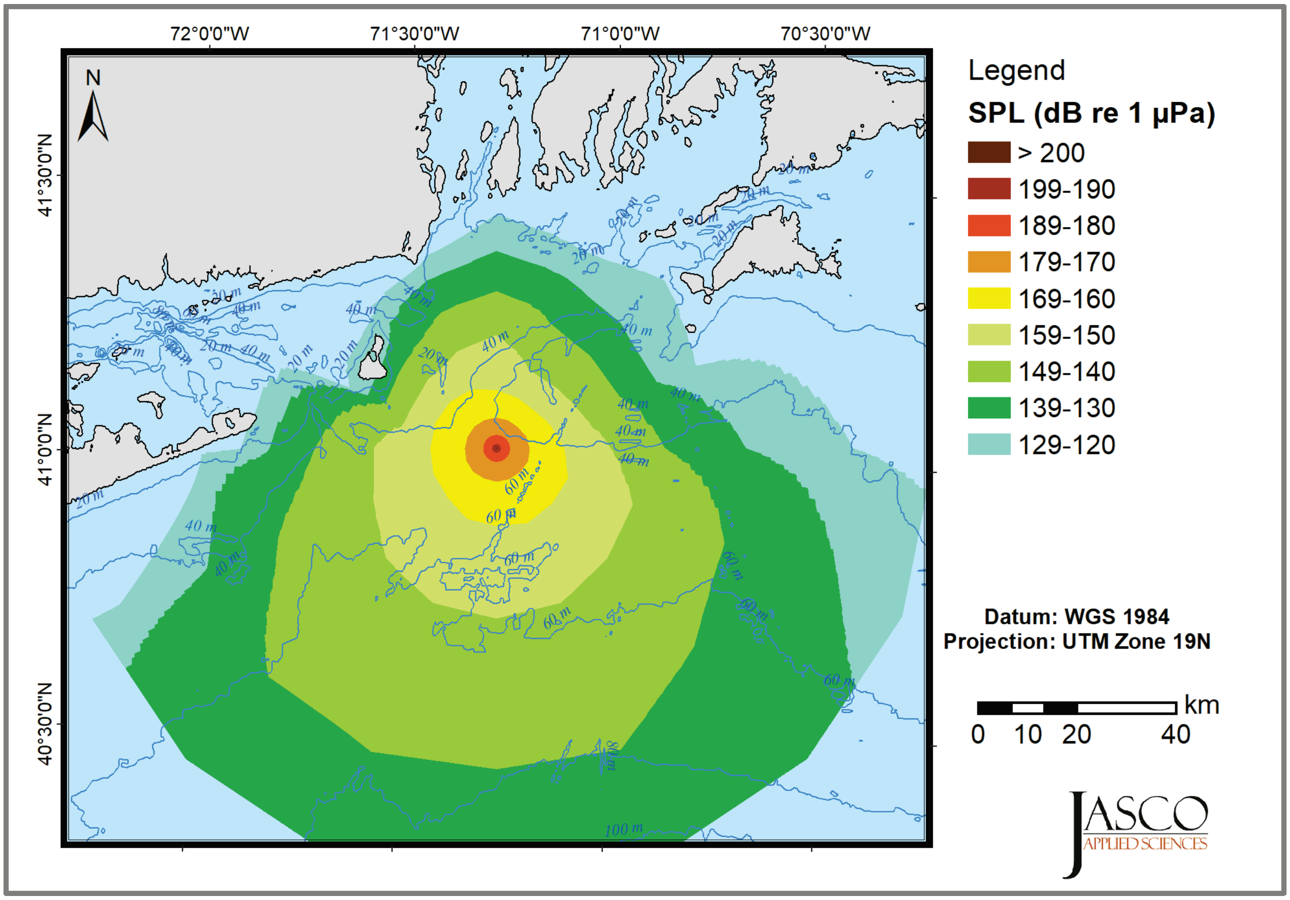


Figure G-8. Location ID-97, winter: Unweighted single-strike sound pressure level (SPL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 3200 kJ.

Table G-22. Location ID-97, summer and winter: Distance, in km, to the single-strike unweighted (flat) sound pressure level (SPL) for a 7/12 m monopile using an IHC S-4000 at each hammer energy.

Level (L_p)	Summer												Winter											
	1000 kJ		1500 kJ		2000 kJ		2500 kJ		3200 kJ		4000 kJ		1000 kJ		1500 kJ		2000 kJ		2500 kJ		3200 kJ		4000 kJ	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.08	0.07	0.10	0.10	0.12	0.12	0.14	0.13	0.15	0.15	0.17	0.16	0.07	0.07	0.10	0.10	0.13	0.12	0.14	0.13	0.16	0.15	0.17	0.17
190	0.29	0.28	0.43	0.41	0.60	0.57	0.69	0.67	0.87	0.83	0.94	0.90	0.29	0.28	0.44	0.43	0.64	0.61	0.72	0.69	0.89	0.85	0.96	0.92
180	1.25	1.20	1.70	1.62	2.09	1.99	2.38	2.26	2.67	2.53	2.88	2.74	1.32	1.25	1.77	1.68	2.21	2.10	2.48	2.36	2.78	2.64	3.00	2.85
175	2.12	2.02	2.76	2.60	3.36	3.13	3.79	3.49	4.24	3.94	4.59	4.25	2.25	2.12	2.87	2.70	3.63	3.38	4.07	3.76	4.57	4.23	4.95	4.58
170	3.38	3.12	4.29	3.97	5.11	4.69	5.59	5.11	6.21	5.68	6.67	6.11	3.66	3.40	4.62	4.27	5.58	5.12	6.16	5.62	6.92	6.33	7.59	6.89
160	7.27	6.57	8.66	7.91	9.88	8.95	10.69	9.60	12.43	11.18	13.44	12.06	8.11	7.36	10.32	9.25	12.07	10.90	13.95	12.53	16.39	14.57	17.51	15.64
150	14.07	12.60	16.19	14.61	17.90	16.23	19.02	17.29	21.88	19.52	23.92	21.21	17.37	15.63	21.33	18.98	25.50	22.74	30.10	26.91	34.48	31.02	36.72	33.03
140	23.94	20.94	26.68	23.88	30.24	26.74	32.04	28.73	35.66	31.91	37.56	33.61	32.90	29.49	42.22	38.56	47.36	43.24	58.55	52.69	66.50	61.02	72.28	65.56
130	36.12	31.84	39.74	36.00	44.22	39.77	46.33	42.25	50.92	46.49	53.48	48.97	56.57	51.65	88.99	79.47	>89.0	82.80	>89.0	84.11	>89.0	84.27	>89.0	84.34
120	49.94	44.90	56.96	52.33	62.78	57.44	68.15	61.56	76.79	69.51	81.92	74.63	>89.0	83.87	>89.0	84.40	>89.0	84.41	>89.0	84.59	>89.0	84.61	>89.0	84.52

R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-23. Location ID-97, summer and winter: Distance, in km, to the single-strike unweighted (flat) and frequency weighted sound pressure level (SPL) categories (Finneran et al. 2017, NMFS 2018) for a 7/12 m monopile using an IHC S-4000 at the highest scheduled hammer energy (3200 kJ).

Level (L_p)	Summer										Winter									
	Unweighted		LF		MF		HF		PPW		Unweighted		LF		MF		HF		PPW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.15	0.15	0.15	0.15	0.01	0.01	0.00	0.00	0.10	0.10	0.16	0.15	0.16	0.15	0.01	0.01	0.00	0.00	0.10	0.10
190	0.87	0.83	0.86	0.82	0.16	0.15	0.12	0.12	0.43	0.41	0.89	0.85	0.88	0.85	0.16	0.16	0.13	0.12	0.44	0.42
180	2.67	2.53	2.65	2.52	0.87	0.82	0.54	0.52	1.72	1.62	2.78	2.64	2.77	2.62	0.88	0.84	0.54	0.52	1.77	1.68
175	4.24	3.94	4.20	3.90	1.64	1.57	1.12	1.07	2.74	2.59	4.57	4.23	4.53	4.19	1.70	1.62	1.16	1.10	2.87	2.71
170	6.21	5.68	6.16	5.64	2.67	2.52	1.95	1.86	4.31	3.99	6.92	6.33	6.86	6.28	2.80	2.65	2.05	1.94	4.69	4.31
160	12.43	11.18	12.36	11.11	6.06	5.52	4.81	4.41	8.86	8.06	16.39	14.57	16.31	14.48	6.69	6.10	5.26	4.80	10.87	9.62
150	21.88	19.52	21.76	19.43	11.97	10.76	9.41	8.52	17.37	15.66	34.48	31.02	34.28	30.84	16.62	14.63	11.87	10.52	26.60	23.98
140	35.66	31.91	35.54	31.80	22.22	19.94	18.16	16.40	30.50	27.21	66.50	61.02	65.66	60.34	37.46	33.96	29.42	26.48	53.96	49.06
130	50.92	46.49	50.75	46.32	37.06	33.30	32.00	28.66	45.28	41.15	>89.00	84.27	>89.00	84.25	83.82	75.30	63.09	57.58	>89.00	83.92
120	76.79	69.51	76.25	69.02	53.97	49.46	47.80	43.48	66.71	60.82	>89.00	84.61	>89.00	84.60	>89.00	84.44	>89.00	84.27	>89.00	84.59

LF: low-frequency cetaceans, MF: mid-frequency cetaceans, HF: high-frequency cetaceans, PPW: phocid pinnipeds in water.
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

G.3.2. Location ID-259: Hammer Energy Level

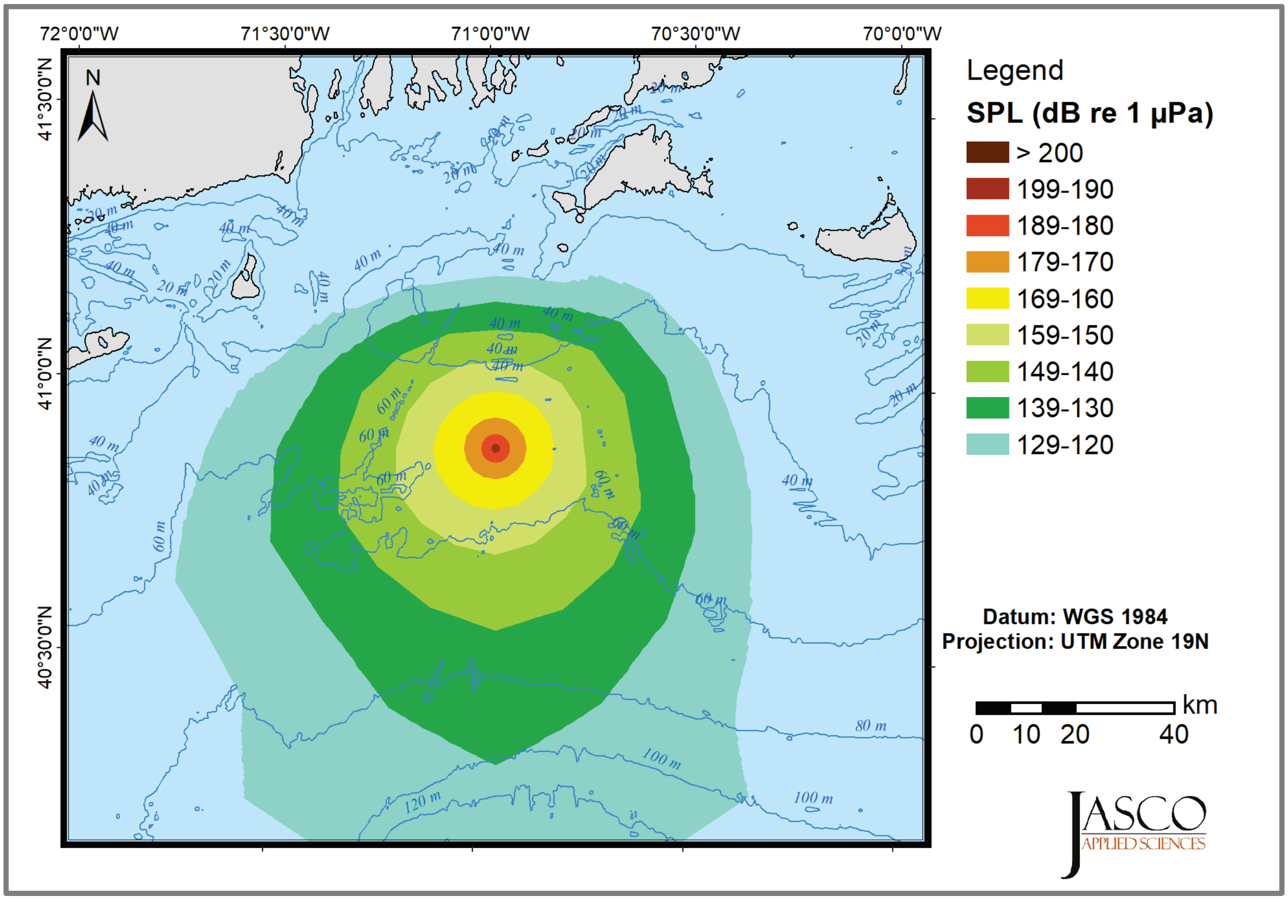


Figure G-9. Location ID-259, summer: Unweighted single-strike sound pressure level (SPL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 3200 kJ.

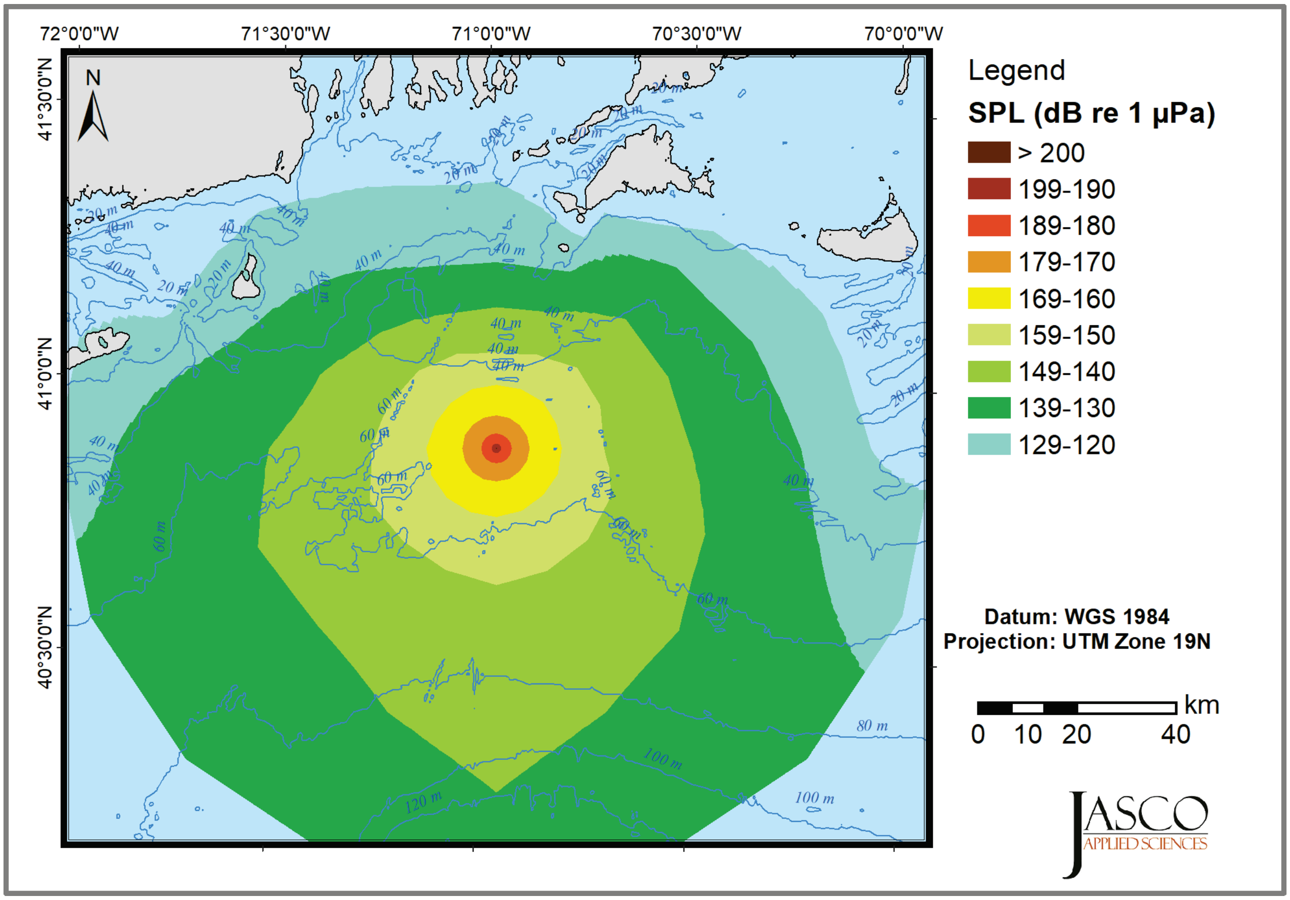


Figure G-10. Location ID-259, winter: Unweighted single-strike sound pressure level (SPL) for a 7/12 m monopile using an IHC S-4000 hammer operating at 3200 kJ.

Table G-24. Location ID-259, summer and winter: Distance, in km, to the single-strike unweighted (flat) sound pressure level (SPL) for a 7/12 m monopile using an IHC S-4000 at each hammer energy.

Level (L_p)	Summer												Winter											
	1000 kJ		1500 kJ		2000 kJ		2500 kJ		3200 kJ		4000 kJ		1000 kJ		1500 kJ		2000 kJ		2500 kJ		3200 kJ		4000 kJ	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.09	0.09	0.12	0.12	0.14	0.13	0.15	0.15	0.17	0.17	0.18	0.18	0.09	0.09	0.12	0.12	0.14	0.14	0.15	0.15	0.17	0.17	0.19	0.19
190	0.35	0.34	0.54	0.51	0.64	0.62	0.74	0.71	0.91	0.88	1.06	1.02	0.34	0.33	0.56	0.54	0.65	0.63	0.78	0.74	0.96	0.91	1.12	1.07
180	1.57	1.51	2.07	1.95	2.48	2.37	2.66	2.54	2.95	2.82	3.24	3.10	1.64	1.57	2.14	2.04	2.55	2.44	2.72	2.60	3.10	2.93	3.44	3.27
175	2.64	2.53	3.34	3.20	3.49	3.34	4.09	3.90	4.53	4.30	4.88	4.63	2.73	2.61	3.49	3.34	4.06	3.87	4.24	4.04	4.76	4.52	5.22	4.93
170	4.08	3.89	4.94	4.66	5.62	5.30	5.85	5.50	6.47	6.07	6.92	6.49	4.29	4.07	5.22	4.93	6.04	5.68	6.28	5.91	6.93	6.50	7.50	6.97
160	8.24	7.61	9.70	8.96	11.20	10.05	11.72	10.67	12.78	11.77	13.46	12.41	9.16	8.43	11.36	10.29	12.66	11.61	13.36	12.27	14.27	13.06	14.98	13.70
150	14.58	13.41	17.01	15.55	18.15	16.64	19.55	17.85	21.93	19.66	23.32	21.02	17.58	16.06	20.69	18.61	25.04	22.76	26.52	24.10	27.76	25.11	28.84	26.06
140	23.64	21.45	27.32	24.81	29.92	26.95	33.36	29.73	36.92	32.49	38.84	33.95	30.52	27.47	42.90	37.37	57.84	47.96	58.66	48.59	69.72	55.95	>89.0	70.32
130	35.66	31.43	43.36	37.34	49.02	41.64	56.06	47.04	64.20	53.29	69.22	57.19	64.72	53.72	>89.0	82.51	>89.0	84.05	>89.0	83.63	>89.0	84.15	>89.0	84.21
120	54.30	45.22	85.94	67.82	>89.0	76.06	>89.0	81.33	>89.0	82.43	>89.0	82.65	>89.0	83.93	>89.0	84.25	>89.0	84.54	>89.0	84.43	>89.0	84.56	>89.0	84.48

R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-25. Location ID-259, summer and winter: Distance, in km, to the single-strike unweighted (flat) and frequency weighted sound pressure level (SPL) categories (Finneran et al. 2017, NMFS 2018) for a 7/12 m monopile using an IHC S-4000 at the highest scheduled hammer energy (3200 kJ).

Level (L_p)	Summer										Winter									
	Unweighted		LF		MF		HF		PPW		Unweighted		LF		MF		HF		PPW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.17	0.17	0.17	0.17	0.02	0.02	-	-	0.11	0.11	0.17	0.17	0.17	0.17	0.02	0.02	-	-	0.10	0.10
190	0.91	0.88	0.90	0.86	0.18	0.18	0.15	0.14	0.48	0.47	0.96	0.91	0.94	0.89	0.19	0.19	0.15	0.15	0.49	0.47
180	2.95	2.82	2.92	2.80	0.98	0.93	0.63	0.61	1.90	1.82	3.10	2.93	3.06	2.89	1.01	0.96	0.64	0.62	1.95	1.88
175	4.53	4.30	4.49	4.26	1.88	1.79	1.30	1.23	3.06	2.90	4.76	4.52	4.72	4.48	1.92	1.83	1.36	1.30	3.26	3.08
170	6.47	6.07	6.43	6.03	2.98	2.85	2.32	2.19	4.64	4.38	6.93	6.50	6.88	6.44	3.18	3.01	2.45	2.33	4.92	4.64
160	12.78	11.77	12.72	11.69	6.34	5.94	5.16	4.85	8.96	8.24	14.27	13.06	14.17	12.98	6.96	6.46	5.64	5.27	9.94	9.14
150	21.93	19.66	21.81	19.55	11.86	10.74	9.60	8.82	16.45	15.06	27.76	25.11	27.63	24.98	13.54	12.42	11.28	10.15	19.56	17.76
140	36.92	32.49	36.76	32.36	20.85	18.76	17.16	15.65	29.74	26.73	69.72	55.95	67.72	54.72	28.79	25.90	22.28	19.76	45.96	39.36
130	64.20	53.29	63.72	52.91	38.12	33.38	31.54	28.24	52.28	43.79	89.00	84.15	89.00	84.13	89.00	80.87	71.98	57.18	89.00	83.91
120	89.00	82.43	89.00	82.39	72.44	59.21	58.16	48.17	89.00	80.85	89.00	84.56	89.00	84.55	89.00	84.40	89.00	84.21	89.00	84.52

Dashes indicate that the acoustic threshold was not reached.
LF: low-frequency cetaceans, MF: mid-frequency cetaceans, HF: high-frequency cetaceans, PPW: phocid pinnipeds in water.
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

G.3.3. Location ID-200: Hammer Energy Level

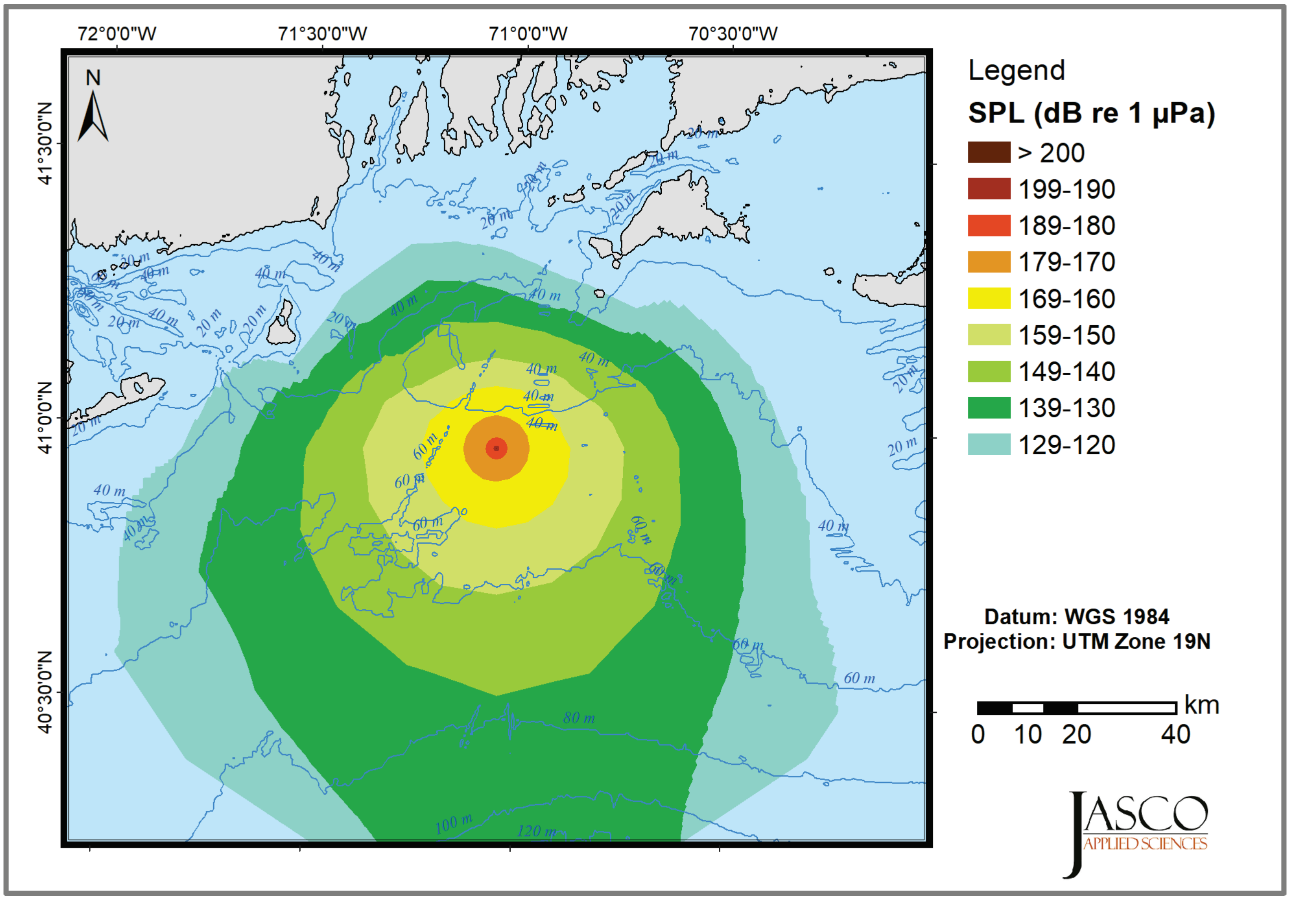


Figure G-11. Location ID-200, summer: Unweighted single-strike sound pressure level (SPL) for a jacket foundation pile using an IHC S-4000 hammer operating at 4000 kJ.

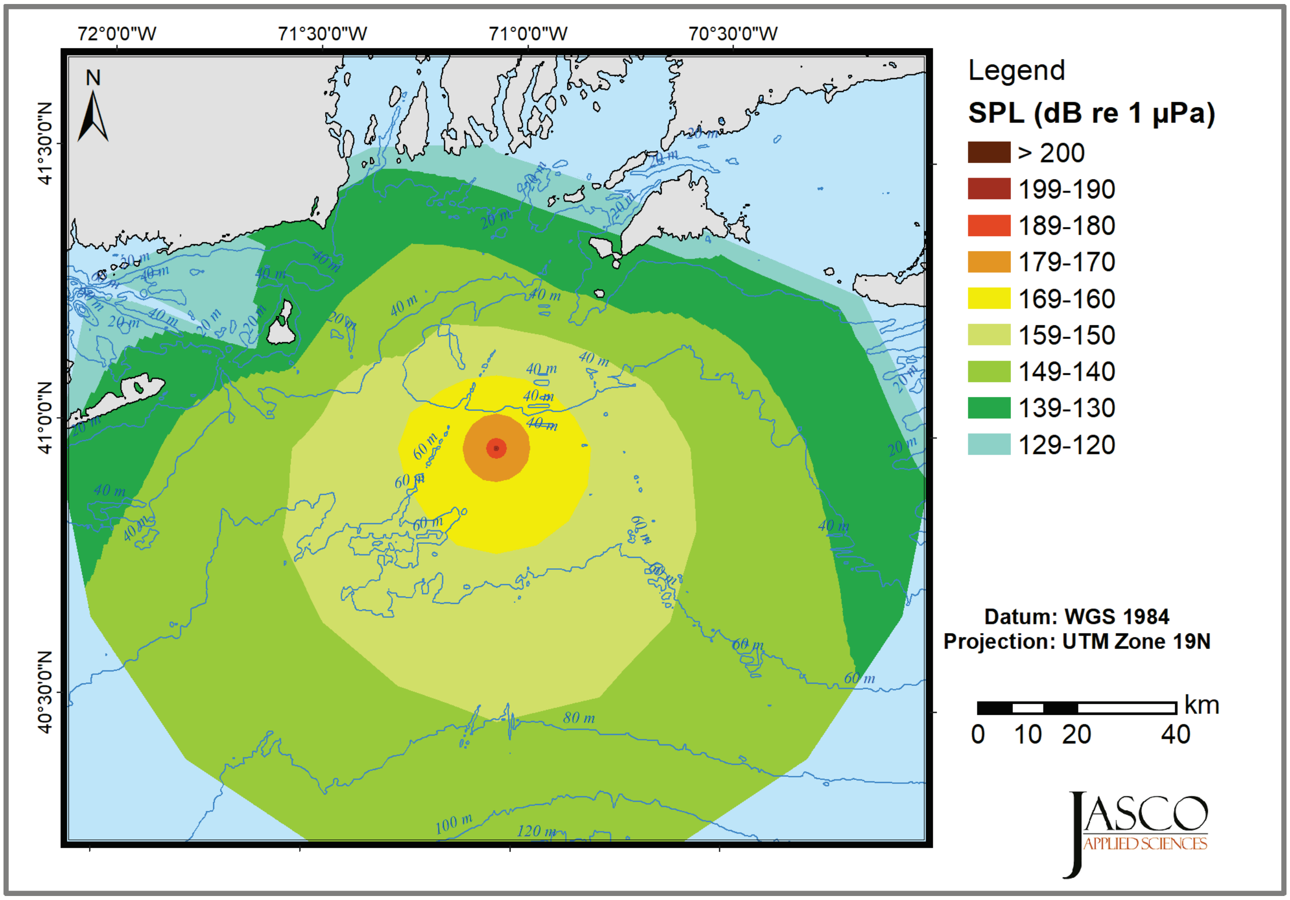


Figure G-12. Location ID-200, winter: Unweighted single-strike sound pressure level (SPL) for a jacket foundation pile using an IHC S-4000 hammer operating at 4000 kJ.

Table G-26. Location ID-200, summer and winter: Distances, in km, to the single-strike unweighted (flat) sound pressure level (SPL) for a jacket foundation pile using an IHC S-4000 at each hammer energy.

Level (L_p)	Summer												Winter											
	300 kJ		750 kJ		1000 kJ		2000 kJ		3000 kJ		4000 kJ		300 kJ		750 kJ		1000 kJ		2000 kJ		3000 kJ		4000 kJ	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	-	-	0.09	0.09	0.10	0.09	0.13	0.13	0.11	0.11	0.09	0.09	-	-	0.08	0.08	0.10	0.09	0.13	0.13	0.11	0.11	0.09	0.09
190	0.13	0.13	0.29	0.28	0.44	0.42	0.66	0.63	0.61	0.58	0.60	0.58	0.14	0.14	0.29	0.28	0.44	0.43	0.68	0.66	0.64	0.60	0.59	0.56
180	0.68	0.64	1.37	1.31	1.69	1.61	2.38	2.27	2.36	2.23	2.26	2.15	0.72	0.69	1.43	1.38	1.77	1.67	2.49	2.36	2.34	2.22	2.11	2.01
175	1.39	1.33	2.36	2.24	2.77	2.64	3.66	3.45	3.79	3.60	4.13	3.94	1.45	1.38	2.47	2.34	2.86	2.72	3.86	3.65	3.97	3.78	3.92	3.72
170	2.37	2.25	3.57	3.36	4.13	3.90	5.05	4.78	5.89	5.60	6.82	6.47	2.48	2.35	3.73	3.52	4.30	4.07	5.35	5.05	6.47	6.16	7.04	6.63
160	5.07	4.79	6.54	6.17	7.36	6.90	8.73	8.10	13.23	12.03	16.24	14.85	5.30	5.01	6.95	6.54	7.98	7.40	9.52	8.82	18.30	16.68	21.40	19.36
150	9.09	8.45	12.25	11.18	13.48	12.32	15.50	14.20	24.16	21.85	29.96	27.16	9.77	9.06	13.90	12.61	15.83	14.34	18.82	17.17	42.82	38.64	55.44	49.04
140	16.47	15.07	20.98	18.59	23.71	21.18	26.86	23.99	38.60	34.96	50.14	44.35	20.12	18.34	29.04	25.98	30.08	27.26	42.74	38.73	89.00	83.85	89.00	84.18
130	27.84	25.04	34.57	30.77	36.86	33.03	41.53	37.43	64.74	55.24	>89.00	79.90	37.88	34.02	61.94	53.93	80.26	66.62	>89.00	84.11	>89.00	84.44	>89.00	84.43
120	40.96	37.07	54.10	47.80	57.88	50.67	69.60	59.48	>89.00	82.53	>89.00	83.80	>89.00	83.28	>89.00	84.31	>89.00	84.38	>89.00	84.44	>89.00	84.61	>89.00	84.61

Dashes indicate that the acoustic threshold was not reached.
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

Table G-27. Location ID-200, summer and winter: Distance, in km, to the single-strike unweighted (flat) and frequency weighted sound pressure level (SPL) categories (Finneran et al. 2017, NMFS 2018) for a jacket foundation pile using an IHC S-4000 at the highest scheduled hammer energy (4000 kJ).

Level (L_p)	Summer										Winter									
	Unweighted		LF		MF		HF		PPW		Unweighted		LF		MF		HF		PPW	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	0.09	0.09	0.09	0.09	0.05	0.05	0.05	0.05	0.06	0.06	0.09	0.09	0.09	0.09	0.05	0.05	0.05	0.05	0.06	0.06
190	0.60	0.58	0.60	0.57	0.21	0.20	0.10	0.10	0.35	0.34	0.59	0.56	0.59	0.56	0.20	0.19	0.11	0.10	0.36	0.34
180	2.26	2.15	2.25	2.13	0.93	0.89	0.71	0.67	1.54	1.49	2.11	2.01	2.09	2.00	0.96	0.92	0.73	0.68	1.56	1.49
175	4.13	3.94	4.11	3.92	1.77	1.69	1.41	1.33	2.83	2.70	3.92	3.72	3.90	3.69	1.77	1.68	1.41	1.34	2.69	2.56
170	6.82	6.47	6.78	6.45	3.09	2.94	2.40	2.28	5.08	4.81	7.04	6.63	7.00	6.59	2.90	2.77	2.33	2.21	4.89	4.62
160	16.24	14.85	16.18	14.79	8.74	8.20	6.73	6.40	13.23	12.15	21.40	19.36	21.22	19.20	9.34	8.86	6.80	6.41	16.46	15.06
150	29.96	27.16	29.85	27.05	19.62	17.95	16.46	15.03	26.39	23.94	55.44	49.04	54.30	48.23	30.03	27.29	22.50	20.51	43.82	39.65
140	50.14	44.35	49.78	44.07	35.88	32.59	31.31	28.33	44.18	39.78	>89.00	84.18	>89.00	84.14	>89.00	80.52	69.78	59.53	>89.00	83.85
130	>89.00	79.90	>89.00	79.43	66.06	55.97	55.80	48.37	>89.00	72.51	>89.00	84.43	>89.00	84.39	>89.00	84.31	>89.00	84.25	>89.00	84.37
120	>89.00	83.80	>89.00	83.75	>89.00	83.17	>89.00	82.40	>89.00	83.53	>89.00	84.61	>89.00	84.60	>89.00	84.59	>89.00	84.59	>89.00	84.60

LF: low-frequency cetaceans, MF: mid-frequency cetaceans, HF: high-frequency cetaceans, PPW: phocid pinnipeds in water.
R_{max} = maximum range at which the sound level was encountered in the modeled maximum-over-depth sound field.
$R_{95\%}$ = maximum range at which the sound level was encountered after the 5% farthest such points were excluded.

G.4. Impact Pile Driving Per-Pile SEL24h Ranges

Table G-28. All locations: Ranges ($R_{95\%}$ in km) to injury thresholds (NMFS 2018) for marine mammal functional hearing groups due to single-pile impact hammering in 24 hours, using an IHC S-4000 hammer for each attenuation level at each location.

Hearing group	Season	Threshold (dB)	Location ID-97 (7/12 m monopile)				Location ID-259 (7/12 m monopile)				Location ID-200 (jacket foundation pile)			
			Attenuation level (dB)				Attenuation level (dB)				Attenuation level (dB)			
			0	6	10	15	0	6	10	15	0	6	10	15
Low-frequency cetaceans	Summer	183	9.24	6.39	4.91	3.35	10.15	7.32	5.70	4.00	13.52	8.68	6.60	4.77
Mid-frequency cetaceans		185	-	-	-	-	-	-	-	-	0.25	0.07	0.04	-
High-frequency cetaceans		155	0.28	0.11	0.06	0.01	0.67	0.19	0.09	0.03	3.53	2.17	1.46	0.88
Phocid pinnipeds		185	2.22	1.13	0.65	0.29	2.63	1.32	0.73	0.34	3.78	2.21	1.42	0.72
Sea turtles		204	3.20	1.81	1.15	0.56	3.85	2.11	1.31	0.63	4.27	2.53	1.63	0.84
Low-frequency cetaceans	Winter	183	11.91	7.27	5.40	3.63	11.81	8.04	6.14	4.26	18.98	10.44	7.22	4.95
Mid-frequency cetaceans		185	-	-	-	-	-	-	-	-	0.13	0.07	0.04	-
High-frequency cetaceans		155	0.30	0.11	0.05	0.01	0.48	0.32	0.09	0.03	3.30	1.98	1.36	0.76
Phocid pinnipeds		185	2.37	1.20	0.69	0.29	2.77	1.37	0.74	0.34	3.91	2.28	1.48	0.75
Sea turtles		204	3.46	1.89	1.21	0.57	4.06	2.24	1.36	0.65	4.43	2.60	1.69	0.88

Dashes indicate that the acoustic threshold was not reached.

G.5. Fish Acoustic Ranges to Threshold

Table G-29. Summer, 0 dB attenuation: Modelled acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish, corresponding to each hammer energy with 0 dB attenuation, for pile installations in summer.

Faunal group	Metric	Threshold	Location ID-97 (7/12 m monopile)					Location ID-259 (7/12 m monopile)					Location ID-200 (jacket foundation pile)					
			Hammer energy (kJ)					Hammer energy (kJ)					Hammer energy (kJ)					
			1000	1500	2000	2500	3200	1000	1500	2000	2500	3200	300	750	1000	2000	3000	4000
Small fish[a]	L_E	183	14.89					15.65					**1 pile**: 18.91; **2 piles**: 22.95; **3 piles**: 25.08; **4 piles**: 26.29;					
	L_{pk}	206	0.15	0.26	0.35	0.41	0.44	0.28	0.34	0.40	0.47	0.52	0.14	0.28	0.36	0.47	0.46	0.40
Large fish[a]	L_E	187	11.96					12.81					**1 pile**: 15.15; **2 piles**: 17.93; **3 piles**: 19.92; **4 piles**: 21.66;					
	L_{pk}	206	0.15	0.26	0.35	0.41	0.44	0.28	0.34	0.40	0.47	0.52	0.14	0.28	0.36	0.47	0.46	0.40
All fish[b]	L_p	150	12.60	14.61	16.23	17.29	19.52	13.41	15.55	16.64	17.85	19.66	8.45	11.18	12.32	14.20	21.85	27.16
Fish without swim bladder[c]	L_E	219	0.72					0.81					**1 pile**: 0.93; **2 piles**: 1.48; **3 piles**: 1.78; **4 piles**: 2.01;					
	L_{pk}	213	0.09	0.11	0.14	0.15	0.16	0.12	0.14	0.17	0.17	0.18	0.07	0.12	0.13	0.15	0.13	0.12
Fish with swim bladder not involved in hearing[c]	L_E	210	2.20					2.58					**1 pile**: 2.72; **2 piles**: 3.62; **3 piles**: 4.18; **4 piles**: 4.60;					
	L_{pk}	207	0.14	0.24	0.29	0.36	0.40	0.17	0.32	0.36	0.38	0.47	0.13	0.27	0.29	0.45	0.43	0.37
Fish with swim bladder involved in hearing[c]	L_E	207	2.85					3.46					**1 pile**: 3.62; **2 piles**: 4.60; **3 piles**: 5.22; **4 piles**: 5.70;					
	L_{pk}	207	0.14	0.24	0.29	0.36	0.40	0.17	0.32	0.36	0.38	0.47	0.13	0.27	0.29	0.45	0.43	0.37
Eggs and larvae[c]	L_E	210	2.20					2.58					**1 pile**: 2.72; **2 piles**: 3.62; **3 piles**: 4.18; **4 piles**: 4.60;					
	L_{pk}	207	0.14	0.24	0.29	0.36	0.40	0.17	0.32	0.36	0.38	0.47	0.13	0.27	0.29	0.45	0.43	0.37

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

L_E = unweighted sound exposure level (dB re 1 µPa²·s) over the entire pile (so encompasses all hammer energies); L_p = unweighted sound pressure level (dB re 1 µPa); L_{pk} = unweighted peak sound pressure level (dB re 1 µPa).

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

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

[c] Popper et al. (2014).

Table G-30. Winter, 0 dB attenuation: Modelled acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish, corresponding to each hammer energy with 0 dB attenuation, for pile installations in winter.

Faunal group	Metric	Threshold	Location ID-97 (7/12 m monopile)					Location ID-259 (7/12 m monopile)					Location ID-200 (jacket foundation pile)					
			Hammer energy (kJ)					Hammer energy (kJ)					Hammer energy (kJ)					
			1000	1500	2000	2500	3200	1000	1500	2000	2500	3200	300	750	1000	2000	3000	4000
Small fish[a]	L_E	183	20.55					19.39					**1 pile**: 30.32; **2 piles**: 39.60; **3 piles**: 46.60; **4 piles**: 52.63;					
	L_{pk}	206	0.16	0.26	0.38	0.44	0.47	0.26	0.34	0.38	0.51	0.57	0.15	0.28	0.36	0.47	0.44	0.40
Large fish[a]	L_E	187	15.35					15.20					**1 pile**: 21.57; **2 piles**: 27.93; **3 piles**: 32.42; **4 piles**: 36.19;					
	L_{pk}	206	0.16	0.26	0.38	0.44	0.47	0.26	0.34	0.38	0.51	0.57	0.15	0.28	0.36	0.47	0.44	0.40
All fish[b]	L_p	150	15.63	18.98	22.74	26.91	31.02	16.06	18.61	22.76	24.10	25.11	9.06	12.61	14.34	17.17	38.64	49.04
Fish without swim bladder[c]	L_E	219	0.75					0.84					**1 pile**: 0.95; **2 piles**: 1.51; **3 piles**: 1.82; **4 piles**: 2.08;					
	L_{pk}	213	0.09	0.12	0.14	0.15	0.17	0.12	0.15	0.17	0.17	0.19	0.06	0.13	0.14	0.16	0.13	0.13
Fish with swim bladder not involved in hearing[c]	L_E	210	2.32					2.67					**1 pile**: 2.79; **2 piles**: 3.77; **3 piles**: 4.34; **4 piles**: 4.78;					
	L_{pk}	207	0.15	0.24	0.29	0.38	0.43	0.18	0.31	0.36	0.38	0.51	0.14	0.26	0.28	0.45	0.42	0.37
Fish with swim bladder involved in hearing[c]	L_E	207	3.05					3.64					**1 pile**: 3.76; **2 piles**: 4.77; **3 piles**: 5.45; **4 piles**: 6.02;					
	L_{pk}	207	0.15	0.24	0.29	0.38	0.43	0.18	0.31	0.36	0.38	0.51	0.14	0.26	0.28	0.45	0.42	0.37
Eggs and larvae[c]	L_E	210	2.32					2.67					**1 pile**: 2.79; **2 piles**: 3.77; **3 piles**: 4.34; **4 piles**: 4.78;					
	L_{pk}	207	0.15	0.24	0.29	0.38	0.43	0.18	0.31	0.36	0.38	0.51	0.14	0.26	0.28	0.45	0.42	0.37

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

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

Table G-31. Summer, 6 dB attenuation: Modelled acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish, corresponding to each hammer energy with 6 dB attenuation, for pile installations in summer.

Faunal group	Metric	Threshold	Location ID-97 (7/12 m monopile)					Location ID-259 (7/12 m monopile)					Location ID-200 (jacket foundation piles)					
			Hammer energy (kJ)					Hammer energy (kJ)					Hammer energy (kJ)					
			1000	1500	2000	2500	3200	1000	1500	2000	2500	3200	300	750	1000	2000	3000	4000
Small fish[a]	L_E	183	10.44					11.52					**1 pile**:13.36; **2 piles**:16.10; **3 piles**:15.88; **4 piles**:17.04;					
	L_{pk}	206	0.10	0.12	0.14	0.16	0.22	0.13	0.16	0.17	0.18	0.29	0.09	0.13	0.14	0.26	0.22	0.18
Large fish[a]	L_E	187	8.04					9.01					**1 pile**:9.94; **2 piles**:12.53; **3 piles**:12.34; **4 piles**:13.38;					
	L_{pk}	206	0.10	0.12	0.14	0.16	0.22	0.13	0.16	0.17	0.18	0.29	0.09	0.13	0.14	0.26	0.22	0.18
All fish[b]	L_p	150	8.45	10.24	11.82	12.62	14.21	9.53	11.55	12.63	13.33	14.47	6.03	7.75	8.50	9.96	15.49	18.95
Fish without swim bladder[c]	L_E	219	0.27					0.31					**1 pile**:0.40; **2 piles**:0.61; **3 piles**:0.58; **4 piles**:0.72;					
	L_{pk}	213	-	0.05	0.08	0.09	0.10	-	0.05	0.09	0.09	0.11	-	0.02	0.06	0.10	0.08	0.06
Fish with swim bladder not involved in hearing[c]	L_E	210	1.12					1.29					**1 pile**:1.47; **2 piles**:2.01; **3 piles**:1.94; **4 piles**:2.28;					
	L_{pk}	207	0.09	0.11	0.14	0.15	0.16	0.12	0.14	0.17	0.17	0.18	0.07	0.12	0.13	0.15	0.13	0.12
Fish with swim bladder involved in hearing[c]	L_E	207	1.60					1.83					**1 pile**:2.0; **2 piles**:2.72; **3 piles**:2.67; **4 piles**:2.97;					
	L_{pk}	207	0.09	0.11	0.14	0.15	0.16	0.12	0.14	0.17	0.17	0.18	0.07	0.12	0.13	0.15	0.13	0.12
Eggs and larvae[c]	L_E	210	1.12					1.29					**1 pile**:1.47; **2 piles**:2.01; **3 piles**:1.94; **4 piles**:2.28;					
	L_{pk}	207	0.09	0.11	0.14	0.15	0.16	0.12	0.14	0.17	0.17	0.18	0.07	0.12	0.13	0.15	0.13	0.12

Small fish are defined as having a total mass of less than 2 g; large fish are defined as having a total mass of greater than or equal to 2 g.
Dashes indicate that the acoustic threshold was not reached.
L_E = unweighted sound exposure level (dB re 1 µPa²·s) over the entire pile (so encompasses all hammer energies); L_p = unweighted sound pressure level (dB re 1 µPa); L_{pk} = unweighted peak sound pressure level (dB re 1 µPa).
[a] FHWG (2008), Stadler and Woodbury (2009).
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011).
[c] Popper et al. (2014).

Table G-32. Winter, 6 dB attenuation: Modelled acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish, corresponding to a 4000 kJ hammer energy with 6 dB attenuation, for pile installations in winter.

Faunal group	Metric	Threshold	Location ID-97 (7/12 m monopile)					Location ID-259 (7/12 m monopile)					Location ID-200 (jacket foundation piles)					
			Hammer energy (kJ)					Hammer energy (kJ)					Hammer energy (kJ)					
			1000	1500	2000	2500	3200	1000	1500	2000	2500	3200	300	750	1000	2000	3000	4000
Small fish[a]	L_E	183	13.29					13.39					**1 pile**:17.81; **2 piles**:23.66; **3 piles**:23.17; **4 piles**:25.72;					
	L_{pk}	206	0.10	0.13	0.15	0.17	0.18	0.13	0.16	0.18	0.19	0.20	0.09	0.13	0.15	0.23	0.21	0.17
Large fish[a]	L_E	187	9.36					10.14					**1 pile**:12.49; **2 piles**:16.42; **3 piles**:16.08; **4 piles**:17.83;					
	L_{pk}	206	0.10	0.13	0.15	0.17	0.18	0.13	0.16	0.18	0.19	0.20	0.09	0.13	0.15	0.23	0.21	0.17
All fish[b]	L_p	150	10.01	13.00	14.68	16.92	19.58	11.09	13.38	14.93	15.90	16.71	6.32	8.46	9.22	11.48	23.77	28.41
Fish without swim bladder[c]	L_E	219	0.27					0.30					**1 pile**:0.40; **2 piles**:0.63; **3 piles**:0.60; **4 piles**:0.74;					
	L_{pk}	213	-	0.03	0.07	0.09	0.10	-	0.04	0.08	0.09	0.11	-	0.02	0.05	0.09	0.09	0.06
Fish with swim bladder not involved in hearing[c]	L_E	210	1.17					1.33					**1 pile**:1.51; **2 piles**:2.08; **3 piles**:2.01; **4 piles**:2.34;					
	L_{pk}	207	0.09	0.12	0.14	0.15	0.17	0.12	0.15	0.17	0.17	0.19	0.06	0.13	0.14	0.16	0.13	0.13
Fish with swim bladder involved in hearing[c]	L_E	207	1.66					1.90					**1 pile**:2.08; **2 piles**:2.79; **3 piles**:2.74; **4 piles**:3.08;					
	L_{pk}	207	0.09	0.12	0.14	0.15	0.17	0.12	0.15	0.17	0.17	0.19	0.06	0.13	0.14	0.16	0.13	0.13
Eggs and larvae[c]	L_E	210	1.17					1.33					**1 pile**:1.51; **2 piles**:2.08; **3 piles**:2.01; **4 piles**:2.34;					
	L_{pk}	207	0.09	0.12	0.14	0.15	0.17	0.12	0.15	0.17	0.17	0.19	0.06	0.13	0.14	0.16	0.13	0.13

Small fish are defined as having a total mass of less than 2 g; large fish are defined as having a total mass of greater than or equal to 2 g.
Dashes indicate that the acoustic threshold was not reached.
L_E = unweighted sound exposure level (dB re 1 µPa²·s) over the entire pile (so encompasses all hammer energies); L_p = unweighted sound pressure level (dB re 1 µPa); L_{pk} = unweighted peak sound pressure level (dB re 1 µPa).
[a] FHWG (2008), Stadler and Woodbury (2009).
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011).
[c] Popper et al. (2014).

Table G-33. Summer, 15 dB attenuation: Modelled acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish, corresponding to a 4000 kJ hammer energy with 15 dB attenuation, for summer installation of single 7/12 m monopiles (ID-97 and ID-259 locations) and 1–4 jacket foundation piles (ID-200 location).

Faunal group	Metric	Threshold	Location ID-97 (7/12 m monopile)					Location ID-259 (7/12 m monopile)					Location ID-200 (jacket foundation piles)					
			Hammer energy (kJ)					Hammer energy (kJ)					Hammer energy (kJ)					
			1000	1500	2000	2500	3200	1000	1000	1500	2000	3200	300	750	1000	1500	2000	4000
Small fish[a]	L_E	183	5.80					6.68					**1 pile**:6.98; **2 piles**:8.65; **3 piles**:9.72; **4 piles**:10.87;					
	L_{pk}	206	-	0.01	0.03	0.06	0.08	-	0.02	0.03	0.05	0.09	-	-	-	0.08	0.06	0.06
Large fish[a]	L_E	187	4.39					5.13					**1 pile**:5.30; **2 piles**:6.50; **3 piles**:7.39; **4 piles**:8.08;					
	L_{pk}	206	-	0.01	0.03	0.06	0.08	-	0.02	0.03	0.05	0.09	-	-	-	0.08	0.06	0.06
All fish[b]	L_p	150	4.70	5.68	6.60	7.10	7.97	5.47	6.49	7.48	7.82	8.51	3.42	4.66	5.23	6.23	8.26	9.95
Fish without swim bladder[c]	L_E	219	0.08					0.09					**1 pile**:0.09; **2 piles**:0.13; **3 piles**:0.17; **4 piles**:0.24;					
	L_{pk}	213	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fish with swim bladder not involved in hearing[c]	L_E	210	0.27					0.31					**1 pile**:0.40; **2 piles**:0.61; **3 piles**:0.80; **4 piles**:0.94;					
	L_{pk}	207	-	-	0.01	0.03	0.06	-	-	0.02	0.03	0.04	-	-	-	0.02	0.06	0.05
Fish with swim bladder involved in hearing[c]	L_E	207	0.45					0.53					**1 pile**:0.61; **2 piles**:0.93; **3 piles**:1.24; **4 piles**:1.48;					
	L_{pk}	207	-	-	0.01	0.03	0.06	-	-	0.02	0.03	0.04	-	-	-	0.02	0.06	0.05
Eggs and larvae[c]	L_E	210	0.27					0.31					**1 pile**:0.40; **2 piles**:0.61; **3 piles**:0.80; **4 piles**:0.94;					
	L_{pk}	207	-	-	0.01	0.03	0.06	-	-	0.02	0.03	0.04	-	-	-	0.02	0.06	0.05

Small fish are defined as having a total mass of less than 2 g; large fish are defined as having a total mass of greater than or equal to 2 g.
Dashes indicate that the acoustic threshold was not reached.
L_E = unweighted sound exposure level (dB re 1 µPa^2·s) over the entire pile (so encompasses all hammer energies); L_p = unweighted sound pressure level (dB re 1 µPa); L_{pk} = unweighted peak sound pressure level (dB re 1 µPa).
[a] FHWG (2008), Stadler and Woodbury (2009).
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011).
[c] Popper et al. (2014).

Table G-34. Winter, 15 dB attenuation: Modelled acoustic radial distances ($R_{95\%}$ in km) to thresholds for fish, corresponding to each hammer energy with 15 dB attenuation, for pile installations in winter.

Faunal group	Metric	Threshold	Location ID-97 (7/12 m monopile)					Location ID-259 (7/12 m monopile)					Location ID-200 (jacket foundation piles)					
			Hammer energy (kJ)					Hammer energy (kJ)					Hammer energy (kJ)					
			1000	1500	2000	2500	3200	1000	1000	1500	2000	3200	300	750	1000	1500	2000	4000
Small fish[a]	L_E	183	6.44					7.28					**1 pile**:7.82; **2 piles**:10.21; **3 piles**:12.23; **4 piles**:13.70;					
	L_{pk}	206	-	0.01	0.03	0.06	0.08	-	0.02	0.03	0.04	0.08	-	-	-	0.06	0.06	0.06
Large fish[a]	L_E	187	4.75					5.46					**1 pile**:5.55; **2 piles**:7.15; **3 piles**:8.35; **4 piles**:9.23;					
	L_{pk}	206	-	0.01	0.03	0.06	0.08	-	0.02	0.03	0.04	0.08	-	-	-	0.06	0.06	0.06
All fish[b]	L_p	150	5.13	6.34	7.43	8.22	9.28	5.84	7.21	8.32	8.63	9.29	3.60	4.89	5.53	6.68	10.15	11.71
Fish without swim bladder[c]	L_E	219	0.08					0.09					**1 pile**:0.09; **2 piles**:0.13; **3 piles**:0.15; **4 piles**:0.23;					
	L_{pk}	213	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fish with swim bladder not involved in hearing[c]	L_E	210	0.27					0.30					**1 pile**:0.40; **2 piles**:0.63; **3 piles**:0.82; **4 piles**:0.96;					
	L_{pk}	207	-	-	0.01	0.03	0.06	-	-	0.02	0.03	0.04	-	-	-	0.02	0.06	0.05
Fish with swim bladder involved in hearing[c]	L_E	207	0.45					0.55					**1 pile**:0.63; **2 piles**:0.96; **3 piles**:1.27; **4 piles**:1.51;					
	L_{pk}	207	-	-	0.01	0.03	0.06	-	-	0.02	0.03	0.04	-	-	-	0.02	0.06	0.05
Eggs and larvae[c]	L_E	210	0.27					0.30					**1 pile**:0.40; **2 piles**:0.63; **3 piles**:0.82; **4 piles**:0.96;					
	L_{pk}	207	-	-	0.01	0.03	0.06	-	-	0.02	0.03	0.04	-	-	-	0.02	0.06	0.05

Small fish are defined as having a total mass of less than 2 g; large fish are defined as having a total mass of greater than or equal to 2 g.
Dashes indicate that the acoustic threshold was not reached.
L_E = unweighted sound exposure level (dB re 1 µPa^2·s) over the entire pile (so encompasses all hammer energies); L_p = unweighted sound pressure level (dB re 1 µPa); L_{pk} = unweighted peak sound pressure level (dB re 1 µPa).
[a] FHWG (2008), Stadler and Woodbury (2009).
[b] Andersson et al. (2007), Wysocki et al. (2007), Mueller-Blenkle et al. (2010), Purser and Radford (2011).
[c] Popper et al. (2014).

Appendix H. ITAP Comparison Results

ITAP GmbH is a German agency accredited for measuring and forecasting sound levels produced during impact pile driving for installations such as wind farms (see Appendix H.1). Sound level predictions were made using ITAP's empirical model (Bellmann et al. 2020a) to forecast single-strike SEL at 750 m from the pile (Appendix H.2). ITAP's empirical forecasting model was created by compiling and fitting numerous measurements at 750 m for a variety of pile dimensions, hammer types and hammer energy levels, and at several locations (though primarily in the North Sea). The ITAP model is based on the 95th percentile of the single-strike SEL measurement. That is, the SEL value used to generate the model was the level inclusive of 95% of the single-strike measurements at a given hammer energy level (the highest 5% of single-strike SEL measurements were discarded). Because the ITAP model forecasts are from aggregated measurements, application to specific pile driving scenarios may be expected to differ to some degree from the forecast.

As a way of validating the acoustic modeling for this study, single-strike SEL received levels at 750 m from the driven pile were determined from the calculated 3-D sound fields (see Appendices D, E, and G) and compared to the ITAP forecast (Table H-1 and Table H-2 for monopiles and jacket foundation piles, respectively). ITAP's model forecasts the 95th percentile of SEL values while the acoustic modeling in this study results in an estimate of a median value (50th percentile), so the levels calculated for this study at 750 m are expected to be lower than the forecasted levels.

For the monopiles, Table H-1 shows that the single-strike SEL levels at 750 m predicted in this study compare well with the ITAP forecast.

In most cases this study's predicted received levels are lower than the ITAP forecast. The largest difference between predicted levels and ITAP levels occurs at the lowest hammer energy level (1000 kJ). At higher hammer energies, the predicted received levels are within a few dB of the ITAP forecasts, and the maximum predicted sound level in the water column is within ~2 dB of the forecasted levels. The increasing sound production with hammer energy of JASCO's model relative to ITAP is likely due to pile penetration depth. When more of the pile has penetrated into the seabed, the pile as a sound source has a larger radiating area in the water and substrate, which produces more sound energy. In this study, lower hammer energy settings were used at the start of pile driving, when little of the pile has penetrated into the substrate. Within the ITAP model, measurements from all hammer energy levels represent a range of pile penetration depths such that measurements of lower hammer energy strikes include piles near full penetration and driven with smaller hammers, which may produce louder sounds. That JASCO's predictions are a few dB less than the ITAP forecasts is expected because, as noted above, ITAP forecasts the 95th percent value while the JASCO models the 50th percentile, the difference is the variation in measurement and is expected to be ~2 dB.

Similar results were found for the jacket foundation piles (Table H-2), JASCO predictions generally increase relative to the ITAP forecasts as a function of hammer energy, but the predicted SEL at the middle of the water column in most cases is within <1 dB from the forecast levels.

Table H-1. Monopile foundation: Broadband single-strike SEL (dB re 1 µPa²·s) comparison of WTG monopile foundation modeled sound field with ITAP (Appendix H.2) at 750 m. Modeled SELs are presented as minimum-maximum SEL over the entire water column. The SEL at the middle of the water column is shown in parenthesis.

Source location, Season	Hammer energy (kJ)					
	1000	1500	2000	2500	3200 kJ	4000
ITAP (12 m)	179	180	181	182	183	184
ID-97, Summer	161.1–174.5 (173.9)	163.8–177.5 (175.7)	165.4–179.0 (178.9)	167.0–180.3 (179.3)	168.6–181.9 (180.9)	169.7–183.3 (182)
ID-259, Summer	161.9–176.5 (173.3)	164.7–178.5 (177.2)	166.0–180.0 (177.3)	167.6–181.3 (177.7)	169.6–183.2 (180.1)	170.6–184.1 (181.4)
ID-97, Winter	161.5–175.1 (173.4)	164.2–178.1 (175.7)	165.8–179.7 (178.3)	167.6–180.2 (179.0)	169.4–182.1 (181.1)	170.4–183.4 (182.2)
ID-259, Winter	162.5–176.3 (173.6)	165.5–178.5 (177.3)	166.6–179.9 (177.5)	168.3–181.5 (178.3)	170.3–183.4 (180.4)	171.3–184.4 (181.7)

Table H-2. Jacket foundation pile: Broadband single-strike SEL (dB re 1 µPa²·s) comparison of WTG jacket foundation pile modeled sound field with ITAP (Appendix H.2) at 750 m. Modeled SEL are presented as minimum-maximum SEL over the entire water column. The SEL at the middle of the water column is shown within parenthesis. The modelled results in this table do not include the 2 dB increase which was applied to other jacket foundation pile results in this report.

Source location, Season	Hammer energy (kJ)					
	300	750	1000	2000	3000	4000
ITAP (4 m)	<170	170–173*	173	175	177	178
ID-200, Summer	158.4–168.7 (166.1)	163.0–173.4 (169.3)	164.9–175.8 (172.3)	168.2–178.8 (175.6)	168.7–177.9 (176.1)	168.5–177.9 (176.1)
ID-200, Winter	159.0–169.1 (166.2)	163.6–174.0 (170.1)	165.7–176.3 (172.4)	168.9–179.1 (175.8)	169.7–178.2 (176.8)	169.5–178.0 (175.6)

* ITAP SEL correspond to 500 kJ and 1000 kJ, respectively. 750 kJ was not calculated for ITAP.

H.1. ITAP Description and Qualifications

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Ørsted Wind Power

INSTITUT FÜR TECHNISCHE UND ANGEWANDTE PHYSIK GMBH

Messstelle nach §29b BImSchG für Geräusche

Oldenburg, August 10th 2020

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Qualification and References of the *itap GmbH*

Dear Mr. Matej Simurda,

as requested, please find below a short description / biography of the *itap GmbH*. In case you need more detailed information, please feel free to contact me.

Short description of the *itap GmbH*

Graduates from the Carl von Ossietzky University of Oldenburg founded the Institute of Technical and Applied Physics (itap) in 1992 (https://www.itap.de/en/). As the demand for technical-scientific services rose, the institute was transferred into an independent limited liability company in 1995.

Meanwhile, the company can look on 25 years business experience, during which new areas of activity opened up constantly. Over time, different physical problems were dealt with; the focus however always was in the field of technical acoustics. To be named hereby in particular: our sustainable activities in the field of immission (pollution) control onshore as well as our pioneering role in the investigation of underwater noise with the aim to protect marine life.

Akkreditiertes Prüflaboratorium nach ISO/IEC 17025:
Ermittlung von Geräuschen und Erschütterungen; Lärm am Arbeitsplatz;
ausgewählte Verfahren zu Geräuschmessungen an Windenergieanlagen; Unterwasserschall; Modul Immissionsschutz

Qualification and certification

The *itap GmbH* is a notified measuring agency in Germany according to §29b BImSchG (Federal Control of Pollution Act) and has an accredited quality management system (QMS) according to the ISO/IEC 17025 for emission and immission (pollution) measurements of sounds and vibrations (accreditation in accordance with the DAkkS – German accreditation body – for measurements and forecasts of underwater noise (impulse and continuous noise), the immission (pollution) protection module sounds and vibrations, as well as noise in the workplace).

Technical references: underwater noise

The itap GmbH was involved in all German Offshore Windfarm (OWF) construction projects since 2008, by predicting the estimated pile-driving noise during construction, consultancy services regarding noise measurements and noise mitigation strategies, as well as measuring ambient and pile-driving noise during the construction phase and operational noise of Offshore Wind Turbine Generators after completion of construction works.

Within a Research and Development (R&D) project the technical information system for underwater noise MarinEARS (Marine Explorer and Registry of Sound https://marinears.bsh.de) was designed in cooperation with the German regulatory authority BSH (Bundesamt für Seeschifffahrt und Hydrographie). All quality checked and post-processed underwater noise measurement data from 2012 till 2020 for German OWF projects within MarinEARS were provided by the *itap GmbH*. The technical field report regarding the experiences with impact pile-driving noise as well as the application of noise mitigation measures of this R&D project is available in German and English version at our homepage: https://www.itap.de/en/news/field-report-pile-driving-noise-published/.

Furthermore, the *itap GmbH* was also involved in OWF construction projects in Belgium, The Netherlands, Denmark, Sweden, United Kingdom and Taiwan, providing underwater noise predictions and consultancy services as well as performing underwater noise measurements.

The *Itap GmbH* has measured underwater noise during use of all available noise mitigation measures (noise mitigation systems as well as noise abatement systems) for offshore constructions worldwide under offshore conditions (offshore reliable and state-of-the-art noise mitigation measures as well as prototypes in accordance to DIN SPEK 45653 (2017)).

Besides the main task domain of underwater noise in connection with OWF construction projects (pile-driving noise), the *itap GmbH* predicts and measures underwater noise of all kinds of maritime activities. Such as for offshore projects like cable or pipe laying activities, cable fault detection, any acoustical surveys (e. g. sonar operations), clearance of unexploded ordnances (UXO), detonations or decommissioning of any offshore constructions, vessel based noise as well as for costal projects (e. g. within harbor facilities).

Services: underwater noise

Consultancy: The *itap GmbH* provides consultancy services related to the full scope of underwater noise predictions and measurements (especially related to Offshore Wind Farms). In recent years, our experience in Europe has expanded and extended beyond Europe to the United States of America, Taiwan and Australia. Due to our pioneering role in this field and the associated 20 years of experience in Europe, we can offer a wide range of consulting services. Such as preparation of noise mitigation concepts, selection of suitable noise mitigation measures, support within approval procedures and contact to local authorities.

Underwater noise prognosis: In recent years, our portfolio of underwater noise prediction services regarding pile driving noise has grown to meet a variety of different local regulatory requirements for various noise mitigation values throughout Europe and Taiwan and to assist the environmental impact assessment by species specific underwater noise modelling like in UK, Australia and the USA. The *itap GmbH* is able to perform underwater noise prognosis for various noise sources regarding impulsiveness and continuous noise according to national guidelines and project-specific requirements of the local approval authorities and respective local environmental conditions.

For underwater noise prognosis we are using our extensive experiences within this domain. Based on this, we have developed two models for underwater noise prediction:

1) Impulsiveness underwater noise model: Our validated pile-driving noise model based on measured values over the last 20 years within more than 35 pcs OWF and more than 30 pcs single foundation projects (empirical approach). With this pile-driving model, mitigated as well as unmitigated pile-driving noise can be predicted (broadband as well as frequency depending).
   This model also contains the empirical approach of Soloway and Dahl (2014) as well as own measured data during UXO clearance activities and detonations.
2) Continuous noise model: *Itap GmbH* also developed a model for continuous noise activities like vessel based construction projects (pipe and cable laying projects as well as operational noise from Offshore Wind Turbine Generator). However, this model will currently be extended to vibro-piling activities based on measured data as well.

Qualification and References

Underwater noise measurements: At the beginning of the underwater noise measurements with regard to OWFs in 2000, there was no measurement device commercially available on the market, so the decision was made to develop an own system. The benefit of our own developed and constructed devices is that we can adapt our measurement devices to a variety of special requirements regarding amplitude and frequency range (from ambient noise till noise during UXO clearance from 20 Hz up to 200 kHz). Furthermore, the mooring systems for our measurement devices are self-constructed and can be adapted to the local environmental conditions easily. During the last 20 years we have been able to gain a lot of experience with different measurements under different environmental conditions.

All measurement devices of *itap GmbH* are fulfilling the requirements of national and international standards (e. g. BSH, 2011; ISO 18406) and the calibration is performed in accordance to ISO/IEC 17025 (2018).

Research and Development: Due the special expertise in the field of technical acoustics the *itap GmbH* has participated in various research projects dealing with underwater noise (https://www.itap.de/en/research-projects/). E. g. in the field of underwater sound propagation, further development of noise mitigation measures and the evaluation of the impact of underwater noise on marine mammals.

itap GMBH Marie-Curie-Str. 8 26129 Oldenburg

Dr. Michael A. Bellmann

CEO

H.2. ITAP Sunrise Offshore Wind Farm Technical Report

Sunrise offshore wind farm technical report

Modeling of underwater noise emissions during pile driving construction work

Oldenburg, October 20th 2021

Version 1

Project Nr. 3741

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Execution: Patrick Remmers, B. Eng.
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Scope of report: 20 pages

Akkreditiertes Prüflaboratorium nach ISO/IEC 17025:
Ermittlung von Erschütterungen und Unterwasserschall

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Table of contents

Revision table

Version	Date	Comment
1	20.10.2021	First Draft

This version replaces all previous versions.

Units:

dB - decibel

kJ - kilojoule

s - second

Metrics:

E - sound exposure

L_{hg} - background noise level

$L_{p,pk}$ - zero-to-peak Sound Pressure Level

$L_{pk,pk}$ - peak-to-peak Sound Pressure Level

SEL - single strike Sound Exposure Level

SEL_{05} - 5 % exceedance Sound Exposure Level

SPL - (energy-) equivalent continuous Sound Pressure Level

SPL_{SS} - single strike (energy) equivalent Sound Pressure Level

T - averaging time

f_g - cut off frequency

n - count

$p(t)$ - time variant sound pressure

$p0$ - reference sound pressure

p_{pk} - maximum sound pressure

Abbreviations:

BSH	Bundesamt für Seeschifffahrt und Hydrographie (engl. Federal Maritime and Hydrographic Agency
itap	Institute for Technical and Applied Physics GmbH
OCW	Ocean Wind
OSS	Offshore Substation
OWF	*cjfshore wind farm*
rms	*root mean square*
WTG	wind turbine generator

1. Summary and assignment of tasks

Ørsted Wind Power A/S is planning the construction and installation of foundations for the US *Sunrise cjfshore Wind Farm* (OWF). The *Sunrise cjfshore Wind Farm* is located approximately 30.4 km south of Martha's Vineyard, Massachusetts, 48.1 km east of Montauk, New York, and 26.8 km from Block Island, Rhode Island. The water depth in the project area is between 50.6 m to 56.6 m. It is intended to install the wind turbine generators (WTG) on monopile foundations of 12 m in diameter and an Offshore substation (OSS) with pin-piles of 4 m in diameter. The installation of the monopiles and pin-piles might require blow energies up to 4,000 kJ.

The installation of foundation structures into the seabed by means of impact pile-driving causes noise levels, which might be harmful for marine mammals and fish (Lucke, et al. 2009). The *itap – Institute for Technical and Applied Physics GmbH* was commissioned to carry out modeling underwater pile-driving noise.

Modeling scenarios, including different blow energies between 500 kJ and 4,000 kJ, were defined to reflect the actual project to the highest extent possible, with the objective to determine expected noise levels in 750 m distance. Modelling included single strike Sound Exposure Levels (SEL) as well as zero-to-peak Sound Pressure Level ($L_{p,pk}$) levels.

Table 1: Calculated level of the sound exposure level (SEL) and the zero-to-peak sound pressure level ($L_{p,pk}$) in and 750 m distance for the 12 m monopile WTG foundations.

Diameter	Blow energy	*SEL* in 750 m distance	$L_{p,pk}$ in 750 m distance
12	500	176	199
12	1,000	179	202
12	1,500	180	203
12	2,000	181	204
12	2,500	182	205
12	3,000	183	206
12	3,500	183	206
12	4,000	184	207

Table 2: Calculated level of the sound exposure level (SEL) and the zero-to-peak sound pressure level ($L_{p,pk}$) in and 750 m distance for the 4 m pin-pile of the OSS foundation.

Diameter	Installation method	Blow energy	*SEL* in 750 m distance	$L_{p,pk}$ in 750 m distance
4	pre piling	500	170	193
4	pre piling	1,000	173	196
4	pre piling	1,500	174	197
4	pre piling	2,000	175	198
4	pre piling	2,500	176	199
4	pre piling	3,000	177	200
4	pre piling	3,500	177	200
4	pre piling	4,000	178	201

Oldenburg, October 20th 2021

P. Remmers

Patrick Remmers, B. Eng.

2. Acoustic basics

In acoustics, the intensity of sounds is generally not described by the measurand sound pressure (or particle velocity), but by the level in dB (decibel) known from the telecommunication engineering. There are different sound levels, however:

- (energy-) equivalent continuous Sound Pressure Level – SPL ,
- single strike Sound Exposure Level – SEL,
- zero-to-peak Sound Pressure Level $L_{p,pk}$.

SPL and SEL can be specified independent of frequency, which means as broadband single values, as well as frequency-resolved, for example, in one-third octave bands (third spectrum).

In the following, the level values mentioned above are briefly described.

(Energy-) equivalent continuous Sound Pressure Level (SPL)

The SPL is the most common measurand in acoustics and is defined as:

$$SPL = 10\ \log_{10}\left(\frac{1}{T}\int_0^T \frac{p(t)^2}{p_0^2}\,\mathrm{d}t\right)\ [\mathrm{dB}]$$

Equation 1

with

$p(t)$ - time-variant sound pressure,
p_0 - reference sound pressure (in underwater sound 1 µPa),
T - averaging time.

Sometimes in literature the label SPL is used for a Sound Pressure Level without time averaging. According to this definition the continuous Sound Pressure Level over an interval is then labeled as SPL_{rms} with the index rms for root mean square. In this report, the terminology according to DIN ISO 18406 (2017) is used and the index rms is omitted, since a definition according to Equation 1 already implies averaging.
In some nations the rms value of the Sound Pressure Level (SPL_{SS}) of each single strike shall be determined. Therefore, the duration of each single strike shall be considered.

Sound Exposure Level (SEL)

For the characterization of pile driving sounds, the SPL solely is an insufficient measure, since it does not only depend on the strength of the pile driving blows, but also on the averaging time and the breaks between the pile driving blows. The sound exposure – E or rather the resulting Sound Exposure Level – SEL is more appropriate. Both values are defined as follows:

$$E = \frac{1}{T_0} \int_{T_1}^{T_2} \frac{p(t)^2}{p_0^2} \, \mathrm{d}t$$

Equation 2

$$SEL = 10 \, \log_{10} \left(\frac{1}{T_0} \int_{T_1}^{T_2} \frac{p(t)^2}{p_0^2} \, \mathrm{d}t \right) \, [\mathrm{dB}]$$

Equation 3

with

T_1 and T_2 - starting and ending time of the averaging (should be determined, so that the sound event is between T_1 and T_2),

T_0 - reference 1 second.

Therefore, the Sound Exposure Level of a sound impulse (pile driving blow) is the (SPL) level of a continuous sound of 1 s duration and the same acoustic energy as the impulse.

The Sound Exposure Level (SEL) and the Sound Pressure Level (SPL) can be converted into each other:

$$SEL = 10 \, \log_{10} \left(10^{\frac{SPL}{10}} - 10^{\frac{L_{hg}}{10}} \right) - 10 \, \log_{10} \left(\frac{nT_0}{T} \right) \, [\mathrm{dB}]$$

Equation 4

with

n - number of sound events, thus the pile driving blows, within the time T,

T_0 - 1 s,

L_{hg} - noise and background level between the single pile driving blows.

Thus, Equation 4 provides the average Sound Exposure Level (SEL) of n sound events (pile driving blows) from just one Sound Pressure Level (SPL) measurement. In case, that the background level between the pile driving blows is significantly minor to the pile driving sound (for instance > 10 dB), it can be calculated with a simplification of Equation 4 and a sufficient degree of accuracy as follows:

$$SEL \approx SPL - 10 \log_{10}\left(\frac{nT_0}{T}\right) \text{ [dB]}$$

Equation 5

Zero-to-peak Sound Pressure Level ($L_{p,\,pk}$)

This parameter is a measure for sound pressure peaks. Compared to Sound Pressure Level (SPL) and Sound Exposure Level (SEL), there is no average determination:

$$L_{p,pk} = 20 \log_{10}\left(\frac{|p_{pk}|}{p_0}\right) \text{ [dB]}$$

Equation 6

with
$|p_{pk}|$ - maximum determined Sound Pressure.

Figure 1 depicts an example. The zero-to-peak Sound Pressure Level ($L_{p,\,pk}$) is always higher than the Sound Exposure Level (SEL). Generally, the difference between $L_{p,\,pk}$ and SEL during pile driving work is 20 dB to 25 dB. Some authors prefer the peak-to-peak value ($L_{pk,}$) instead of $L_{p,pk}$. A visual definition of this parameter is given in Figure 1 but this metric is not defined in the ISO 18405 (2017). This factor does not describe the maximum achieved (absolute) Sound Pressure Level, but the difference between the maximum negative and the maximum positive amplitude of an impulse. This value is maximal 6 dB higher than the zero-to-peak Sound Pressure Level $L_{p,\,pk}$.

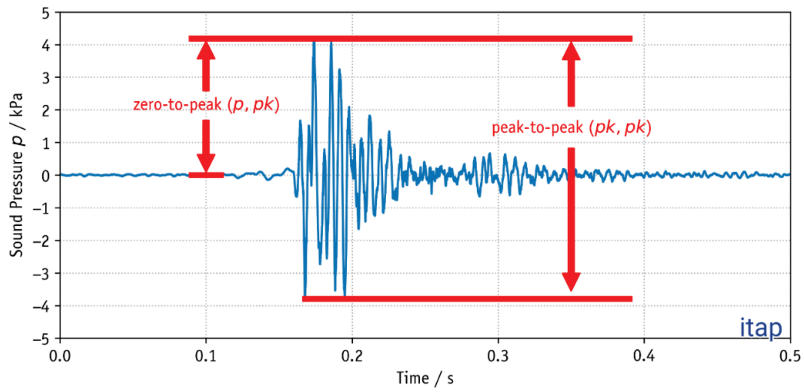

Figure 1: Typical measured time signal cf underwater sound due to pile driving in a distance cf several hundreds cf meters.

3. Model approaches

3.1 Impact of water depth

Sound propagation in the ocean is influenced by water depth. Below a certain cut-off frequency (f_g), a continuous sound propagation is impossible. The shallower the water, the higher this cut-off frequency. The cut-off frequency (f_g) also depends on the type of sediment. The lower limit frequency for predominantly arenaceous soil as a function of water depth is depicted in Figure 2. Moreover, the band widths of the lower cut-off frequency (f_g) at different soil layers, e. g. clay and chalk (till or moraine), are illustrated in grey (Jensen, et al. 2011). Sound around the cut-off frequency (f_g) is reduced or damped to a larger extent with an increasing distance to the sound source.

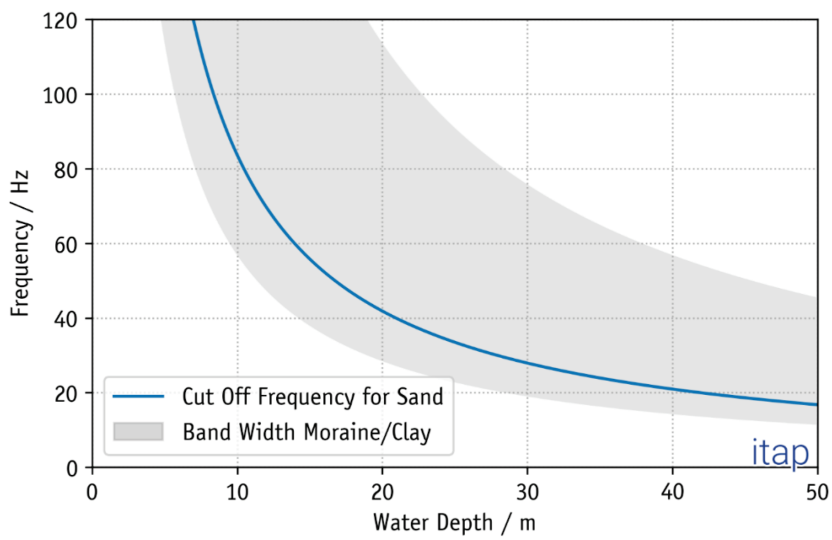

Figure 2: Theoretical lower (limit) frequency (f_g) for an undisturbed sound propagation in water as a function of the water depth for different soil stratifications (example adapted from Urick (1983); Jensen et al., (2011); the example shows the possible range caused by different layers, the layer does not correspond to the layers in the construction field).

3.2 Model description

The (standard-) model of the *itap GmbH* is an empirical model, i. e., it is based on measured Sound Exposure Levels (SEL) and of zero-to-peak Sound Pressure Levels ($L_{p,pk}$) of previous projects. Therefore, this sort of model is an "adaptive" model, which becomes more "precise" with increasing input data.

The emitted sound level depends on many different factors, such as e. g. wall thickness, blow energy, diameter and soil composition (soil resistance) and water depth. But since all parameters mentioned might interact with each other, it is not possible to make exact statements on the impact of a single parameter. In a first step, only one parameter, the "pile diameter", is considered.

Figure 3 shows sound levels measured during pile driving construction works at a number of windfarms plotted over the input parameter "pile diameter". The bigger the sound emitting surface in the water, the bigger the sound entry. This means, the evaluation-relevant level values increase with increasing pile surface, thus the diameter of the pile. It should also be noted that the relationship is not linear.

The model uncertainty is ± 5 dB, just taking into account the input parameter „pile diameter", and is based on the scatter of the actual existing measuring results from Figure 3 that is probably due to further influencing factors, such as e. g. blow energy and reflecting pile skin surface.

Technical note: Over the last years monopile designs occurred with various diameters between the pile bottom and top. For the upcoming underwater noise prognosis only the maximum pile diameter will be considered since this diameter mostly covered the pile design within the full water column and thus reflects the sound emitting pile-surface.

The following comparison between the predicted values and the actually measured level values was covered adequately in any case by the specified model uncertainty (± 5 dB). In most cases, the model slightly overestimated the level value in 750 m distance (not published data). Therefore, an application in the present case is possible from a practical point of view. Therefore, the model is likely to be conservative.

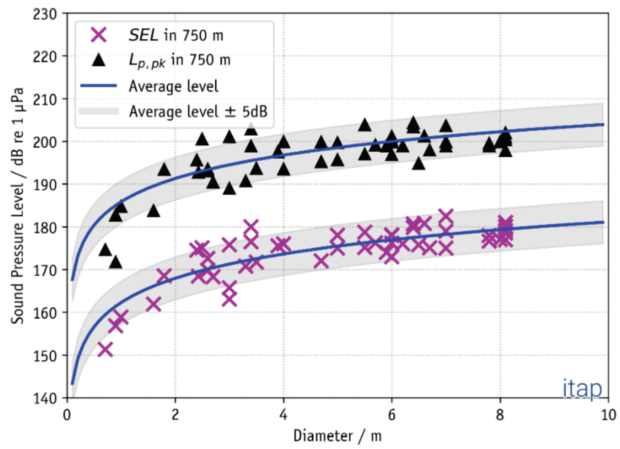

Figure 3: *Measured zero-to-peak Sound Pressure Level ($L_{p,}$) and broad-band 5 % exceedance Sound Exposure Levels (SEL_{05}) at pile driving construction works at a number cf cjfshore wind farms (OWFs) as function cf the pile diameter.*

Moreover, in this model, additions resp. deductions for very high and very low maximum blow energies are used in a second step. Considering the actually applied maximum blow energy resp. the maximum blow energy estimated in the model, normally, differences between the model and the real measuring values of about 2 dB were obtained. In the majority of cases, the model slightly overestimated the level value at a distance of 750 m with the input data "pile diameter" and "maximum blow energy".

Within the scope of a master's thesis at the *itap GmbH*, it was established, that the impact of the blow energy used is on average about 2.5 dB per duplication of blow energy (Gündert, 2014). This finding resulted from investigations at different foundations, at which the variations of the blow energy during pile driving (penetration depth) were statistically compared to corresponding level changes (each from soft-start to maximum blow energy).

Therefore, this additional module for the existing model of the *itap GmbH* is able to predict the evaluation-relevant level values for each single blow with given courses of blow energy. The model uncertainty of this statistic model (*itap GmbH* basic model + extension) is verifiably ± 2 dB; a slight overestimation of this model could be proven as well.

Gündert (2014) shows that the blow energies used and the penetration depth influence the resulting sound pollution significantly with a significant correlation of penetration depth and blow energy used. Considering the influencing factors "pile diameter", "maximum blow energy" and "penetration depth", a model uncertainty of ± 2 dB in the range of measurement

inaccuracy could be achieved. The biggest amount of the measured variances could thus be traced back to the three influencing factors mentioned above.

Since an exact modeling of the blow energy to be applied over the entire penetration depth (per blow) is not possible without further “uncertainties”, additions and deductions for the maximum blow energy are considered.

Based on experiences of the last few years and the findings from the master’s thesis, it can be assumed, that the model uncertainty can be minimized significantly in due consideration of the above mentioned additions and deductions.

3.3 Determination of the source and propagation level

The Sound Exposure Level (SEL) varies in the course of a pile driving and depends on, as mentioned before, several parameters (e. g. reflecting pile skin surface, blow energy, soil conditions, wall thickness, etc.). The applied model just considers the pile diameter as influencing parameter in a first step. To get a statistically valid result of the loudest expected blows, the empirical model for this model is based on the 5 % exceedance of the Sound Exposure Level (SEL_{05}) during one pile installation.

3.3.1 Blow energy

The modelled level values (SEL, and $L_{p,pk}$) increase with growing blow energy. Based on the experiences of previous construction projects, a starting point for the determination of the influence parameter “blow energy” is assumed. Assuming this, additions resp. deductions of 2.5 dB per doubling/halving for higher resp. lower maximum blow energies are estimated in the model.

3.3.2 Hydraulic hammer

Currently, the influence of different hydraulic hammer types is not taken into account, since too many influencing parameters and factors exist, e. g. anvil design, contact area between hammer and pile, pile-gripper or pile-guiding frame. Theoretical studies point out that the influence of different hammer types could be in a range of 0 dB to max. 3 dB. Additionally, no valid empirical data regarding different hammer types currently exist. Therefore, the *itap* model is focusing on the worst case (loudest possible) scenario. In case new and statistically valid results for the influencing factor hammer type will be available within the project duration, these findings will be taken into account.

3.3.3 Ground couplings

The influence of different ground conditions is currently still subject to research. However, it can be assumed, that the used blow energy will also increase with growing soil resistance (SRD-value) of a soil layer. As in the construction field there is a sandy underground mixed with small quartzite cobbles/gravel and the measurement data shown in chapter 3.2 Figure 3 were largely determined on sandy and medium-tight, argillaceous underground, it can be assumed, that the sound emissions to be expected are the same as the regression line shown in Figure 3. For this reason, in the model, a frequency-independent safety margin for the soil conditions (ground coupling) is not necessary.

3.3.4 Spectrum of piling noise

The estimations of the broad-band Sound Exposure Level (SEL)- and zero-to-peak Sound Pressure Level ($L_{p,pk}$)-value shown in chapter 3.2 are based on the broad-band measuring data of different studies (Figure 3). However, sound propagation in the sea is highly frequency-dependent. For this reason, estimations of the frequency composition of the respective source levels[1] have to be made for the calculations.

Figure 4 shows the spectral distribution of the Sound Exposure Levels (SEL), which have been determined during pile driving works at different piles (gray lines). The spectra determined at different distances as well as at different blow energies and pile diameters run similarly. The frequency spectrum shows a maximum within the range 60-250 Hz. At frequencies above approx. 250 Hz the level decrease gradually, while for frequencies lower than approx. 60 Hz, a steep decrease in levels is observed. The cutoff frequency for the steeply fall off at low frequencies depends on water depth. The deeper the water, the lower the cutoff frequency. For the water depths in the project area between 50.6 m and 56.6 m, the cutoff frequency will be within 17 Hz and 15 Hz.

From measurements collected over the last two years, it has become apparent, that the hydraulic hammer type as well as the pile diameter can have an influence on the piling noise spectrum to be expected. By trend, the local maximum shifts in case of larger pile hammer

[1] "Source level" means the Sound Exposure Level (SEL) or zero-to-peak Sound Pressure Level ($L_{p,pk}$) at a fictive distance 750 m to an imagined point sound source.

types and larger pile diameters to lower frequencies. At present, however, these influencing factors cannot be estimated with statistical validity.

In detail, the spectral course of a piling noise event is not exactly predictable according to the present state of knowledge. Thus, for the modeling, an idealized model spectrum for the Sound Exposure Level will be extracted from the measured data of comparable construction projects. Figure 4 shows the shape of this idealized 1/3-octave-spectrum in red color. The frequency-dependent amplitudes are normalized in a way that the sum level of this spectrum in 750 m distance corresponds to the source levels determined before. Since 2016, the model of the *itap GmbH* calculates level values on the measured Sound Exposure Level (5 % percentile level, SEL_{05}) and the measured zero-to-peak Sound Pressure Level ($L_{p,pk}$).

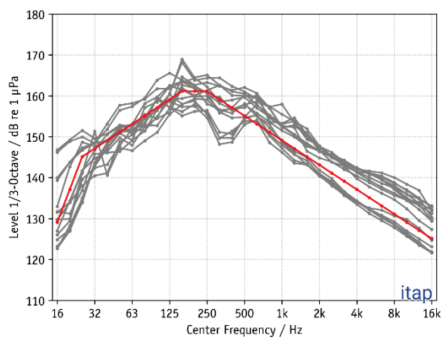

Figure 4: *The model spectrum (red) estimated for piling noise, based on different measuring data (grey: measuring data) for monopiles.*

3.3.5 Water depth

The water depth also influences sound propagation in the sea. Below a certain cut-off frequency, however, a continuous sound propagation is not possible. The shallower the water, the higher this frequency is. Figure 2 in chapter 3.1 shows the cut-off frequencies for an undisturbed sound propagation. For the modeling, all frequencies below this cut-off frequency will decrease with 12 dB/octave. Decisive is the minimum water depth between source and receiver. The water depth in the project area is between 50.6 m and 56.6 m. This results to cut-off frequencies of 17 Hz for 50.6 m and 15 Hz for 56.6 m.

3.3.6 Model requirements

The validated empirical pile-driving model fulfills the national guidelines from regulators in Germany (BSH 2013) and Denmark (Danish Energy Agency 2016) for impact pile-driving predictions including the required outputs. Other international guidelines or standards for underwater pile-driving noise predictions do not exist today. Other nations also do not have fixed guidance for the predictions; typically, the requirements on the predictions will be defined separately for each construction project. This model has already been applied in countries like Germany, Denmark, The Netherlands, United Kingdom, Belgium, France, USA, Australia and Taiwan.

3.4 Determination of SEL at 750 m distance to the source

The *itap* model predicts the Sound Exposure Level (SEL) and the zero-to-peak Sound Pressure Level ($L_{p,pk}$) based on the empirical data base in a specified distance of 750 m to the source in accordance to the requirements of the German measurement guidance (BSH 2011) and the international standard (ISO 18406 2017). The model results depend on the following parameter:

(i) the pile diameter,
(ii) the maximum blow energy (worst-case-scenario) and
(iii) the water depth

3.5 Model uncertainties

Both, the modeling of "source strength" or "source level" of the pile driving noise and the pile driving analysis for the determination of the maximum blow energies includes a certain degree of uncertainty and thereby the derived calculated/predicted level values as well as their impact range.

Measurements from completed construction projects (Bellmann, et al. 2020) with large monopiles show, that the measured SEL at the end of the pile driving sequence stays constant or decreases by up to 25 % despite an increase of the blow energy, i. e., it does not increase. One possible explanatory approach for this is the high penetration depth of the monopiles and the resulting elevated stiffness of the pile to be driven.

Occasionally, however, the Sound Exposure Levels steadily increased until the maximum penetration depth was reached (at simultaneous increase of the blow energy). This is why always the maximum blow energy is applied for all calculations.

By determining the source level just with the input parameter "pile diameter", an uncertainty of +/- 5 dB arises (Figure 3). To reduce the uncertainty assumptions for the second relevant effective parameter "blow energy" are made and additions and deductions are considered based on an initial value.

By considering the effective parameter "blow energy" the uncertainty is clearly reduced. The comparison of the model predictions with real measuring data from 2012 until now shows an uncertainty of ± 2 dB (not published data from different projects) for the Sound Exposure Level in a distance of 750 m to the piling event with the tendency, that the *itap* model results with the input data "pile diameter" and "blow energy" mostly slightly overestimates the metrics SEL and $L_{p,pk}$ in a distance of 750 m.

3.6 Acoustically relevant input data

The following input data will be considered for the model:

Input data for the foundations	
- Foundation types:	monopile and pin-pile
- Pile diameter:	pin-piles: 4 m monopiles: 12 m
- Water depth:	50.6 m to 56.6 m
- Water condition:	good intermixing of the water without a distinct sound velocity profile
- blow energy:	between 500 to 4,000 kJ

Model assumption to calculate the source level:	
- Input parameter #1:	pile diameter
- Input parameter #2:	blow energy: initial value (model internal parameter); 2.5 dB addition or deduction per duplication or halving of blow energy,
- Soil conditions:	no additions
- Broad band shifts and safety margins:	For soil conditions: 0 dB for decreasing pile surface: 0 dB for ground couplings: 0 dB for penetration depth: 0 dB (see possible impact in chapter 3.3.3) total: 0 dB for monopiles and pin-piles
- Water depth:	Cutoff frequency between 15 Hz (56.6 m) and 17 Hz (50.6 m)
- Model version:	1.03

4. Modeling results

For the model, the Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) are calculated separately by an empirical model (Model-Version: 1.03). The presented Sound Exposure Level (SEL) in Table 3 and Table 4 are related to the listed blow energy. This levels represent the sound energy for every single blow by using the stated blow energy. However, pile driving usually requires several thousand blows with different pile driving energies.

Considering the model approaches in chapter 3 the following Sound Exposure Levels (SEL) are expected in 750 m distance to pile-driving (Table 3 and Table 4).

Table 3: Calculated level of the sound exposure level (SEL) and the zero-to-peak sound pressure level ($L_{p,pk}$) in and 750 m distance for the 12 m monopile WTG foundations.

Diameter	Blow energy	SEL in 750 m distance	$L_{p,pk}$ in 750 m distance
12	500	176	199
12	1,000	179	202
12	1,500	180	203
12	2,000	181	204
12	2,500	182	205
12	3,000	183	206
12	3,500	183	206
12	4,000	184	207

Table 4: Calculated level of the sound exposure level (SEL) and the zero-to-peak sound pressure level ($L_{p,pk}$) in and 750 m distance for the 4 m pin-pile of the OSS foundation.

Diameter	Installation method	Blow energy	SEL in 750 m distance	$L_{p,pk}$ in 750 m distance
4	pre piling	500	170	193
4	pre piling	1,000	173	196
4	pre piling	1,500	174	197
4	pre piling	2,000	175	198
4	pre piling	2,500	176	199
4	pre piling	3,000	177	200
4	pre piling	3,500	177	200
4	pre piling	4,000	178	201

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Appendix I. 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. 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).

I.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. A description of parameters relating to travel in these two planes are briefly described below. JASCO maintains species-specific choices of values for the behavioral parameters used in this study. The parameter values are available for limited distribution upon request.

Travel sub-models
Direction–determines an animat's choice of direction in the horizontal plane. Sub-models are available for determining the heading of animats, allowing for movement to range from strongly biased to undirected. A random walk model can be used for behaviors with no directional preference, such as feeding and playing. In a random walk, all bearings are equally likely at each parameter transition time step. A correlated random walk can be used to smooth the changes in bearing by using the current heading as the mean of the distribution from which to draw the next heading. An additional variant of the correlated random walk is available that includes a directional bias for use in situations where animals have a preferred absolute direction, such as migration. A user-defined vector of directional probabilities can also be input to control animat heading. For more detailed discussion of these parameters, see Houser (2006) and Houser and Cross (1999).

- **Travel rate**–defines an animat's rate of travel in the horizontal plane. When combined with vertical speed and dive depth, the dive profile of the animat is produced.

Dive sub-models
- **Ascent rate**–defines an animat's rate of travel in the vertical plane during the ascent portion of a dive.
- **Descent rate**–defines an animat's rate of travel in the vertical plane during the descent portion of a dive.
- **Depth**–defines an animat's maximum dive depth.
- **Bottom following**–determines whether an animat returns to the surface once reaching the ocean floor, or whether it follows the contours of the bathymetry.
- **Reversals**–determines whether multiple vertical excursions occur once an animat reaches the maximum dive depth. This behavior is used to emulate the foraging behavior of some marine mammal species at depth. Reversal-specific ascent and descent rates may be specified.
- **Surface interval**–determines the duration an animat spends at, or near, the surface before diving again.

I.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 from the SRWF (see figures in Appendix I.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 I.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.

I.1.2. Aversion

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. 2017b). As a supplement to this modeling study for comparison purposes only, parameters determining aversion at specified sound levels were implemented for the North Atlantic right whale (NARW), in recognition of its endangered status, and harbor porpoise, a species known to have a strong aversive response to loud sounds.

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.2-1 and H.2-2). 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.2-1 and H.2-2). 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.2-1 and H.2-2), 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 I-1. North Atlantic right whales: Aversion parameters for the animal movement simulation based on Wood et al. (2012) behavioral response criteria.

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

Table I-2. Harbor porpoises: Aversion parameters for the animal movement simulation based on Wood et al. (2012) behavioral response criteria.

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

I.1.3. Simulation Area: Animat Seeding

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.

I.2. Animal Movement Modeling Supplemental Results

I.2.1. Marine Mammal Exposure Estimates

This section contains mean marine mammal exposure estimates for the proposed construction schedules described in Section 1.2.3, assuming 0, 6, 10, 15 and 20 dB of broadband attenuation.

I.2.1.1. Sequential Operations

Table I-3. Construction Schedule 1 (WTG monopile 2 piles per day, OCS-DC jacket 4 pin piles per day): The mean number of marine mammals predicted to receive sound levels above exposure criteria for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	42.49	21.47	12.95	5.89	1.88	0.26	0.08	0.04	0.04	0	83.35	41.82	26.15	14.62	8.08	82.58	47.76	32.26	19.16	11.64
LF	Minke whale (migrating)	38.76	22.54	13.60	4.88	0.72	0.07	<0.01	<0.01	0	0	89.04	56.38	40.48	27.01	17.20	288.23	196.12	150.19	108.26	76.91
LF	Humpback whale	26.65	14.29	9.26	4.40	1.68	0.03	<0.01	0	0	0	50.10	26.86	17.34	10.12	5.41	48.27	28.52	19.61	11.88	7.18
LF	North Atlantic right whale[c]	27.01	14.28	8.08	3.57	0.98	0.09	<0.01	<0.01	<0.01	0	60.02	33.24	22.49	13.19	7.63	63.23	36.03	24.82	15.04	9.02
LF	Sei whale[c] (migrating)	2.73	1.38	0.79	0.39	0.14	0.02	<0.01	<0.01	<0.01	0	6.26	3.31	2.21	1.30	0.69	28.23	18.79	13.66	9.15	6.14
MF	Atlantic white sided dolphin	0	0	0	0	0	0.78	0.06	0	0	0	2654.02	1614.32	1147.75	754.32	464.79	1048.94	647.39	451.05	281.60	167.26
MF	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	14.47	6.33	4.11	2.79	2.15	6.35	3.38	2.25	1.29	0.70
MF	Short-beaked common dolphin	0	0	0	0	0	7.75	0	0	0	0	12332.28	7566.19	5476.86	3556.40	2116.46	5687.93	3111.24	2134.04	1299.11	766.18
MF	Bottlenose dolphin	0	0	0	0	0	0.81	0	0	0	0	1886.95	1236.44	909.27	585.13	351.39	833.04	513.81	368.54	226.07	136.01
MF	Risso's dolphin	0	0	0	0	0	0.01	<0.01	0	0	0	24.44	13.70	9.37	5.81	3.94	9.97	5.73	4.00	2.43	1.48
MF	Long-finned pilot whale	0	0	0	0	0	0.08	0	0	0	0	168.56	104.58	75.52	49.63	31.04	67.08	40.99	29.01	17.91	10.80
MF	Short-finned pilot whale	0	0	0	0	0	0.03	0	0	0	0	117.03	70.77	51.42	32.77	20.80	46.93	28.19	19.76	12.20	6.94
MF	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	8.71	4.96	3.27	1.93	1.13	3.48	1.95	1.29	0.78	0.44
HF	Harbor porpoise	12.58	5.29	2.51	0.39	0	33.21	15.10	6.16	1.87	0.46	1087.98	593.89	387.50	225.81	123.68	9305.83	6106.04	3870.23	2102.26	1201.40
PW	Gray seal	53.58	10.04	3.27	0.64	0.06	0.06	0	0	0	0	3052.48	1457.67	866.10	469.65	245.07	2761.13	1333.86	811.01	433.34	218.48
PW	Harbor seal	145.25	36.31	6.27	0.41	0	6.48	3.09	2.98	1.49	0	3281.64	1654.84	1063.59	609.77	338.87	2711.59	1397.02	884.99	510.77	273.67
PW	Harp seal	132.99	24.02	4.43	0.41	0	1.96	0.23	0	0	0	3545.56	1687.76	1051.55	579.49	310.25	3109.68	1543.23	951.13	509.12	266.35

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

Table I-4. Construction Schedule 2 (WTG monopile 3 piles per day, OCS-DC jacket 4 pin piles per day): The mean number of marine mammals predicted to receive sound levels above exposure criteria for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	42.52	21.50	12.33	6.03	2.16	0.29	0.09	0.06	0.03	0	82.22	43.53	27.19	14.89	8.15	74.78	44.60	30.55	18.71	11.61
	Minke whale (migrating)	39.10	22.16	13.44	5.38	0.81	0.14	<0.01	<0.01	0	0	89.19	56.98	41.62	27.31	17.32	247.84	172.98	134.76	99.18	72.63
	Humpback whale	28.51	15.69	9.88	4.87	2.13	0.11	0.02	0.02	0.02	0	52.10	29.59	19.72	11.53	6.55	46.74	28.50	20.10	12.60	7.86
	North Atlantic right whale[c]	27.94	14.93	8.84	4.09	1.24	0.16	0.02	<0.01	<0.01	0	58.05	34.25	23.85	14.69	8.46	51.94	31.80	22.71	14.68	9.23
	Sei whale[c] (migrating)	2.99	1.54	0.92	0.47	0.16	0.03	<0.01	<0.01	<0.01	0	6.85	3.77	2.50	1.44	0.85	25.55	17.42	12.99	8.93	6.16
MF	Atlantic white sided dolphin	0	0	0	0	0	0.09	0.06	0	0	0	2622.47	1643.71	1193.26	779.26	490.68	1036.58	644.54	459.53	291.79	173.10
	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	13.78	5.80	3.59	2.39	1.60	5.93	3.15	1.96	1.07	0.57
	Short-beaked common dolphin	0	0	0	0	0	5.84	0	0	0	0	13043.16	8020.40	5783.17	3743.92	2321.93	6041.65	3339.67	2303.89	1408.87	836.75
	Bottlenose dolphin	0	0	0	0	0	0.03	0	0	0	0	1844.08	1193.98	877.58	576.48	357.59	791.31	499.49	355.61	229.06	133.70
	Risso's dolphin	0	0	0	0	0	0.03	<0.01	0	0	0	26.00	15.22	10.72	6.90	4.26	10.45	6.31	4.32	2.71	1.64
	Long-finned pilot whale	0	0	0	0	0	0.03	0	0	0	0	160.37	103.55	75.53	49.59	31.00	63.89	39.65	28.33	17.83	10.82
	Short-finned pilot whale	0	0	0	0	0	0	0	0	0	0	113.80	71.26	50.66	31.55	19.80	44.69	26.95	19.06	11.95	7.02
	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	8.74	5.16	3.52	2.13	1.25	3.44	1.99	1.36	0.82	0.48
HF	Harbor porpoise	12.47	5.29	2.51	0.39	0	36.90	17.43	5.44	1.67	0.65	1048.97	594.04	398.97	242.37	148.15	5477.85	3678.23	2582.84	1631.82	1045.42
PW	Gray seal	48.23	11.08	4.24	0.64	0.06	1.04	0	0	0	0	3256.63	1616.21	962.81	510.38	252.76	2779.46	1372.60	855.07	465.86	233.82
	Harbor seal	152.69	33.27	6.79	0.41	0	6.62	2.19	2.07	1.04	0	3389.64	1802.23	1165.92	675.46	373.94	2753.81	1431.62	931.54	537.71	300.55
	Harp seal	135.47	21.72	6.39	0.41	0	2.64	0.23	0	0	0	3682.07	1890.51	1170.10	656.33	333.56	3127.83	1591.47	1000.65	548.73	288.90

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

I.2.1.2. Concurrent Operations

Table I-5. Construction Schedule 3 (proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): The mean number of marine mammals predicted to receive sound levels above exposure criteria for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	38.33	20.67	13.18	7.17	2.91	0.26	0.05	0.04	0.04	0	64.44	36.03	23.19	13.59	8.21	61.79	37.08	25.78	15.85	9.84
	Minke whale (migrating)	33.41	21.73	15.02	6.87	1.08	0.11	0.02	0.02	0.01	0	67.99	44.27	33.13	23.45	16.31	205.46	144.83	111.67	80.25	58.38
	Humpback whale	25.31	14.95	9.91	5.41	2.17	0.11	0.01	0.01	0.01	0	42.59	24.61	16.62	9.89	5.88	39.99	24.21	17.12	10.63	6.65
	North Atlantic right whale[c]	23.35	13.83	9.53	5.26	1.75	0.11	0.02	<0.01	<0.01	0	44.29	26.90	19.10	12.76	8.54	39.81	24.99	17.97	11.93	7.89
	Sei whale[c] (migrating)	2.84	1.51	0.98	0.56	0.21	0.03	<0.01	<0.01	<0.01	0	5.80	3.30	2.19	1.31	0.81	23.05	15.87	11.91	7.93	5.44
MF	Atlantic white sided dolphin	0	0	0	0	0	0.45	0.06	0	0	0	2005.98	1279.19	938.54	654.69	445.07	825.38	526.47	383.61	247.00	148.26
	Atlantic spotted dolphin	0	0	0	0	0	<0.01	0	0	0	0	17.19	10.51	7.99	6.13	4.76	7.94	4.87	3.59	2.42	1.40
	Short-beaked common dolphin	0	0	0	0	0	6.09	0	0	0	0	10349.03	6540.18	4812.63	3357.23	2312.68	5293.02	2848.54	1992.26	1299.65	762.09
	Bottlenose dolphin	0	0	0	0	0	0.43	0	0	0	0	1425.96	984.52	750.74	534.18	359.52	642.33	421.70	312.43	202.93	118.73
	Risso's dolphin	0	0	0	0	0	0.01	<0.01	0	0	0	21.14	12.29	8.61	5.86	4.05	8.78	5.28	3.77	2.36	1.46
	Long-finned pilot whale	0	0	0	0	0	0.02	0	0	0	0	125.30	80.59	59.23	41.81	28.47	51.52	32.84	24.11	15.41	9.31
	Short-finned pilot whale	0	0	0	0	0	0.05	0	0	0	0	88.84	56.39	41.44	28.48	19.34	36.53	22.61	16.58	10.63	6.10
	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	7.06	4.10	2.80	1.75	1.12	2.81	1.62	1.13	0.68	0.39
HF	Harbor porpoise	12.75	5.29	2.51	0.39	0	43.51	20.72	5.21	1.57	0.27	818.06	488.38	334.86	214.03	139.42	3795.41	2470.07	1824.18	1227.39	786.53
PW	Gray seal	64.46	10.15	3.27	0.64	0.06	0.06	0	0	0	0	2450.97	1277.65	762.94	391.98	242.71	2682.97	1161.56	674.62	357.88	195.54
	Harbor seal	204.25	39.30	5.58	0.41	0	7.45	0.98	0.86	0.06	0	2674.70	1496.94	1000.14	623.45	384.50	2612.71	1231.06	773.76	458.45	266.60
	Harp seal	185.85	37.17	5.18	0.41	0	4.99	0.23	0	0	0	2963.72	1505.24	915.75	535.32	347.91	3037.19	1341.44	813.71	455.80	250.56

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

Table I-6. Construction Schedule 4 (distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): The mean number of marine mammals predicted to receive sound levels above exposure criteria for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	42.58	21.09	12.90	6.82	2.81	0.25	0.07	0.06	0.02	0	84.72	42.16	25.92	14.62	8.52	74.28	43.73	30.68	19.24	11.96
	Minke whale (migrating)	39.85	22.83	13.66	5.35	0.78	0.15	0.03	0.02	0.01	0	88.91	57.22	41.91	27.86	17.58	228.73	164.04	129.35	96.32	70.56
	Humpback whale	28.66	14.79	8.94	4.08	1.47	0.10	0.01	0.01	0.01	0	56.36	28.82	18.37	9.89	5.35	47.95	28.41	20.13	12.61	7.76
	North Atlantic right whale[c]	29.10	15.58	9.47	4.58	1.34	0.13	0.04	0.01	<0.01	0	60.90	36.10	24.84	15.31	9.38	49.95	31.65	23.00	15.29	9.85
	Sei whale[c] (migrating)	3.20	1.60	0.98	0.50	0.19	0.03	<0.01	<0.01	<0.01	0	7.52	4.01	2.58	1.48	0.88	25.44	17.77	13.53	9.42	6.52
MF	Atlantic white sided dolphin	0	0	0	0	0	0.09	0.06	0	0	0	2626.97	1640.52	1195.27	772.09	475.43	1025.14	641.82	456.86	287.30	171.74
	Atlantic spotted dolphin	0	0	0	0	0	<0.01	0	0	0	0	18.29	10.03	7.70	5.98	4.71	8.51	5.22	3.68	2.37	1.38
	Short-beaked common dolphin	0	0	0	0	0	2.14	0	0	0	0	13601.89	8524.81	6136.16	4042.04	2526.03	6263.60	3506.74	2450.03	1499.30	872.19
	Bottlenose dolphin	0	0	0	0	0	0.03	0	0	0	0	1878.73	1206.88	886.89	576.88	352.27	785.17	498.76	359.08	227.66	131.86
	Risso's dolphin	0	0	0	0	0	0.01	<0.01	0	0	0	28.96	16.28	11.21	7.28	4.61	10.99	6.77	4.75	2.87	1.73
	Long-finned pilot whale	0	0	0	0	0	0.04	0	0	0	0	163.84	103.08	73.39	48.21	30.01	62.13	39.56	28.47	17.88	10.54
	Short-finned pilot whale	0	0	0	0	0	0.05	0	0	0	0	117.35	71.83	51.92	33.00	20.61	44.64	27.79	19.92	12.22	7.08
	Sperm whale[c]	0	0	0	0	0	<0.01	0	0	0	0	9.23	5.04	3.32	2.00	1.17	3.42	2.04	1.36	0.78	0.45
HF	Harbor porpoise	12.02	5.29	2.51	0.39	0	38.10	16.78	5.21	1.57	0.27	1087.04	615.85	402.53	246.27	145.82	4169.55	2847.92	2158.17	1508.34	1028.09
PW	Gray seal	70.41	9.40	4.01	0.64	0.06	0.06	0	0	0	0	3653.41	1669.54	936.95	482.70	233.05	3065.71	1460.49	917.04	504.15	252.57
	Harbor seal	148.48	29.63	6.33	0.41	0	9.68	0.98	0.86	0.06	0	3669.66	1853.14	1183.08	685.17	389.70	2990.10	1504.71	996.11	585.68	306.76
	Harp seal	146.44	36.42	6.66	0.41	0	6.47	0.23	0	0	0	4165.41	1927.62	1156.68	634.22	350.14	3434.96	1666.85	1075.91	602.37	307.60

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

Table I-7. Construction Schedule 5 (proximal assumptions for concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day), and remaining WTG foundations): The mean number of marine mammals predicted to receive sound levels above exposure criteria for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

	Species	Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	41.48	21.10	12.81	5.94	1.98	0.25	0.07	0.04	0.04	0	80.86	40.87	25.75	14.57	8.15	80.14	46.44	31.45	18.73	11.42
	Minke whale (migrating)	37.98	22.18	13.49	4.95	0.79	0.07	<0.01	<0.01	0	0	86.85	55.14	39.70	26.61	17.05	280.41	190.83	146.23	105.48	75.03
	Humpback whale	26.42	14.29	9.30	4.46	1.77	0.04	<0.01	0	0	0	49.45	26.62	17.34	10.20	5.53	47.63	28.17	19.43	11.81	7.17
	North Atlantic right whale[c]	26.29	14.04	8.03	3.58	1.02	0.08	<0.01	<0.01	<0.01	0	57.90	32.36	22.09	13.11	7.63	59.87	34.46	23.88	14.59	8.82
	Sei whale[c] (migrating)	2.74	1.39	0.80	0.40	0.15	0.02	<0.01	<0.01	<0.01	0	6.23	3.32	2.23	1.32	0.71	28.03	18.66	13.57	9.10	6.12
MF	Atlantic white sided dolphin	0	0	0	0	0	0.82	0.03	0	0	0	2582.91	1575.69	1121.25	740.21	459.87	1021.83	631.06	441.01	276.51	164.18
	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	14.24	6.30	4.02	2.71	2.09	6.25	3.29	2.21	1.27	0.70
	Short-beaked common dolphin	0	0	0	0	0	7.20	0	0	0	0	12264.50	7522.43	5455.89	3551.61	2133.15	5698.18	3098.73	2125.58	1295.53	765.47
	Bottlenose dolphin	0	0	0	0	0	0.82	0.03	0	0	0	1835.58	1207.41	892.17	577.83	349.52	811.28	501.75	360.88	222.09	133.58
	Risso's dolphin	0	0	0	0	0	0.01	0	0	0	0	24.21	13.63	9.36	5.83	3.97	9.89	5.70	3.98	2.43	1.49
	Long-finned pilot whale	0	0	0	0	0	0.08	0	0	0	0	163.00	101.38	73.37	48.40	30.57	64.91	39.71	28.19	17.48	10.52
	Short-finned pilot whale	0	0	0	0	0	0.03	0	0	0	0	113.16	68.65	49.99	31.99	20.47	45.48	27.34	19.20	11.90	6.81
	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	8.51	4.86	3.22	1.92	1.12	3.40	1.91	1.27	0.77	0.44
HF	Harbor porpoise	12.43	5.35	2.57	0.44	0	33.97	15.48	6.66	2.00	0.45	1049.65	579.81	380.34	223.88	123.40	8424.91	5524.76	3547.74	1967.14	1139.24
PW	Gray seal	54.93	11.05	3.56	1.05	0	0.12	0	0	0	0	3023.92	1450.28	868.07	473.45	250.80	2771.34	1334.29	808.81	431.46	217.59
	Harbor seal	147.47	38.04	6.86	0.29	0	6.23	2.94	2.94	1.44	0	3238.55	1632.79	1054.69	606.33	339.74	2710.37	1391.49	878.30	505.88	270.70
	Harp seal	133.93	25.50	5.13	0.41	0	2.61	0.29	0.06	0.06	0	3497.59	1663.95	1041.60	580.22	311.69	3114.07	1536.54	947.53	504.99	264.13

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

I.2.2. Potential Impacts Relative to Species' Abundance

This section contains marine mammal exposures as a percentage of abundance for the proposed construction schedules described in Section 1.2.3, assuming 0, 6, 10, 15, and 20 dB of broadband attenuation.

I.2.2.1. Sequential Operations

Table I-8. Construction Schedule 1 (WTG monopile 2 piles per day, OCS-DC jacket 4 pin piles per day): Marine mammal exposures as a percentage of abundance for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	0.62	0.32	0.19	0.09	0.03	<0.01	<0.01	<0.01	<0.01	0	1.23	0.61	0.38	0.21	0.12	1.21	0.70	0.47	0.28	0.17
	Minke whale (migrating)	0.18	0.10	0.06	0.02	<0.01	<0.01	<0.01	<0.01	0	0	0.41	0.26	0.18	0.12	0.08	1.31	0.89	0.68	0.49	0.35
	Humpback whale	1.91	1.02	0.66	0.32	0.12	<0.01	<0.01	0	0	0	3.59	1.92	1.24	0.73	0.39	3.46	2.04	1.40	0.85	0.51
	North Atlantic right whale[c]	7.34	3.88	2.20	0.97	0.27	0.02	<0.01	<0.01	<0.01	0	16.31	9.03	6.11	3.58	2.07	17.18	9.79	6.74	4.09	2.45
	Sei whale[c] (migrating)	0.04	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0	0.10	0.05	0.04	0.02	0.01	0.45	0.30	0.22	0.15	0.10
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	2.85	1.73	1.23	0.81	0.50	1.13	0.69	0.48	0.30	0.18
	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	0.04	0.02	0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01
	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	7.13	4.37	3.17	2.06	1.22	3.29	1.80	1.23	0.75	0.44
	Bottlenose dolphin	0	0	0	0	0	<0.01	0	0	0	0	3.00	1.97	1.45	0.93	0.56	1.33	0.82	0.59	0.36	0.22
	Risso's dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	0.07	0.04	0.03	0.02	0.01	0.03	0.02	0.01	<0.01	<0.01
	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	0.43	0.27	0.19	0.13	0.08	0.17	0.10	0.07	0.05	0.03
	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	0.40	0.24	0.18	0.11	0.07	0.16	0.10	0.07	0.04	0.02
	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	0.20	0.11	0.08	0.04	0.03	0.08	0.04	0.03	0.02	0.01
HF	Harbor porpoise	0.01	<0.01	<0.01	<0.01	0	0.03	0.02	<0.01	<0.01	<0.01	1.14	0.62	0.41	0.24	0.13	9.74	6.39	4.05	2.20	1.26
PW	Gray seal	0.20	0.04	0.01	<0.01	<0.01	<0.01	0	0	0	0	11.18	5.34	3.17	1.72	0.90	10.11	4.89	2.97	1.59	0.80
	Harbor seal	0.24	0.06	0.01	<0.01	0	0.01	<0.01	<0.01	<0.01	0	5.35	2.70	1.73	0.99	0.55	4.42	2.28	1.44	0.83	0.45
	Harp seal	<0.01	<0.01	<0.01	<0.01	0	<0.01	<0.01	0	0	0	0.05	0.02	0.01	<0.01	<0.01	0.04	0.02	0.01	<0.01	<0.01

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

Table I-9. Construction Schedule 2 (WTG monopile 3 piles per day, OCS-DC jacket 4 pin piles per day): Marine mammal exposures as a percentage of abundance for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

	Species	Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	0.63	0.32	0.18	0.09	0.03	<0.01	<0.01	<0.01	<0.01	0	1.21	0.64	0.40	0.22	0.12	1.10	0.66	0.45	0.28	0.17
	Minke whale (migrating)	0.18	0.10	0.06	0.02	<0.01	<0.01	<0.01	<0.01	0	0	0.41	0.26	0.19	0.12	0.08	1.13	0.79	0.61	0.45	0.33
	Humpback whale	2.04	1.12	0.71	0.35	0.15	<0.01	<0.01	<0.01	<0.01	0	3.73	2.12	1.41	0.83	0.47	3.35	2.04	1.44	0.90	0.56
	North Atlantic right whale[c]	7.59	4.06	2.40	1.11	0.34	0.04	<0.01	<0.01	<0.01	0	15.78	9.31	6.48	3.99	2.30	14.11	8.64	6.17	3.99	2.51
	Sei whale[c] (migrating)	0.05	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0	0.11	0.06	0.04	0.02	0.01	0.41	0.28	0.21	0.14	0.10
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	2.81	1.76	1.28	0.84	0.53	1.11	0.69	0.49	0.31	0.19
	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	0.03	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	7.54	4.64	3.34	2.16	1.34	3.49	1.93	1.33	0.81	0.48
	Bottlenose dolphin	0	0	0	0	0	<0.01	0	0	0	0	2.93	1.90	1.40	0.92	0.57	1.26	0.79	0.57	0.36	0.21
	Risso's dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	0.07	0.04	0.03	0.02	0.01	0.03	0.02	0.01	<0.01	<0.01
	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	0.41	0.26	0.19	0.13	0.08	0.16	0.10	0.07	0.05	0.03
	Short-finned pilot whale	0	0	0	0	0	0	0	0	0	0	0.39	0.25	0.18	0.11	0.07	0.15	0.09	0.07	0.04	0.02
	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	0.20	0.12	0.08	0.05	0.03	0.08	0.05	0.03	0.02	0.01
HF	Harbor porpoise	0.01	<0.01	<0.01	<0.01	0	0.04	0.02	<0.01	<0.01	<0.01	1.10	0.62	0.42	0.25	0.16	5.73	3.85	2.70	1.71	1.09
PW	Gray seal	0.18	0.04	0.02	<0.01	<0.01	<0.01	0	0	0	0	11.93	5.92	3.53	1.87	0.93	10.18	5.03	3.13	1.71	0.86
	Harbor seal	0.25	0.05	0.01	<0.01	0	0.01	<0.01	<0.01	<0.01	0	5.53	2.94	1.90	1.10	0.61	4.49	2.33	1.52	0.88	0.49
	Harp seal	<0.01	<0.01	<0.01	<0.01	0	<0.01	<0.01	0	0	0	0.05	0.02	0.02	<0.01	<0.01	0.04	0.02	0.01	<0.01	<0.01

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

I.2.2.2. Concurrent Operations

Table I-10. Construction Schedule 3 (proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): Marine mammal exposures as a percentage of abundance for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	0.56	0.30	0.19	0.11	0.04	<0.01	<0.01	<0.01	<0.01	0	0.95	0.53	0.34	0.20	0.12	0.91	0.55	0.38	0.23	0.14
	Minke whale (migrating)	0.15	0.10	0.07	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	0	0.31	0.20	0.15	0.11	0.07	0.94	0.66	0.51	0.37	0.27
	Humpback whale	1.81	1.07	0.71	0.39	0.16	<0.01	<0.01	<0.01	<0.01	0	3.05	1.76	1.19	0.71	0.42	2.86	1.73	1.23	0.76	0.48
	North Atlantic right whale[c]	6.35	3.76	2.59	1.43	0.48	0.03	<0.01	<0.01	<0.01	0	12.04	7.31	5.19	3.47	2.32	10.82	6.79	4.88	3.24	2.14
	Sei whale[c] (migrating)	0.05	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0	0.09	0.05	0.03	0.02	0.01	0.37	0.25	0.19	0.13	0.09
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	2.15	1.37	1.01	0.70	0.48	0.89	0.56	0.41	0.26	0.16
	Atlantic spotted dolphin	0	0	0	0	0	<0.01	0	0	0	0	0.04	0.03	0.02	0.02	0.01	0.02	0.01	<0.01	<0.01	<0.01
	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	5.98	3.78	2.78	1.94	1.34	3.06	1.65	1.15	0.75	0.44
	Bottlenose dolphin	0	0	0	0	0	<0.01	0	0	0	0	2.27	1.57	1.19	0.85	0.57	1.02	0.67	0.50	0.32	0.19
	Risso's dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	0.06	0.03	0.02	0.02	0.01	0.02	0.01	0.01	<0.01	<0.01
	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	0.32	0.21	0.15	0.11	0.07	0.13	0.08	0.06	0.04	0.02
	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	0.31	0.19	0.14	0.10	0.07	0.13	0.08	0.06	0.04	0.02
	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	0.16	0.09	0.06	0.04	0.03	0.06	0.04	0.03	0.02	<0.01
HF	Harbor porpoise	0.01	<0.01	<0.01	<0.01	0	0.05	0.02	<0.01	<0.01	<0.01	0.86	0.51	0.35	0.22	0.15	3.97	2.59	1.91	1.28	0.82
PW	Gray seal	0.24	0.04	0.01	<0.01	<0.01	<0.01	0	0	0	0	8.98	4.68	2.79	1.44	0.89	9.83	4.25	2.47	1.31	0.72
	Harbor seal	0.33	0.06	<0.01	<0.01	0	0.01	<0.01	<0.01	<0.01	0	4.36	2.44	1.63	1.02	0.63	4.26	2.01	1.26	0.75	0.43
	Harp seal	<0.01	<0.01	<0.01	<0.01	0	<0.01	<0.01	0	0	0	0.04	0.02	0.01	<0.01	<0.01	0.04	0.02	0.01	<0.01	<0.01

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

Table I-11. Construction Schedule 4 (distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): Marine mammal exposures as a percentage of abundance for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

	Species	Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	0.63	0.31	0.19	0.10	0.04	<0.01	<0.01	<0.01	<0.01	0	1.25	0.62	0.38	0.21	0.13	1.09	0.64	0.45	0.28	0.18
LF	Minke whale (migrating)	0.18	0.10	0.06	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0	0.40	0.26	0.19	0.13	0.08	1.04	0.75	0.59	0.44	0.32
LF	Humpback whale	2.05	1.06	0.64	0.29	0.11	<0.01	<0.01	<0.01	<0.01	0	4.04	2.06	1.32	0.71	0.38	3.43	2.04	1.44	0.90	0.56
LF	North Atlantic right whale[c]	7.91	4.23	2.57	1.25	0.36	0.04	0.01	<0.01	<0.01	0	16.55	9.81	6.75	4.16	2.55	13.57	8.60	6.25	4.16	2.68
LF	Sei whale[c] (migrating)	0.05	0.03	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0	0.12	0.06	0.04	0.02	0.01	0.40	0.28	0.22	0.15	0.10
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	2.82	1.76	1.28	0.83	0.51	1.10	0.69	0.49	0.31	0.18
MF	Atlantic spotted dolphin	0	0	0	0	0	<0.01	0	0	0	0	0.05	0.03	0.02	0.01	0.01	0.02	0.01	<0.01	<0.01	<0.01
MF	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	7.86	4.93	3.55	2.34	1.46	3.62	2.03	1.42	0.87	0.50
MF	Bottlenose dolphin	0	0	0	0	0	<0.01	0	0	0	0	2.99	1.92	1.41	0.92	0.56	1.25	0.79	0.57	0.36	0.21
MF	Risso's dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	0.08	0.05	0.03	0.02	0.01	0.03	0.02	0.01	<0.01	<0.01
MF	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	0.42	0.26	0.19	0.12	0.08	0.16	0.10	0.07	0.05	0.03
MF	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	0.41	0.25	0.18	0.11	0.07	0.15	0.10	0.07	0.04	0.02
MF	Sperm whale[c]	0	0	0	0	0	<0.01	0	0	0	0	0.21	0.12	0.08	0.05	0.03	0.08	0.05	0.03	0.02	0.01
HF	Harbor porpoise	0.01	<0.01	<0.01	<0.01	0	0.04	0.02	<0.01	<0.01	<0.01	1.14	0.64	0.42	0.26	0.15	4.36	2.98	2.26	1.58	1.08
PW	Gray seal	0.26	0.03	0.01	<0.01	<0.01	<0.01	0	0	0	0	13.38	6.12	3.43	1.77	0.85	11.23	5.35	3.36	1.85	0.93
PW	Harbor seal	0.24	0.05	0.01	<0.01	0	0.02	<0.01	<0.01	<0.01	0	5.98	3.02	1.93	1.12	0.64	4.87	2.45	1.62	0.95	0.50
PW	Harp seal	<0.01	<0.01	<0.01	<0.01	0	<0.01	<0.01	0	0	0	0.05	0.03	0.02	<0.01	<0.01	0.05	0.02	0.01	<0.01	<0.01

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

Table I-12. Construction Schedule 5 (proximal assumptions for concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day), and remaining WTG foundations): Marine mammal exposures as a percentage of abundance for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	0.61	0.31	0.19	0.09	0.03	<0.01	<0.01	<0.01	<0.01	0	1.19	0.60	0.38	0.21	0.12	1.18	0.68	0.46	0.28	0.17
	Minke whale (migrating)	0.17	0.10	0.06	0.02	<0.01	<0.01	<0.01	<0.01	0	0	0.40	0.25	0.18	0.12	0.08	1.28	0.87	0.67	0.48	0.34
	Humpback whale	1.89	1.02	0.67	0.32	0.13	<0.01	<0.01	0	0	0	3.54	1.91	1.24	0.73	0.40	3.41	2.02	1.39	0.85	0.51
	North Atlantic right whale[c]	7.14	3.82	2.18	0.97	0.28	0.02	<0.01	<0.01	<0.01	0	15.73	8.79	6.00	3.56	2.07	16.27	9.36	6.49	3.97	2.40
	Sei whale[c] (migrating)	0.04	0.02	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0	0.10	0.05	0.04	0.02	0.01	0.45	0.30	0.22	0.14	0.10
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	2.77	1.69	1.20	0.79	0.49	1.10	0.68	0.47	0.30	0.18
	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	0.04	0.02	0.01	0.01	0.01	0.02	0.01	0.01	<0.01	<0.01
	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	7.09	4.35	3.15	2.05	1.23	3.29	1.79	1.23	0.75	0.44
	Bottlenose dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	2.92	1.92	1.42	0.92	0.56	1.29	0.80	0.57	0.35	0.21
	Risso's dolphin	0	0	0	0	0	<0.01	0	0	0	0	0.07	0.04	0.03	0.02	0.01	0.03	0.02	0.01	0.01	<0.01
	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	0.42	0.26	0.19	0.12	0.08	0.17	0.10	0.07	0.04	0.03
	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	0.39	0.24	0.17	0.11	0.07	0.16	0.09	0.07	0.04	0.02
	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	0.20	0.11	0.07	0.04	0.03	0.08	0.04	0.03	0.02	0.01
HF	Harbor porpoise	0.01	0.01	<0.01	<0.01	0	0.04	0.02	0.01	<0.01	<0.01	1.10	0.61	0.40	0.23	0.13	8.82	5.78	3.71	2.06	1.19
PW	Gray seal	0.20	0.04	0.01	<0.01	0	<0.01	0	0	0	0	11.08	5.31	3.18	1.73	0.92	10.15	4.89	2.96	1.58	0.80
	Harbor seal	0.24	0.06	0.01	<0.01	0	0.01	<0.01	<0.01	<0.01	0	5.28	2.66	1.72	0.99	0.55	4.42	2.27	1.43	0.82	0.44
	Harp seal	<0.01	<0.01	<0.01	<0.01	0	<0.01	<0.01	<0.01	<0.01	0	0.05	0.02	0.01	0.01	<0.01	0.04	0.02	0.01	0.01	<0.01

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

I.2.3. Sea Turtle Exposure Estimates

This section contains mean sea turtle exposure estimates for the proposed construction schedules described in Section 1.2.3, assuming 0, 6, 10, 15, and 20 dB of broadband attenuation.

I.2.3.1. Sequential Operations

Table I-13. Construction Schedule 1 (WTG monopile 2 piles per day, OCS-DC jacket 4 pin piles per day): The mean number of sea turtles predicted to receive sound levels above exposure criteria for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	0.47	0.15	0.05	<0.01	0	<0.01	0	0	0	0	0.96	0.48	0.30	0.12	0.05
Leatherback turtle[a]	24.33	8.60	3.01	0.47	0.03	0	0	0	0	0	37.14	16.45	8.63	3.00	0.48
Loggerhead turtle	8.67	2.41	0.24	0	0	0	0	0	0	0	31.02	14.43	8.16	4.53	1.69
Green turtle	0.61	0.23	0.10	<0.01	0	0	0	0	0	0	0.95	0.46	0.29	0.15	0.05

[a] Listed as Endangered under the ESA.

Table I-14. Construction Schedule 2 (WTG monopile 3 piles per day, OCS-DC jacket 4 pin piles per day): The mean number of sea turtles predicted to receive sound levels above exposure criteria for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	0.48	0.17	0.05	<0.01	0	0	0	0	0	0	1.02	0.49	0.31	0.14	0.06
Leatherback turtle[a]	24.17	8.60	3.01	0.36	0.03	0	0	0	0	0	40.16	17.94	9.57	2.72	0.48
Loggerhead turtle	8.49	2.12	0.50	0	0	0	0	0	0	0	34.61	15.94	9.30	4.31	1.91
Green turtle	0.58	0.22	0.07	<0.01	0	<0.01	0	0	0	0	0.97	0.45	0.27	0.11	0.04

[a] Listed as Endangered under the ESA.

I.2.3.2. Concurrent Operations

Table I-15. Construction Schedule 3 (proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): The mean number of sea turtles predicted to receive sound levels above exposure criteria for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	0.49	0.19	0.05	<0.01	0	<0.01	0	0	0	0	0.83	0.45	0.28	0.13	0.05
Leatherback turtle[a]	24.33	7.60	2.83	0.24	0.03	0	0	0	0	0	32.38	13.04	6.51	2.53	0.19
Loggerhead turtle	10.16	2.36	0.35	0	0	0	0	0	0	0	30.91	16.36	8.82	4.03	1.52
Green turtle	0.57	0.24	0.08	<0.01	0	<0.01	0	0	0	0	0.80	0.43	0.25	0.11	0.04

[a] Listed as Endangered under the ESA.

Table I-16. Construction Schedule 4 (distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, and the OCS-DC foundation): The mean number of sea turtles predicted to receive sound levels above exposure criteria for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	0.49	0.17	0.05	<0.01	0	<0.01	0	0	0	0	0.98	0.48	0.30	0.14	0.05
Leatherback turtle[a]	24.21	9.66	4.30	0.83	0.15	0.06	0	0	0	0	34.32	16.27	9.51	4.11	1.07
Loggerhead turtle	8.62	1.86	0.30	0	0	0	0	0	0	0	31.35	15.59	9.26	3.54	1.36
Green turtle	0.54	0.19	0.07	<0.01	0	0	0	0	0	0	0.86	0.43	0.24	0.10	0.04

[a] Listed as Endangered under the ESA.

Table I-17. Construction Schedule 5 (proximal assumptions for concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day), and remaining WTG foundations): The mean number of sea turtles predicted to receive sound levels above exposure criteria for each sound attenuation level. Construction schedule assumptions are summarized in Section 1.2.3.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	0.46	0.15	0.05	<0.01	0	<0.01	0	0	0	0	0.94	0.48	0.29	0.12	0.05
Leatherback turtle[a]	24.19	8.85	2.95	0.52	0.05	0	0	0	0	0	37.01	16.74	8.76	3.05	0.49
Loggerhead turtle	8.70	2.45	0.25	0	0	0	0	0	0	0	30.59	14.32	8.16	4.56	1.67
Green turtle	0.61	0.23	0.10	<0.01	0	0	0	0	0	0	0.94	0.46	0.29	0.15	0.05

[a] Listed as Endangered under the ESA.

I.2.4. Marine Mammal Exposure Ranges ($ER_{95\%}$)

This section contains marine mammal exposure ranges for each of the modeled foundation types and seasons assuming 0, 6, 10, 15, and 20 dB broadband attenuation.

I.2.4.1. Sequential Operations

Table I-18. Monopile foundation (7/12 m diameter), summer, 2 piles per day: Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

	Species	Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	7.92	5.29	3.91	2.32	1.23	0.05	<0.01	<0.01	<0.01	0	11.36	7.52	5.74	3.92	2.72	11.36	7.51	5.70	3.91	2.74
LF	Minke whale (migrating)	4.95	2.94	1.98	0.89	0.49	<0.01	0	0	0	0	10.52	7.08	5.09	3.39	2.21	30.10	22.46	18.22	14.14	10.71
LF	Humpback whale	7.39	4.90	3.63	2.20	0.89	0.04	0	0	0	0	11.03	7.52	5.57	3.82	2.54	11.05	7.50	5.61	3.82	2.55
LF	North Atlantic right whale[c]	5.98	3.96	2.66	1.35	0.53	0.06	0	0	0	0	10.77	7.01	5.43	3.48	2.42	10.80	7.02	5.41	3.47	2.43
LF	Sei whale[c] (migrating)	6.20	4.03	2.69	1.36	0.61	0.05	0.01	<0.01	0	0	11.05	7.27	5.53	3.82	2.53	31.49	23.72	19.08	14.33	11.09
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.45	6.89	5.10	3.41	2.30	5.02	3.36	2.45	1.41	0.77
MF	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	10.66	7.20	4.89	3.34	2.13	4.89	3.30	2.23	1.47	0.79
MF	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.60	7.11	5.16	3.65	2.39	5.11	3.40	2.44	1.53	0.78
MF	Bottlenose dolphin	0	0	0	0	0	<0.01	0	0	0	0	9.25	6.23	4.80	3.15	2.22	5.01	3.16	2.41	1.40	0.63
MF	Risso's dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.77	7.27	5.46	3.60	2.39	5.28	3.46	2.44	1.59	0.80
MF	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	10.63	7.14	5.26	3.65	2.39	5.17	3.43	2.39	1.48	0.80
MF	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	10.59	7.06	5.31	3.51	2.34	5.22	3.42	2.41	1.60	0.69
MF	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	10.84	7.37	5.44	3.66	2.35	5.33	3.48	2.46	1.51	0.78
HF	Harbor porpoise	0.04	0	0	0	0	0.68	0.32	0.20	0.04	0.02	10.58	7.16	5.42	3.55	2.21	41.91	31.99	26.24	20.04	14.97
PW	Gray seal	1.08	0.28	0	0	0	0	0	0	0	0	11.44	7.77	5.91	3.98	2.75	8.28	5.59	4.19	2.77	1.72
PW	Harbor seal	1.29	0.46	<0.01	0	0	0.02	<0.01	<0.01	<0.01	0	10.95	7.38	5.52	3.73	2.48	7.79	5.32	3.85	2.64	1.63
PW	Harp seal	1.16	0.36	0	0	0	0.02	0	0	0	0	11.15	7.35	5.62	3.91	2.51	7.84	5.32	3.99	2.52	1.62

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

Table I-19. Monopile foundation (7/12 m diameter), summer, 3 piles per day: Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	7.80	5.36	3.68	2.21	1.23	0.05	0.02	<0.01	<0.01	0	11.00	7.49	5.73	3.89	2.59	11.06	7.48	5.73	3.89	2.62
LF	Minke whale (migrating)	5.04	3.03	1.86	0.91	0.45	0.08	0	0	0	0	10.31	6.93	5.30	3.53	2.18	30.03	22.29	17.96	13.63	10.42
LF	Humpback whale	7.31	4.88	3.40	2.07	1.07	0.06	<0.01	<0.01	<0.01	0	10.81	7.32	5.52	3.86	2.51	10.86	7.31	5.51	3.79	2.52
LF	North Atlantic right whale[c]	6.00	3.79	2.51	1.40	0.52	0.07	0.01	0	0	0	10.39	6.97	5.26	3.65	2.37	10.51	7.05	5.25	3.63	2.39
LF	Sei whale[c] (migrating)	6.33	4.01	2.67	1.41	0.48	0.09	<0.01	<0.01	<0.01	0	10.75	7.33	5.46	3.76	2.43	31.30	23.32	18.90	14.19	10.80
MF	Atlantic white sided dolphin	0	0	0	0	0	0	0	0	0	0	10.34	6.87	5.13	3.49	2.24	5.06	3.33	2.39	1.48	0.74
MF	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	10.92	7.42	5.28	3.41	2.28	5.26	3.21	2.42	1.66	0.74
MF	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.30	7.00	5.33	3.58	2.42	5.21	3.37	2.49	1.47	0.81
MF	Bottlenose dolphin	0	0	0	0	0	0	0	0	0	0	8.97	6.26	4.54	3.19	2.13	4.81	3.18	2.34	1.45	0.73
MF	Risso's dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.61	7.08	5.32	3.63	2.54	5.21	3.39	2.59	1.55	0.68
MF	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	10.41	7.02	5.22	3.59	2.51	5.15	3.40	2.55	1.47	0.71
MF	Short-finned pilot whale	0	0	0	0	0	0	0	0	0	0	10.28	7.06	5.35	3.55	2.44	5.15	3.33	2.45	1.45	0.78
MF	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	10.63	7.08	5.47	3.76	2.40	5.29	3.49	2.46	1.48	0.77
HF	Harbor porpoise	0.02	0	0	0	0	0.64	0.32	0.18	0.03	0.01	10.31	6.89	5.22	3.52	2.23	41.99	31.80	26.00	19.60	14.67
PW	Gray seal	1.20	0.29	<0.01	0	0	<0.01	0	0	0	0	11.24	7.74	5.84	4.06	2.97	8.21	5.40	4.13	2.98	1.71
PW	Harbor seal	1.27	0.45	0.03	0	0	0.04	<0.01	<0.01	<0.01	0	10.64	7.06	5.47	3.71	2.45	7.59	5.10	3.88	2.49	1.58
PW	Harp seal	1.04	0.23	0.08	0	0	0.08	0	0	0	0	10.83	7.38	5.53	3.74	2.54	7.88	5.27	3.82	2.60	1.52

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

Table I-20. Monopile foundation (7/12 m diameter), winter, 2 piles per day: Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	9.36	5.90	4.19	2.67	1.25	0.08	<0.01	<0.01	<0.01	0	13.38	8.53	6.32	4.02	2.71	13.40	8.49	6.22	4.02	2.62
	Minke whale (migrating)	5.90	3.34	2.12	0.93	0.83	<0.01	0	0	0	0	12.49	7.94	5.60	3.62	2.23	57.49	35.45	27.22	18.08	12.56
	Humpback whale	8.81	5.48	3.80	2.28	0.91	0.04	0	0	0	0	13.32	8.41	6.09	4.04	2.55	13.35	8.34	5.99	4.04	2.52
	North Atlantic right whale[c]	7.09	4.27	2.81	1.45	0.57	0.06	0	0	0	0	12.68	8.03	5.87	3.88	2.46	12.66	8.02	5.80	3.91	2.41
	Sei whale[c] (migrating)	7.40	4.42	3.09	1.50	0.61	0.05	0.01	<0.01	0	0	13.12	8.32	5.98	4.03	2.52	59.36	37.41	28.64	19.37	13.14
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	0	0	0	0	12.27	7.77	5.58	3.72	2.31	5.53	3.56	2.48	1.37	0.80
	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	12.93	8.35	5.51	3.79	2.17	5.68	3.35	2.25	1.43	0.73
	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	12.29	7.91	5.66	3.85	2.42	5.54	3.60	2.61	1.56	0.76
	Bottlenose dolphin	0	0	0	0	0	<0.01	0	0	0	0	11.22	7.02	5.10	3.38	2.23	5.42	3.45	2.48	1.38	0.60
	Risso's dolphin	0	0	0	0	0	<0.01	0	0	0	0	12.94	8.29	6.02	3.83	2.42	5.81	3.60	2.52	1.60	0.79
	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	12.45	8.03	5.86	3.89	2.44	5.71	3.58	2.48	1.49	0.84
	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	12.54	8.00	5.79	3.77	2.51	5.62	3.51	2.54	1.62	0.68
	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	12.75	8.14	6.01	3.98	2.45	5.81	3.70	2.48	1.56	0.71
HF	Harbor porpoise	0.05	0	0	0	0	0.58	0.32	0.20	0.04	0.02	12.74	7.90	5.77	3.73	2.40	99.44	80.55	57.44	35.44	23.61
PW	Gray seal	1.13	0.28	0	0	0	0	0	0	0	0	13.71	8.74	6.37	4.26	2.77	9.51	6.08	4.27	2.91	1.93
	Harbor seal	1.54	0.46	<0.01	0	0	0.02	<0.01	<0.01	<0.01	0	12.86	8.25	5.89	3.92	2.48	8.86	5.63	4.05	2.83	1.60
	Harp seal	1.19	0.36	0	0	0	0.02	0	0	0	0	13.20	8.43	6.12	4.17	2.57	9.22	5.76	4.26	2.75	1.63

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

Table I-21. Monopile foundation (7/12 m diameter), winter, 3 piles per day: Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

	Species	Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	9.40	5.98	4.24	2.46	1.35	0.05	0.02	<0.01	<0.01	0	13.23	8.44	6.16	4.13	2.55	13.22	8.41	6.08	4.15	2.54
LF	Minke whale (migrating)	5.77	3.39	2.02	0.98	0.47	0.07	0	0	0	0	12.34	7.87	5.66	3.73	2.24	57.93	35.60	27.31	18.12	12.46
LF	Humpback whale	8.96	5.52	3.82	2.29	1.06	0.06	<0.01	<0.01	<0.01	0	13.08	8.28	5.97	4.06	2.57	13.08	8.27	5.96	4.04	2.53
LF	North Atlantic right whale[c]	7.01	4.20	2.90	1.43	0.55	0.07	0.01	0	0	0	12.75	7.98	5.78	3.87	2.44	12.78	8.00	5.78	3.85	2.42
LF	Sei whale[c] (migrating)	7.52	4.55	3.01	1.45	0.50	0.09	<0.01	<0.01	<0.01	0	12.85	8.24	5.93	4.08	2.46	59.92	37.24	28.05	18.84	12.85
MF	Atlantic white sided dolphin	0	0	0	0	0	0	0	0	0	0	12.31	7.78	5.75	3.80	2.28	5.62	3.57	2.52	1.48	0.77
MF	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	13.38	8.47	5.82	3.68	2.35	5.79	3.35	2.55	1.68	0.73
MF	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	12.27	7.94	5.80	3.79	2.48	5.70	3.59	2.55	1.51	0.75
MF	Bottlenose dolphin	0	0	0	0	0	0	0	0	0	0	10.99	7.13	5.11	3.45	2.15	5.31	3.41	2.42	1.41	0.70
MF	Risso's dolphin	0	0	0	0	0	<0.01	0	0	0	0	12.81	8.14	5.85	3.98	2.58	5.70	3.62	2.63	1.59	0.77
MF	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	12.43	7.95	5.75	3.90	2.56	5.64	3.55	2.67	1.59	0.72
MF	Short-finned pilot whale	0	0	0	0	0	0	0	0	0	0	12.48	8.00	5.85	3.87	2.43	5.68	3.49	2.49	1.49	0.76
MF	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	12.81	8.05	5.98	3.97	2.46	5.83	3.71	2.70	1.52	0.72
HF	Harbor porpoise	0.02	0	0	0	0	0.57	0.32	0.18	0.03	0.01	12.75	7.96	5.72	3.78	2.36	99.96	82.09	58.03	35.23	23.45
PW	Gray seal	1.34	0.29	<0.01	0	0	<0.01	0	0	0	0	13.31	8.77	6.46	4.31	2.82	9.42	5.94	4.34	3.02	1.74
PW	Harbor seal	1.33	0.45	0.03	0	0	0.04	<0.01	<0.01	<0.01	0	12.70	8.08	5.86	4.05	2.47	8.76	5.60	4.12	2.67	1.66
PW	Harp seal	1.05	0.22	0.08	0	0	0.08	0	0	0	0	12.91	8.31	6.19	3.99	2.54	8.94	5.76	4.05	2.97	1.68

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

Table I-22. Jacket foundation (4 m diameter), summer, 4 pin piles per day: Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

	Species	Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	11.87	7.63	5.55	3.69	2.11	0.06	0.01	<0.01	<0.01	0	14.29	8.84	6.23	3.70	2.16	14.40	8.86	6.24	3.68	2.15
LF	Minke whale (migrating)	6.43	4.05	2.88	1.61	0.72	0.02	<0.01	<0.01	0	0	12.80	7.86	5.53	3.45	2.01	40.73	30.25	24.87	18.69	13.10
LF	Humpback whale	10.56	6.87	5.13	3.40	1.91	0.09	0.01	0	0	0	14.14	8.77	6.23	3.62	2.14	14.22	8.78	6.24	3.59	2.11
LF	North Atlantic right whale[c]	8.10	5.19	3.62	2.17	0.98	0.06	0.03	<0.01	<0.01	0	13.60	8.17	5.75	3.34	2.05	13.88	8.37	5.77	3.35	2.02
LF	Sei whale[c] (migrating)	9.08	5.91	4.22	2.51	1.39	0.08	<0.01	<0.01	<0.01	0	14.12	8.61	6.03	3.64	2.13	43.77	32.11	26.13	19.92	14.20
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	12.97	8.08	5.52	3.42	2.00	7.24	4.02	2.75	1.71	0.91
MF	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	14.33	8.96	6.68	4.05	0	8.16	4.27	0	0	0
MF	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	12.74	7.96	5.54	3.41	2.06	7.19	3.99	2.85	1.74	0.94
MF	Bottlenose dolphin	0	0	0	0	0	<0.01	0	0	0	0	11.10	6.47	4.53	2.91	1.86	5.94	3.64	2.58	1.60	0.86
MF	Risso's dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	13.84	8.44	5.83	3.53	2.06	7.44	4.14	2.86	1.71	0.92
MF	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	13.13	7.96	5.59	3.41	2.06	7.19	3.99	2.82	1.67	0.92
MF	Short-finned pilot whale	0	0	0	0	0	0	0	0	0	0	13.23	8.17	5.63	3.44	2.04	7.37	3.97	2.80	1.68	0.91
MF	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	13.84	8.34	5.93	3.41	2.05	7.52	4.05	2.84	1.63	0.90
HF	Harbor porpoise	2.35	1.27	0.81	0.28	0	0.61	0.28	0.22	0.03	<0.01	13.01	8.22	5.59	3.46	1.94	74.50	53.56	43.29	33.19	25.67
PW	Gray seal	4.02	2.45	1.72	0.80	0.15	<0.01	0	0	0	0	14.97	9.24	6.61	3.95	2.29	12.10	7.32	4.84	2.73	1.73
PW	Harbor seal	2.79	1.29	0.69	0.18	0	0.08	0.01	<0.01	<0.01	0	13.82	8.72	5.94	3.52	2.12	11.24	6.68	4.32	2.61	1.62
PW	Harp seal	2.64	1.07	0.49	0.14	0	0.07	0.04	0	0	0	14.10	8.68	6.13	3.61	2.15	11.70	6.81	4.56	2.67	1.64

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

Table I-23. Jacket foundation (4 m diameter, winter, 4 pin piles per day): Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

	Species	Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	17.75	9.60	6.42	3.94	2.30	0.06	0.01	<0.01	<0.01	0	19.58	10.26	6.35	3.71	2.13	19.62	10.22	6.36	3.72	2.14
LF	Minke whale (migrating)	9.09	4.70	3.20	1.79	0.81	0.03	<0.01	<0.01	0	0	18.01	9.44	5.95	3.49	2.02	108.41	79.77	45.98	28.69	18.15
LF	Humpback whale	16.60	8.75	6.03	3.70	1.98	0.09	0.01	0	0	0	19.35	10.08	6.34	3.67	2.11	19.43	10.08	6.35	3.68	2.11
LF	North Atlantic right whale[c]	11.76	6.06	4.06	2.40	1.09	0.06	0.03	<0.01	<0.01	0	18.46	9.68	6.03	3.51	2.02	18.63	9.75	6.08	3.52	2.01
LF	Sei whale[c] (migrating)	13.31	7.02	4.73	2.92	1.42	0.09	<0.01	<0.01	<0.01	0	19.28	9.84	6.19	3.66	2.14	107.18	80.44	47.82	29.70	19.32
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	17.95	9.38	5.87	3.45	2.01	8.13	4.05	2.72	1.70	0.89
MF	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	19.22	9.95	6.52	4.17	0	8.79	4.30	0	0	0
MF	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	17.49	9.29	5.80	3.48	2.07	8.04	4.04	2.79	1.73	0.93
MF	Bottlenose dolphin	0	0	0	0	0	<0.01	0	0	0	0	15.38	7.93	4.79	3.01	1.84	6.91	3.69	2.55	1.59	0.82
MF	Risso's dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	18.73	9.88	6.04	3.58	2.10	8.45	4.20	2.81	1.71	0.92
MF	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	18.08	9.37	5.87	3.44	2.08	8.00	4.06	2.81	1.67	0.93
MF	Short-finned pilot whale	0	0	0	0	0	0	0	0	0	0	18.07	9.52	5.92	3.48	2.03	8.16	4.02	2.77	1.67	0.91
MF	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	18.76	9.71	6.09	3.51	2.03	8.26	4.08	2.81	1.61	0.92
HF	Harbor porpoise	2.10	1.11	0.59	0.22	0	0.60	0.28	0.18	0.03	<0.01	18.60	9.80	6.03	3.49	1.93	107.76	104.72	103.65	102.75	58.68
PW	Gray seal	4.15	2.48	1.73	0.80	0.15	<0.01	0	0	0	0	20.05	10.59	6.72	3.95	2.30	15.23	7.58	4.84	2.85	1.74
PW	Harbor seal	2.99	1.46	0.69	0.18	0	0.09	0.01	<0.01	<0.01	0	18.63	9.83	6.10	3.52	2.12	14.21	7.12	4.33	2.63	1.58
PW	Harp seal	2.82	1.09	0.57	0.15	0	0.07	0.04	0	0	0	19.30	10.05	6.23	3.71	2.16	14.46	7.04	4.55	2.74	1.64

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

I.2.4.2. Concurrent Operations

Table I-24. Proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, summer: Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	8.72	5.78	4.23	2.49	1.36	0.06	<0.01	<0.01	<0.01	0	12.04	8.29	6.16	4.15	2.80	12.05	8.25	6.14	4.15	2.82
	Minke whale (migrating)	5.61	3.29	2.17	1.24	0.62	0.02	<0.01	<0.01	<0.01	0	11.45	7.80	5.71	3.59	2.38	33.23	24.68	20.23	15.19	11.61
	Humpback whale	8.23	5.35	4.02	2.47	1.21	0.10	<0.01	<0.01	<0.01	0	12.01	8.24	6.02	4.16	2.66	12.10	8.22	6.01	4.07	2.65
	North Atlantic right whale[c]	6.91	4.16	2.94	1.65	0.68	0.08	0.01	0	0	0	11.62	7.91	5.71	3.77	2.59	11.75	7.96	5.71	3.79	2.60
	Sei whale[c] (migrating)	7.16	4.48	3.18	1.62	0.64	0.05	<0.01	<0.01	0	0	11.88	8.18	6.10	4.08	2.51	34.95	25.86	21.04	15.73	11.94
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	0	0	0	0	11.28	7.59	5.45	3.61	2.32	5.31	3.61	2.60	1.52	0.80
	Atlantic spotted dolphin	0	0	0	0	0	<0.01	0	0	0	0	11.23	7.30	5.08	3.33	2.08	5.05	3.31	2.18	1.46	0.79
	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	11.39	7.70	5.64	3.79	2.35	5.48	3.59	2.38	1.51	0.79
	Bottlenose dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.14	6.74	4.94	3.36	2.31	5.27	3.46	2.41	1.54	0.78
	Risso's dolphin	0	0	0	0	0	<0.01	0	0	0	0	11.68	8.14	5.77	3.82	2.56	5.62	3.68	2.62	1.47	0.72
	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	11.47	7.70	5.69	3.84	2.49	5.52	3.68	2.56	1.52	0.81
	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	11.45	7.87	5.74	3.82	2.52	5.50	3.70	2.60	1.59	0.76
	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	11.76	7.96	5.95	3.98	2.54	5.57	3.73	2.64	1.67	0.83
HF	Harbor porpoise	0.05	0	0	0	0	0.68	0.32	0.18	0.05	<0.01	11.39	7.89	5.83	3.80	2.43	47.99	35.31	28.67	21.82	15.97
PW	Gray seal	1.12	0.34	0	0	0	0	0	0	0	0	12.30	8.40	6.40	4.24	2.96	8.71	5.90	4.26	2.98	1.79
	Harbor seal	1.66	0.46	0.22	0	0	0.07	<0.01	<0.01	0	0	11.64	8.09	5.96	3.95	2.61	8.53	5.62	4.13	2.81	1.74
	Harp seal	1.36	0.41	0.02	0	0	0.08	0	0	0	0	12.06	8.16	6.10	4.21	2.73	8.61	5.77	4.22	2.76	1.59

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

Table I-25. Distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, summer: Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	7.89	5.37	3.80	2.19	1.26	0.06	<0.01	<0.01	<0.01	0	11.66	7.51	5.65	3.83	2.52	11.65	7.50	5.65	3.81	2.53
	Minke whale (migrating)	5.08	3.03	1.96	1.05	0.35	0.02	0.01	<0.01	<0.01	0	10.30	6.99	5.20	3.45	2.25	30.72	22.63	18.38	13.85	10.48
	Humpback whale	7.63	4.95	3.66	2.07	1.04	0.05	<0.01	<0.01	<0.01	0	11.53	7.53	5.67	3.82	2.53	11.54	7.50	5.57	3.79	2.48
	North Atlantic right whale[c]	6.12	3.87	2.61	1.39	0.55	0.05	<0.01	<0.01	0	0	10.80	7.17	5.24	3.60	2.43	10.94	7.18	5.24	3.58	2.43
	Sei whale[c] (migrating)	6.43	4.02	2.74	1.44	0.60	0.07	0.01	<0.01	0	0	11.23	7.35	5.48	3.73	2.35	32.43	24.00	19.64	14.54	11.31
MF	Atlantic white sided dolphin	0	0	0	0	0	0	0	0	0	0	10.23	6.80	5.09	3.42	2.19	5.08	3.32	2.34	1.45	0.78
	Atlantic spotted dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.71	6.80	4.83	3.20	2.02	4.88	3.20	2.13	1.46	0.78
	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.31	7.00	5.19	3.58	2.27	5.09	3.38	2.32	1.46	0.79
	Bottlenose dolphin	0	0	0	0	0	0	0	0	0	0	9.59	6.25	4.70	3.23	2.09	4.86	3.28	2.35	1.43	0.73
	Risso's dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.90	7.29	5.36	3.66	2.45	5.22	3.51	2.53	1.43	0.82
	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	10.40	7.01	5.26	3.63	2.35	5.16	3.40	2.42	1.50	0.78
	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	10.57	7.18	5.29	3.65	2.38	5.18	3.42	2.43	1.50	0.80
	Sperm whale[c]	0	0	0	0	0	<0.01	0	0	0	0	10.91	7.32	5.42	3.71	2.39	5.23	3.48	2.46	1.53	0.82
HF	Harbor porpoise	0.04	0	0	0	0	0.70	0.33	0.23	0.06	<0.01	10.70	7.15	5.26	3.58	2.37	44.26	32.97	26.68	20.22	14.87
PW	Gray seal	1.03	0.22	0.17	0	0	0	0	0	0	0	12.00	7.75	5.92	4.00	2.85	8.30	5.71	4.10	2.88	1.71
	Harbor seal	1.32	0.27	0.22	0	0	0.09	<0.01	<0.01	0	0	11.15	7.23	5.48	3.67	2.52	7.69	5.15	3.85	2.62	1.69
	Harp seal	1.09	0.28	0.04	0	0	0.08	0	0	0	0	11.48	7.44	5.70	3.95	2.59	7.95	5.34	4.04	2.63	1.56

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

Table I-26 Proximal assumptions for concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day), summer: Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

	Species	Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	11.64	7.31	5.25	3.50	2.06	0.08	0	0	0	0	13.98	8.45	5.88	3.85	2.41	14.09	8.54	5.83	3.81	2.42
LF	Minke whale (migrating)	6.27	3.87	2.71	1.55	0.78	0.07	<0.01	<0.01	0	0	12.58	7.65	5.42	3.33	2.06	40.55	30.01	24.53	18.48	13.09
LF	Humpback whale	10.43	6.71	4.83	3.10	1.81	0.07	<0.01	0	0	0	13.81	8.39	5.89	3.71	2.31	13.98	8.53	5.91	3.71	2.31
LF	North Atlantic right whale[c]	8.17	4.89	3.49	2.10	1.12	0.07	<0.01	<0.01	<0.01	0	13.16	8.15	5.45	3.51	2.12	13.55	8.30	5.52	3.51	2.09
LF	Sei whale[c] (migrating)	9.01	5.69	3.97	2.50	1.33	0.05	0.01	<0.01	<0.01	0	13.59	8.25	5.89	3.56	2.21	43.48	31.84	25.97	19.65	13.77
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	12.68	7.97	5.50	3.33	2.07	7.08	3.92	2.76	1.67	0.88
MF	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	14.24	8.55	6.70	0	0	7.96	0	0	0	0
MF	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	12.60	7.82	5.46	3.40	2.07	7.01	3.92	2.74	1.68	0.91
MF	Bottlenose dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	9.88	5.95	4.50	3.00	1.85	5.53	3.49	2.50	1.55	0.86
MF	Risso's dolphin	0	0	0	0	0	<0.01	0	0	0	0	13.49	8.24	5.70	3.52	2.08	7.36	3.99	2.75	1.56	0.87
MF	Long-finned pilot whale	0	0	0	0	0	0	0	0	0	0	12.96	7.84	5.47	3.40	2.10	6.99	3.85	2.67	1.67	0.89
MF	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	13.04	7.86	5.60	3.42	2.11	7.06	3.83	2.67	1.59	0.88
MF	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	13.66	8.10	5.56	3.51	2.22	7.24	4.09	2.71	1.66	0.84
HF	Harbor porpoise	2.27	1.25	0.61	0.22	0	0.64	0.31	0.25	0.04	0.01	12.83	7.80	5.45	3.41	2.14	74.06	53.37	43.07	33.15	25.38
PW	Gray seal	3.65	2.62	1.62	0.89	0	0.03	0	0	0	0	14.31	8.59	6.34	3.90	2.72	11.40	7.26	4.28	2.89	1.77
PW	Harbor seal	2.59	1.30	0.75	0.09	0	0.09	<0.01	<0.01	<0.01	0	13.35	8.16	5.79	3.49	2.26	10.99	6.18	4.08	2.58	1.60
PW	Harp seal	2.41	1.15	0.48	0.14	0	0.11	0.04	<0.01	<0.01	0	13.83	8.51	5.87	3.77	2.36	11.51	6.56	4.25	2.68	1.63

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

Table I-27 Proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, winter: Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

Species		Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	10.35	6.62	4.83	2.75	1.55	0.06	<0.01	<0.01	<0.01	0	13.90	9.26	6.67	4.45	2.90	13.91	9.23	6.68	4.44	2.89
	Minke whale (migrating)	6.75	3.72	2.37	1.28	0.59	0.02	<0.01	<0.01	<0.01	0	13.39	8.78	6.22	3.81	2.46	72.68	36.68	27.35	19.26	13.56
	Humpback whale	9.86	6.13	4.32	2.64	1.38	0.10	<0.01	<0.01	<0.01	0	13.90	9.16	6.60	4.27	2.76	13.95	9.16	6.60	4.25	2.74
	North Atlantic right whale[c]	8.14	4.77	3.31	1.69	0.70	0.08	0.01	0	0	0	13.52	8.87	6.29	4.01	2.63	13.68	8.98	6.34	4.01	2.62
	Sei whale[c] (migrating)	8.58	5.13	3.37	1.92	0.75	0.05	<0.01	<0.01	0	0	13.61	9.21	6.54	4.31	2.65	72.63	37.78	28.01	19.74	13.70
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	0	0	0	0	13.10	8.59	6.11	3.85	2.49	6.00	3.75	2.69	1.50	0.78
	Atlantic spotted dolphin	0	0	0	0	0	<0.01	0	0	0	0	13.32	8.40	5.77	3.53	2.13	5.77	3.42	2.19	1.46	0.76
	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	13.18	8.66	6.19	3.93	2.43	6.03	3.74	2.50	1.61	0.78
	Bottlenose dolphin	0	0	0	0	0	<0.01	0	0	0	0	11.70	7.82	5.61	3.57	2.35	5.94	3.61	2.49	1.54	0.77
	Risso's dolphin	0	0	0	0	0	<0.01	0	0	0	0	13.58	9.24	6.31	3.97	2.62	6.21	3.82	2.77	1.55	0.79
	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	13.21	8.77	6.19	4.00	2.56	6.15	3.85	2.66	1.63	0.84
	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	13.29	8.83	6.26	4.05	2.58	6.15	3.81	2.73	1.61	0.76
	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	13.46	9.03	6.40	4.30	2.64	6.34	3.97	2.70	1.73	0.83
HF	Harbor porpoise	0.11	0	0	0	0	0.63	0.32	0.14	0.05	<0.01	13.37	8.78	6.29	3.94	2.51	95.03	93.28	71.46	39.83	23.36
PW	Gray seal	1.12	0.40	0	0	0	0	0	0	0	0	13.75	9.53	6.79	4.54	3.13	10.17	6.40	4.57	3.19	2.00
	Harbor seal	1.82	0.46	0.16	0	0	0.07	<0.01	<0.01	0	0	13.59	8.95	6.39	4.25	2.79	9.48	6.03	4.44	2.97	1.77
	Harp seal	1.53	0.44	0.02	0	0	0.08	0	0	0	0	13.95	9.26	6.62	4.31	2.82	9.88	6.15	4.43	2.93	1.82

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

Table I-28. Distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, winter: Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

	Species	Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	7.89	5.37	3.80	2.19	1.26	0.06	<0.01	<0.01	<0.01	0	11.66	7.51	5.65	3.83	2.52	11.65	7.50	5.65	3.81	2.53
LF	Minke whale (migrating)	5.08	3.03	1.96	1.05	0.35	0.02	0.01	<0.01	<0.01	0	10.30	6.99	5.20	3.45	2.25	30.72	22.63	18.38	13.85	10.48
LF	Humpback whale	7.63	4.95	3.66	2.07	1.04	0.05	<0.01	<0.01	<0.01	0	11.53	7.53	5.67	3.82	2.53	11.54	7.50	5.57	3.79	2.48
LF	North Atlantic right whale[c]	6.12	3.87	2.61	1.39	0.55	0.05	<0.01	<0.01	0	0	10.80	7.17	5.24	3.60	2.43	10.94	7.18	5.24	3.58	2.43
LF	Sei whale[c] (migrating)	6.43	4.02	2.74	1.44	0.60	0.07	0.01	<0.01	0	0	11.23	7.35	5.48	3.73	2.35	32.43	24.00	19.64	14.54	11.31
MF	Atlantic white sided dolphin	0	0	0	0	0	0	0	0	0	0	10.23	6.80	5.09	3.42	2.19	5.08	3.32	2.34	1.45	0.78
MF	Atlantic spotted dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.71	6.80	4.83	3.20	2.02	4.88	3.20	2.13	1.46	0.78
MF	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.31	7.00	5.19	3.58	2.27	5.09	3.38	2.32	1.46	0.79
MF	Bottlenose dolphin	0	0	0	0	0	0	0	0	0	0	9.59	6.25	4.70	3.23	2.09	4.86	3.28	2.35	1.43	0.73
MF	Risso's dolphin	0	0	0	0	0	<0.01	0	0	0	0	10.90	7.29	5.36	3.66	2.45	5.22	3.51	2.53	1.43	0.82
MF	Long-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	10.40	7.01	5.26	3.63	2.35	5.16	3.40	2.42	1.50	0.78
MF	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	10.57	7.18	5.29	3.65	2.38	5.18	3.42	2.43	1.50	0.80
MF	Sperm whale[c]	0	0	0	0	0	<0.01	0	0	0	0	10.91	7.32	5.42	3.71	2.39	5.23	3.48	2.46	1.53	0.82
HF	Harbor porpoise	0.04	0	0	0	0	0.70	0.33	0.23	0.06	<0.01	10.70	7.15	5.26	3.58	2.37	44.26	32.97	26.68	20.22	14.87
PW	Gray seal	1.03	0.22	0.17	0	0	0	0	0	0	0	12.00	7.75	5.92	4.00	2.85	8.30	5.71	4.10	2.88	1.71
PW	Harbor seal	1.32	0.27	0.22	0	0	0.09	<0.01	<0.01	0	0	11.15	7.23	5.48	3.67	2.52	7.69	5.15	3.85	2.62	1.69
PW	Harp seal	1.09	0.28	0.04	0	0	0.08	0	0	0	0	11.48	7.44	5.70	3.95	2.59	7.95	5.34	4.04	2.63	1.56

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

Table I-29. Proximal assumptions for concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day), winter: Exposure radial distances ($ER_{95\%}$) in km to marine mammal threshold criteria for each sound attenuation level.

	Species	Injury										Behavior									
		L_E					L_{pk}					L_p [a]					L_p [b]				
		Attenuation (dB)										Attenuation (dB)									
		0	6	10	15	20	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
LF	Fin whale[c]	17.67	9.43	6.21	3.74	2.09	0.08	0	0	0	0	18.96	9.97	6.27	4.01	2.48	19.11	9.96	6.25	4.01	2.46
LF	Minke whale (migrating)	9.07	4.79	3.07	1.66	0.84	0.07	<0.01	<0.01	0	0	17.72	9.16	5.82	3.46	2.09	108.48	79.22	45.80	28.40	18.05
LF	Humpback whale	16.99	8.59	5.68	3.54	1.92	0.05	<0.01	0	0	0	19.04	9.90	6.17	3.86	2.48	19.13	9.90	6.20	3.92	2.47
LF	North Atlantic right whale[c]	11.75	5.95	3.85	2.28	1.19	0.06	<0.01	<0.01	<0.01	0	18.23	9.55	5.87	3.62	2.16	18.38	9.63	5.89	3.62	2.16
LF	Sei whale[c] (migrating)	13.47	6.97	4.65	2.77	1.39	0.05	0.02	<0.01	<0.01	0	18.74	9.65	6.16	3.71	2.26	107.23	79.67	47.37	29.54	18.88
MF	Atlantic white sided dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	17.81	9.24	5.96	3.46	2.09	7.97	3.99	2.70	1.67	0.87
MF	Atlantic spotted dolphin	0	0	0	0	0	0	0	0	0	0	19.11	9.86	6.81	0	0	8.41	0	0	0	0
MF	Short-beaked common dolphin	0	0	0	0	0	<0.01	0	0	0	0	17.38	9.16	5.87	3.55	2.12	7.83	3.96	2.69	1.66	0.91
MF	Bottlenose dolphin	0	0	0	0	0	<0.01	<0.01	0	0	0	14.49	7.42	4.89	3.15	1.95	6.32	3.58	2.48	1.55	0.83
MF	Risso's dolphin	0	0	0	0	0	<0.01	0	0	0	0	18.54	9.62	6.08	3.75	2.16	8.07	4.06	2.75	1.60	0.88
MF	Long-finned pilot whale	0	0	0	0	0	0	0	0	0	0	17.81	9.25	5.81	3.52	2.13	7.82	3.92	2.66	1.69	0.90
MF	Short-finned pilot whale	0	0	0	0	0	<0.01	0	0	0	0	17.98	9.24	5.88	3.57	2.14	7.81	3.90	2.64	1.59	0.90
MF	Sperm whale[c]	0	0	0	0	0	0	0	0	0	0	18.55	9.58	5.97	3.73	2.26	8.00	4.12	2.71	1.65	0.85
HF	Harbor porpoise	2.21	1.13	0.57	0.22	0	0.57	0.30	0.24	0.04	0.01	18.40	9.52	6.13	3.56	2.15	107.88	105.01	103.77	102.84	58.51
PW	Gray seal	3.75	2.70	1.74	0.91	0	0.03	0	0	0	0	19.30	10.22	6.89	4.22	2.79	14.76	7.30	4.52	2.90	1.84
PW	Harbor seal	2.70	1.36	0.78	0.16	0	0.09	<0.01	<0.01	<0.01	0	18.26	9.63	6.06	3.64	2.30	13.70	6.52	4.30	2.63	1.55
PW	Harp seal	2.57	1.21	0.51	0.15	0	0.11	0.04	<0.01	<0.01	0	18.99	9.74	6.04	3.91	2.50	14.22	6.74	4.35	2.72	1.63

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

I.2.5. Sea Turtle Exposure Ranges ($ER_{95\%}$)

This section contains sea turtle exposure ranges for each of the modeled foundation types and seasons assuming 0, 6, 10, 15, and 20 dB broadband attenuation.

I.2.5.1. Sequential Operations

Table I-30. Monopile foundation (7/12 m diameter), summer, 2 piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	1.90	0.88	0.43	0	0	<0.01	0	0	0	0	3.62	2.13	1.40	0.85	0.26
Leatherback turtle[a]	3.08	1.51	0.76	0.25	0	0	0	0	0	0	4.06	2.44	1.60	0.90	0.29
Loggerhead turtle	1.14	0.40	0.14	0	0	0	0	0	0	0	3.40	1.85	1.24	0.49	0.26
Green turtle	2.73	1.27	0.45	0.13	0	0	0	0	0	0	3.87	2.11	1.35	0.67	0.28

[a] Listed as Endangered under the ESA.

Table I-31. Monopile foundation (7/12 m diameter), summer, 3 piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	1.95	0.72	0.28	0	0	0	0	0	0	0	3.52	2.02	1.43	0.74	0.25
Leatherback turtle[a]	3.12	1.57	0.93	0.24	0	0	0	0	0	0	4.07	2.43	1.58	0.87	0.33
Loggerhead turtle	1.19	0.37	0.12	0	0	0	0	0	0	0	3.19	1.88	1.33	0.61	0.24
Green turtle	2.54	1.03	0.41	<0.01	0	<0.01	0	0	0	0	3.76	2.28	1.47	0.71	0.30

[a] Listed as Endangered under the ESA.

Table I-32. Monopile foundation (7/12 m diameter), winter, 2 piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	2.09	0.87	0.42	0	0	<0.01	0	0	0	0	3.77	2.15	1.54	0.72	0.27
Leatherback turtle[a]	3.30	1.68	0.76	0.25	0	0	0	0	0	0	4.29	2.47	1.66	0.83	0.29
Loggerhead turtle	1.47	0.41	0.14	0	0	0	0	0	0	0	3.62	1.92	1.35	0.43	0.26
Green turtle	2.79	1.40	0.45	0.13	0	0	0	0	0	0	3.98	2.17	1.45	0.72	0.31

[a] Listed as Endangered under the ESA.

Table I-33. Monopile foundation (7/12 m diameter), winter, 3 piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	2.09	0.73	0.28	0	0	0	0	0	0	0	3.81	2.07	1.44	0.72	0.27
Leatherback turtle[a]	3.39	1.74	0.93	0.24	0	0	0	0	0	0	4.27	2.56	1.74	0.83	0.33
Loggerhead turtle	1.40	0.37	0.12	0	0	0	0	0	0	0	3.24	2.05	1.40	0.61	0.25
Green turtle	2.74	1.08	0.42	<0.01	0	<0.01	0	0	0	0	3.95	2.33	1.48	0.72	0.27

[a] Listed as Endangered under the ESA.

Table I-34. Jacket foundation (4 m diameter), summer, 4 pin piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	2.82	1.28	0.62	0.14	0	0	0	0	0	0	3.31	1.82	1.26	0.55	0.26
Leatherback turtle[a]	5.20	3.16	2.15	1.02	0.47	0	0	0	0	0	4.09	2.18	1.33	0.61	0.20
Loggerhead turtle	1.75	0.74	0.30	0	0	0	0	0	0	0	2.99	1.64	1.03	0.49	0.25
Green turtle	3.61	1.77	0.92	0.27	0	0	0	0	0	0	3.47	1.88	1.25	0.51	0.24

[a] Listed as Endangered under the ESA.

Table I-35. Jacket foundation (4 m diameter), winter, 4 pin piles per day: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	3.11	1.35	0.69	0.14	0	0	0	0	0	0	3.40	1.82	1.12	0.53	0.26
Leatherback turtle[a]	5.59	3.32	2.16	1.12	0.47	0	0	0	0	0	4.05	2.16	1.34	0.61	0.20
Loggerhead turtle	2.00	0.86	0.29	<0.01	0	0	0	0	0	0	3.14	1.58	1.03	0.46	0.19
Green turtle	3.98	1.84	0.93	0.37	0	0	0	0	0	0	3.58	1.82	1.21	0.51	0.24

[a] Listed as Endangered under the ESA.

I.2.5.2. Concurrent Operations

Table I-36. Proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, summer: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	2.33	1.04	0.34	<0.01	0	<0.01	0	0	0	0	3.78	2.12	1.59	0.75	0.30
Leatherback turtle[a]	3.53	2.01	0.95	0.29	0	0	0	0	0	0	4.20	2.62	1.68	0.98	0.35
Loggerhead turtle	1.59	0.75	0.18	0	0	0	0	0	0	0	3.53	2.26	1.33	0.67	0.31
Green turtle	3.01	1.47	0.57	0.07	0	<0.01	0	0	0	0	4.06	2.37	1.47	0.65	0.34

[a] Listed as Endangered under the ESA.

Table I-37. Distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, summer: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	1.96	0.85	0.34	<0.01	0	<0.01	0	0	0	0	3.63	1.98	1.42	0.70	0.28
Leatherback turtle[a]	3.23	1.61	0.83	0.24	0.01	<0.01	0	0	0	0	3.97	2.33	1.62	0.83	0.33
Loggerhead turtle	1.31	0.47	0.18	0	0	0	0	0	0	0	3.36	1.91	1.22	0.59	0.29
Green turtle	2.59	1.13	0.53	0.08	0	0	0	0	0	0	3.71	2.25	1.42	0.67	0.26

[a] Listed as Endangered under the ESA.

Table I-38. Proximal assumptions for concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day), summer: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	2.74	1.36	0.65	0.19	0	<0.01	0	0	0	0	3.33	1.90	1.27	0.58	0.25
Leatherback turtle[a]	5.05	3.14	2.20	1.13	0.47	0	0	0	0	0	4.19	2.58	1.64	0.92	0.32
Loggerhead turtle	1.79	0.85	0.26	0	0	0	0	0	0	0	3.10	1.71	1.05	0.58	0.26
Green turtle	3.38	1.65	1.02	0.20	0	0	0	0	0	0	3.61	1.95	1.27	0.61	0.28

[a] Listed as Endangered under the ESA.

Table I-39. Proximal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, winter: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	2.55	1.12	0.34	<0.01	0	<0.01	0	0	0	0	3.91	2.16	1.59	0.68	0.31
Leatherback turtle[a]	3.61	2.23	0.95	0.29	0	0	0	0	0	0	4.55	2.74	1.83	0.94	0.35
Loggerhead turtle	1.75	0.88	0.18	0	0	0	0	0	0	0	3.67	2.27	1.38	0.66	0.31
Green turtle	3.27	1.70	0.59	0.08	0	<0.01	0	0	0	0	4.32	2.50	1.54	0.67	0.35

[a] Listed as Endangered under the ESA.

Table I-40. Distal assumptions for concurrent piling of WTG (two vessels, each installing two monopiles per day) foundations, winter: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	2.15	0.89	0.34	0.01	0	<0.01	0	0	0	0	3.83	2.05	1.46	0.66	0.28
Leatherback turtle[a]	3.33	1.65	0.82	0.28	0.01	<0.01	0	0	0	0	4.30	2.55	1.66	0.88	0.33
Loggerhead turtle	1.49	0.46	0.18	0	0	0	0	0	0	0	3.49	1.95	1.25	0.60	0.30
Green turtle	2.78	1.27	0.53	0.08	0	0	0	0	0	0	3.96	2.34	1.52	0.67	0.26

[a] Listed as Endangered under the ESA.

Table I-41. Proximal assumptions for concurrent piling of WTG (one vessel installing two monopiles per day) and the OCS-DC foundation (one vessel installing four pin piles per day), winter: Exposure ranges ($ER_{95\%}$) in km to sea turtle threshold criteria for each sound attenuation level.

Species	Injury										Behavior				
	L_E					L_{pk}					L_p [a]				
	Attenuation (dB)										Attenuation (dB)				
	0	6	10	15	20	0	6	10	15	20	0	6	10	15	20
Kemp's ridley turtle[a]	3.02	1.41	0.70	0.19	0	<0.01	0	0	0	0	3.53	1.94	1.20	0.53	0.25
Leatherback turtle[a]	5.57	3.20	2.31	1.13	0.47	0	0	0	0	0	4.47	2.65	1.75	0.92	0.32
Loggerhead turtle	1.92	0.87	0.26	0	0	0	0	0	0	0	3.24	1.72	1.09	0.55	0.23
Green turtle	3.88	1.73	1.14	0.18	0	0	0	0	0	0	3.75	2.03	1.22	0.61	0.24

[a] Listed as Endangered under the ESA.

I.3. Animat Seeding Areas

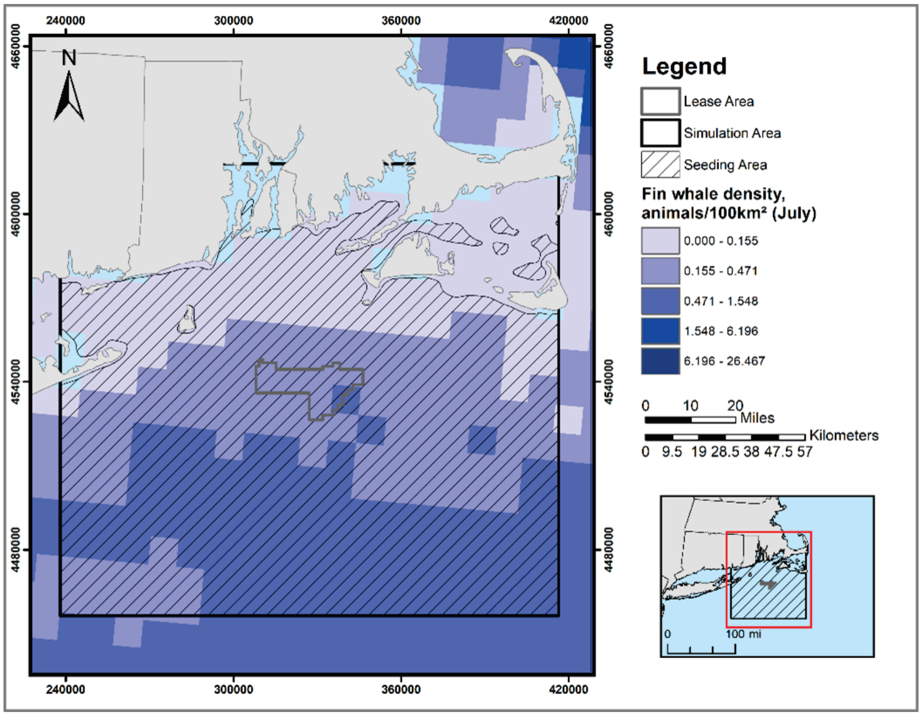

Figure I-1. Map of fin whale animat seeding range for July, the month with the highest density.

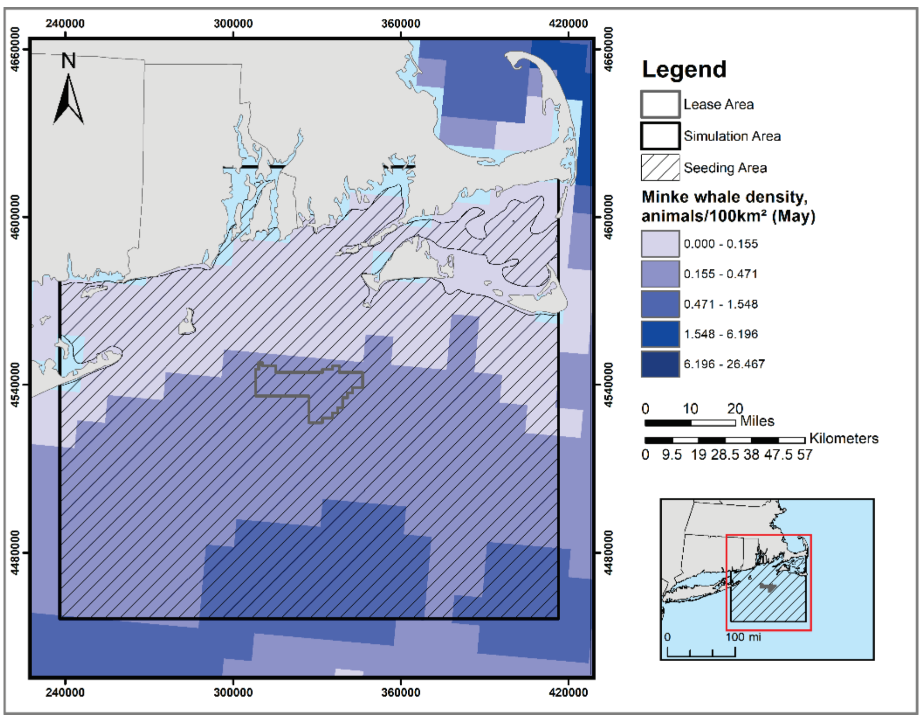

Figure I-2. Map of minke whale animat seeding range for May, the month with the highest density.

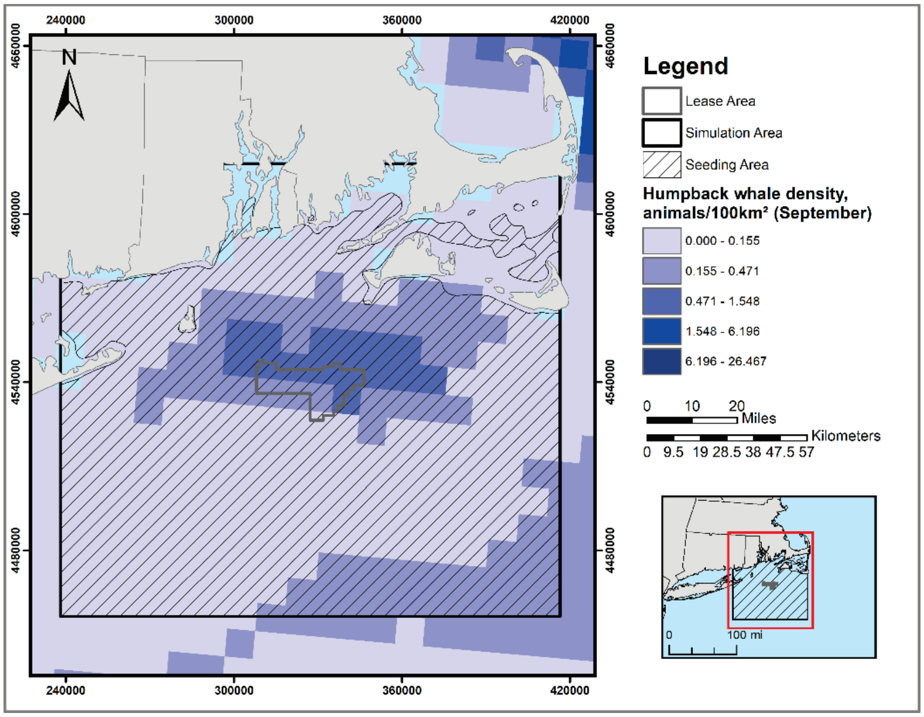

Figure I-3. Map of humpback whale animat seeding range for September, the month with the highest density.

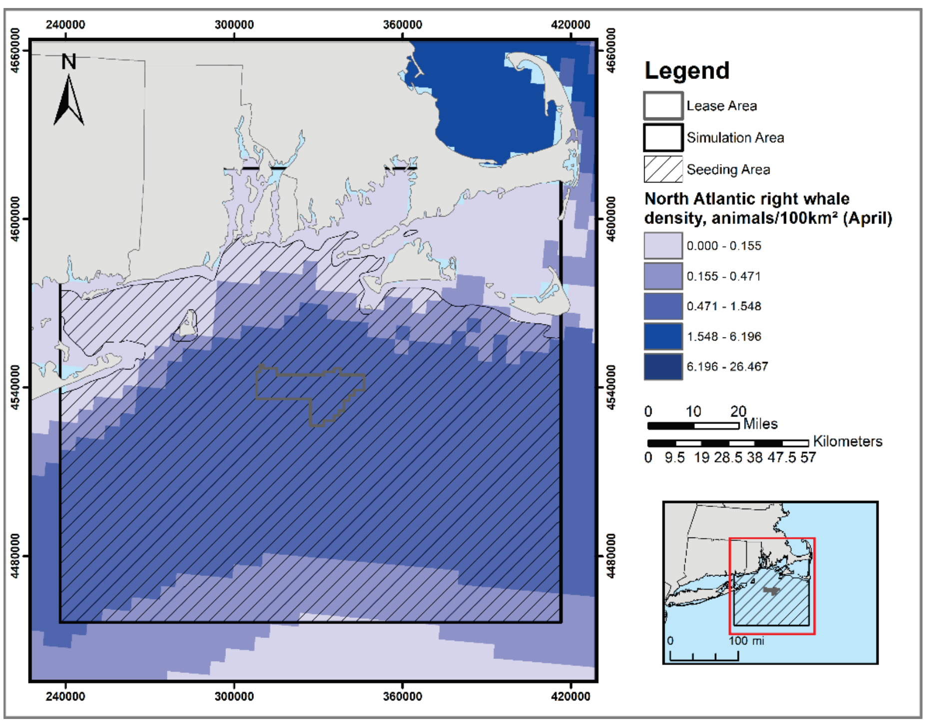

Figure I-4. Map of North Atlantic right whale (NARW) animat seeding range for April, the month with the highest density.

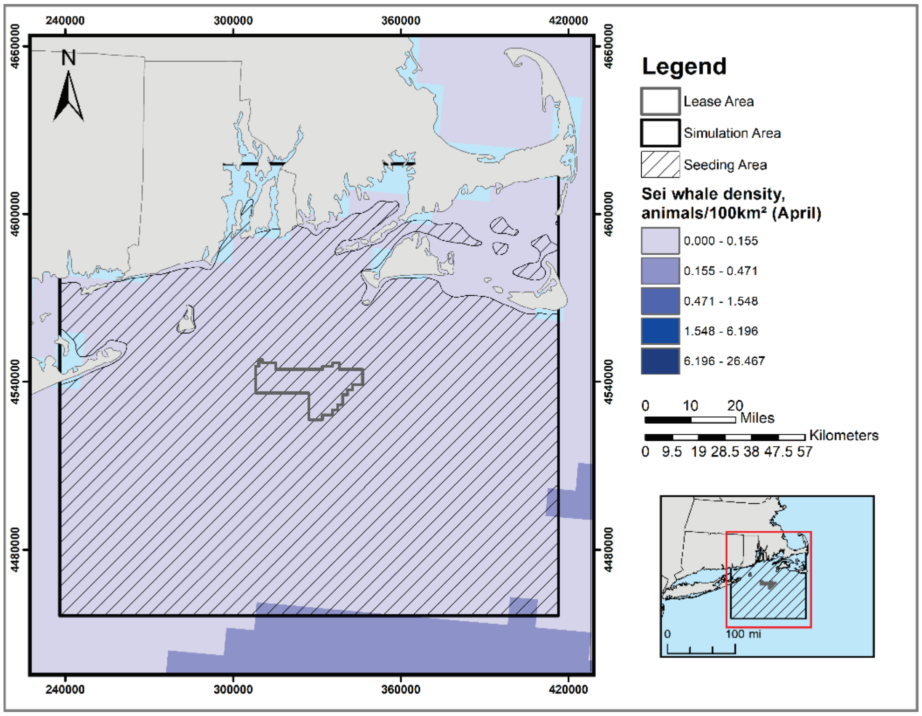

Figure I-5. Map of sei whale density for April, the month with the highest density.

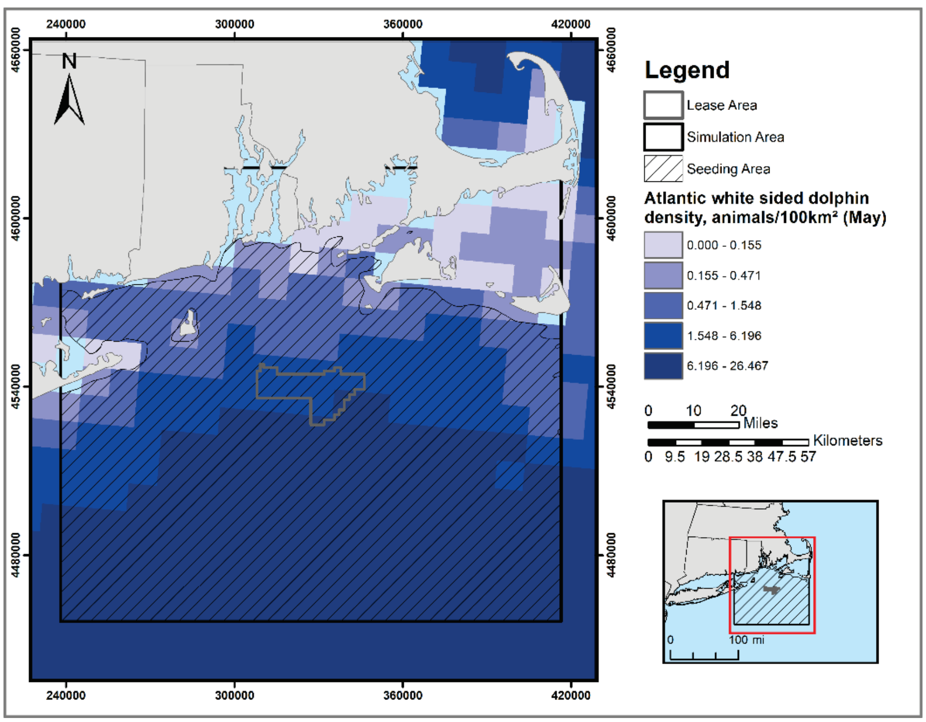

Figure I-6. Map of Atlantic white sided dolphin (AWSD) animat seeding range for May, the month with the highest density.

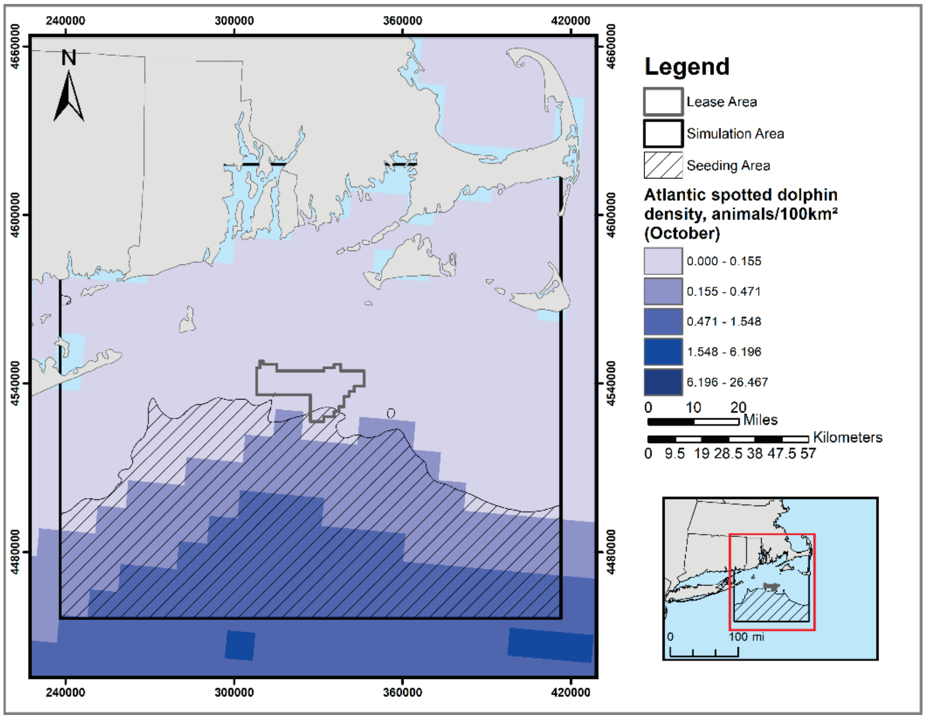

Figure I-7. Map of Atlantic spotted dolphin animat seeding range for October, the month with the highest density.

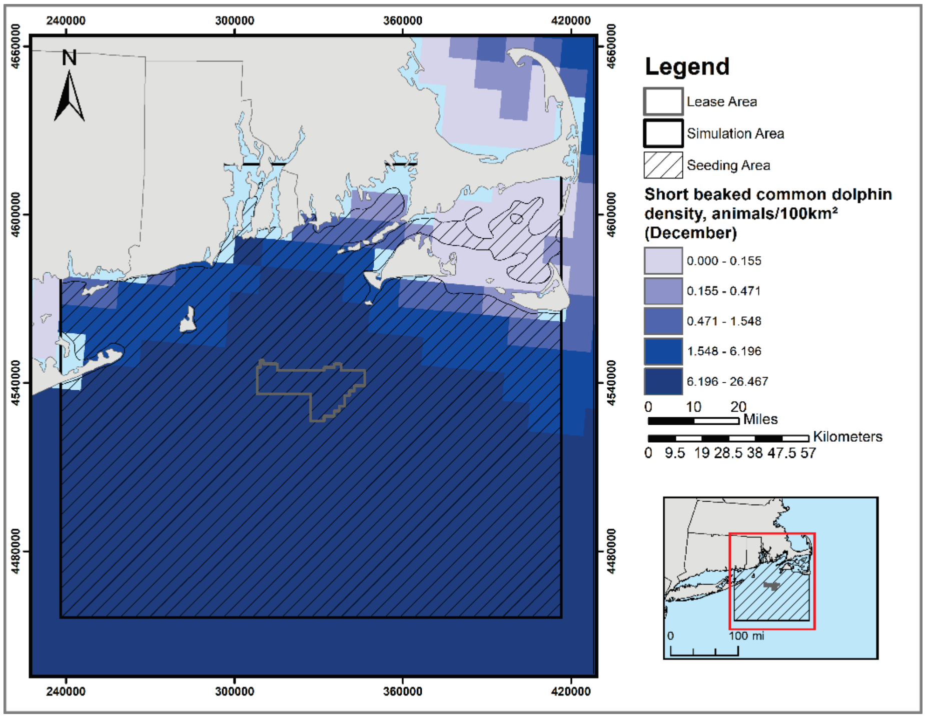

Figure I-8. Map of short beaked common dolphin (SBCD) animat seeding range for December, the month with the highest density.

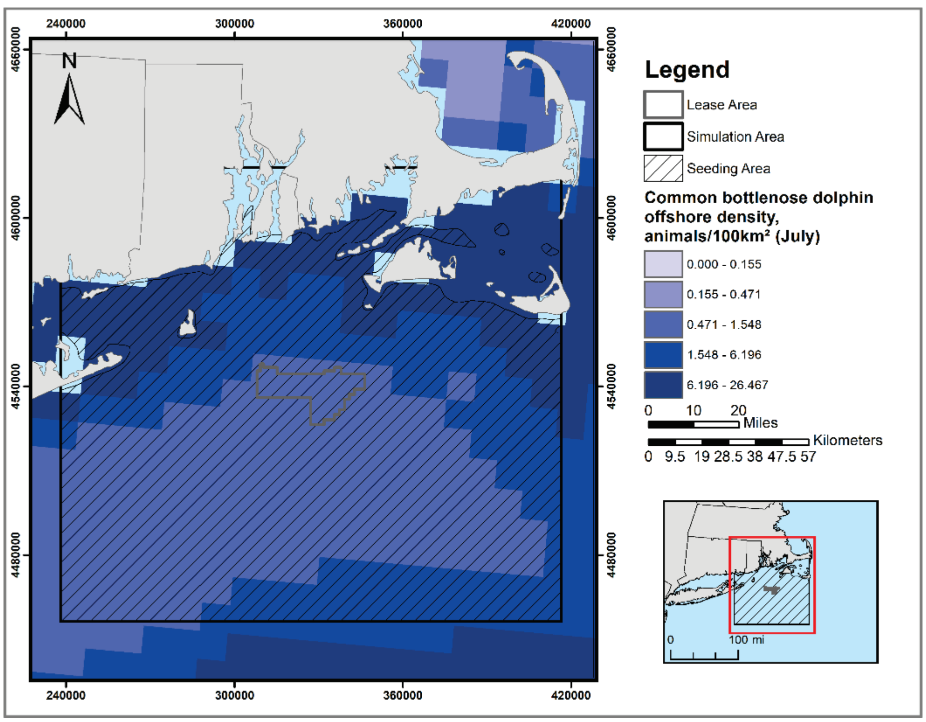

Figure I-9. Map of common bottlenose dolphin animat seeding range for July, the month with the highest density.

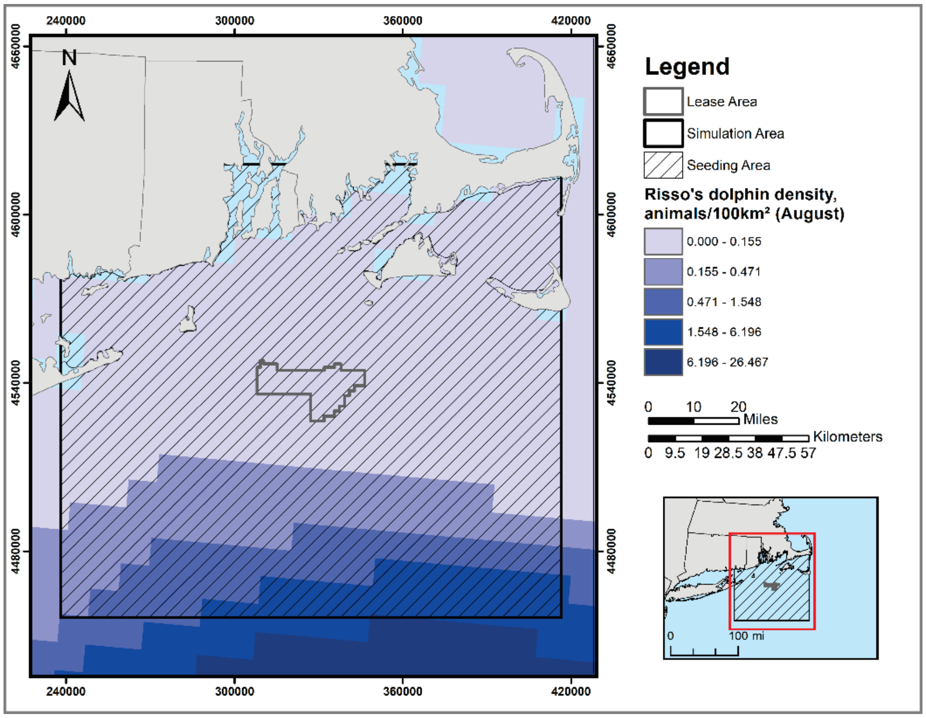

Figure I-10. Map of Risso's dolphin animat seeding range for August, the month with the highest density.

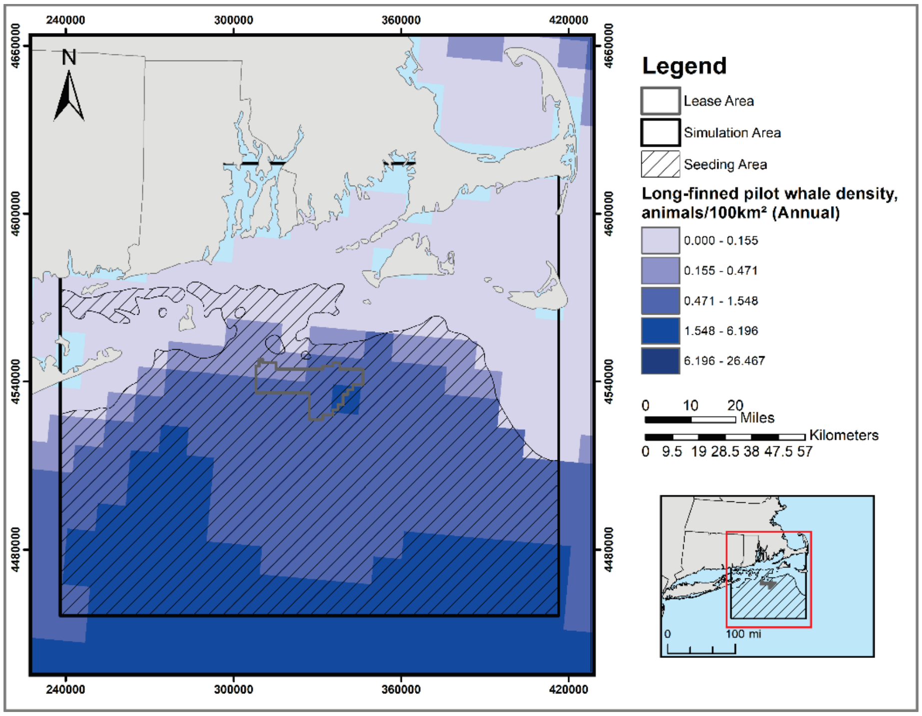

Figure I-11. Map of long-finned pilot whale animat seeding range.

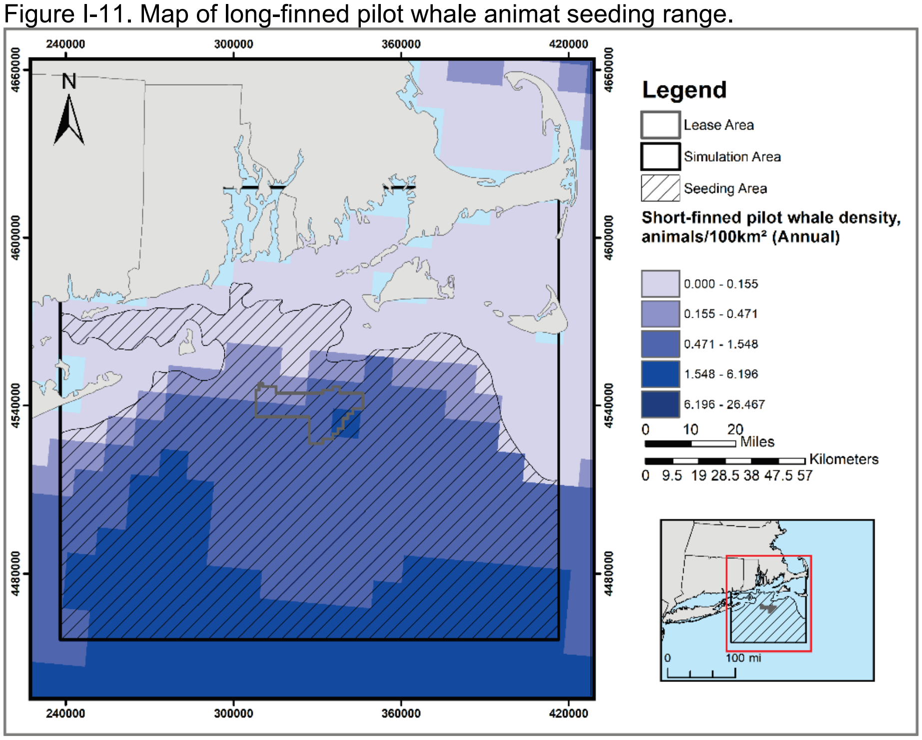

Figure I-12. Map of short-finned pilot whale animat seeding range.

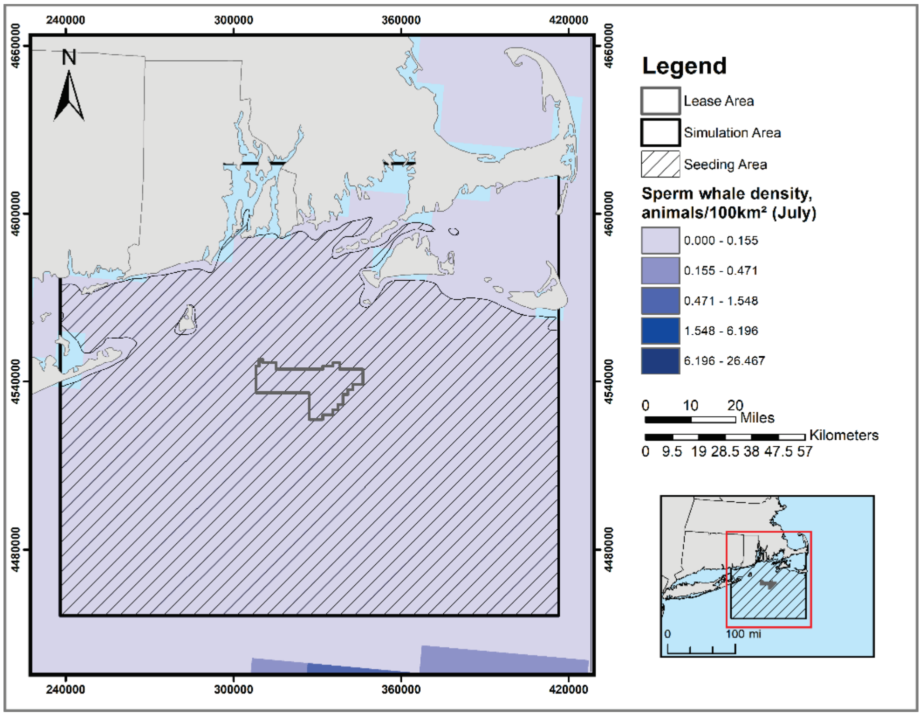

Figure I-13. Map of sperm whale animat seeding range for July, the month with the highest density.

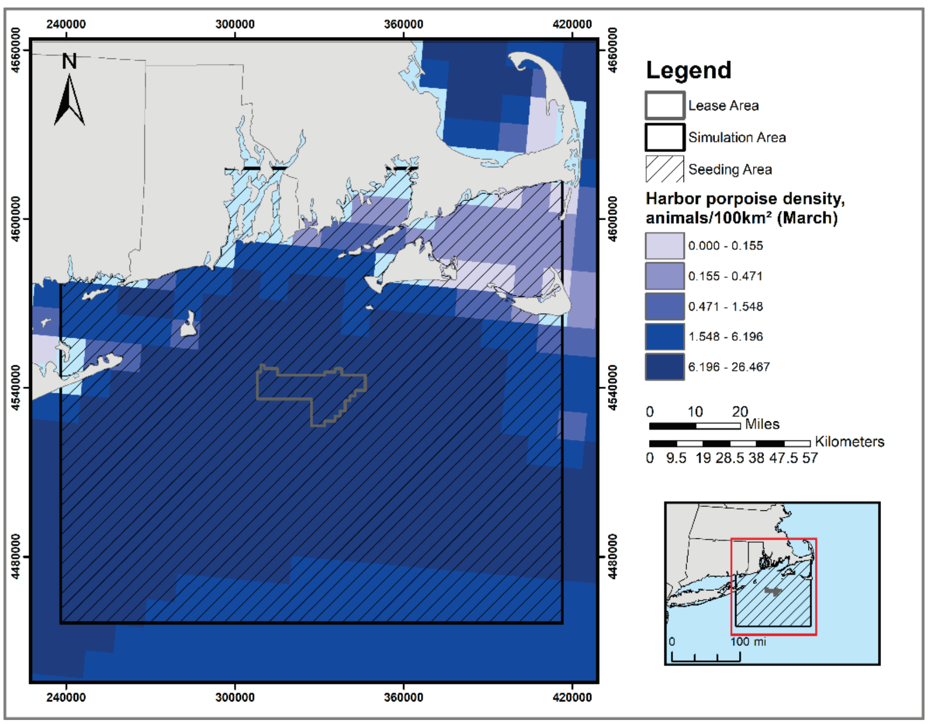

Figure I-14. Map of harbor porpoise animat seeding range for March, the month with the highest density.

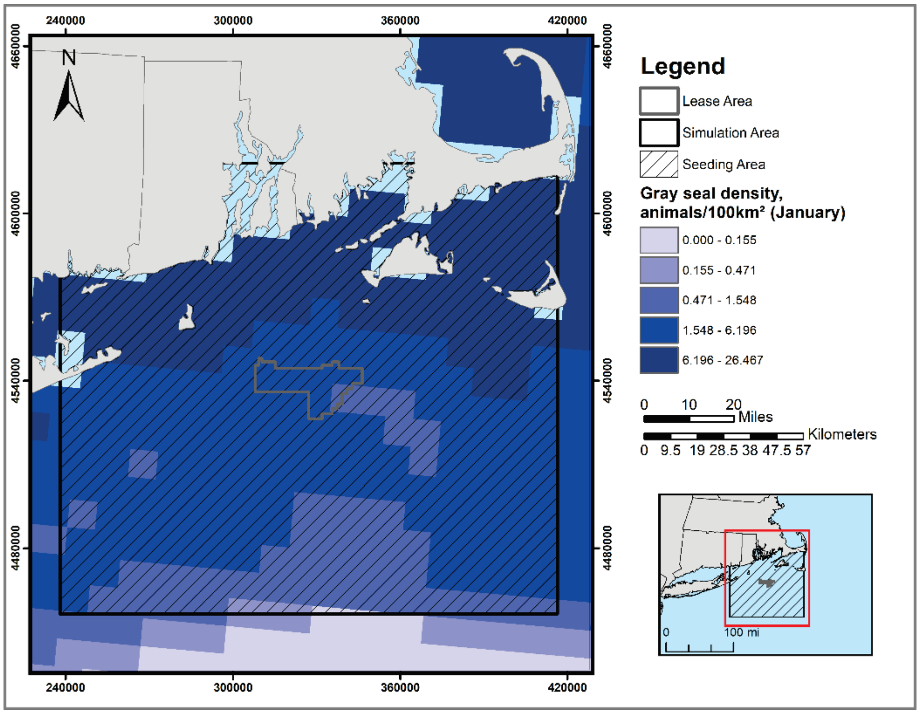

Figure I-15. Map of gray seal animat seeding range for January, the month with the highest density.

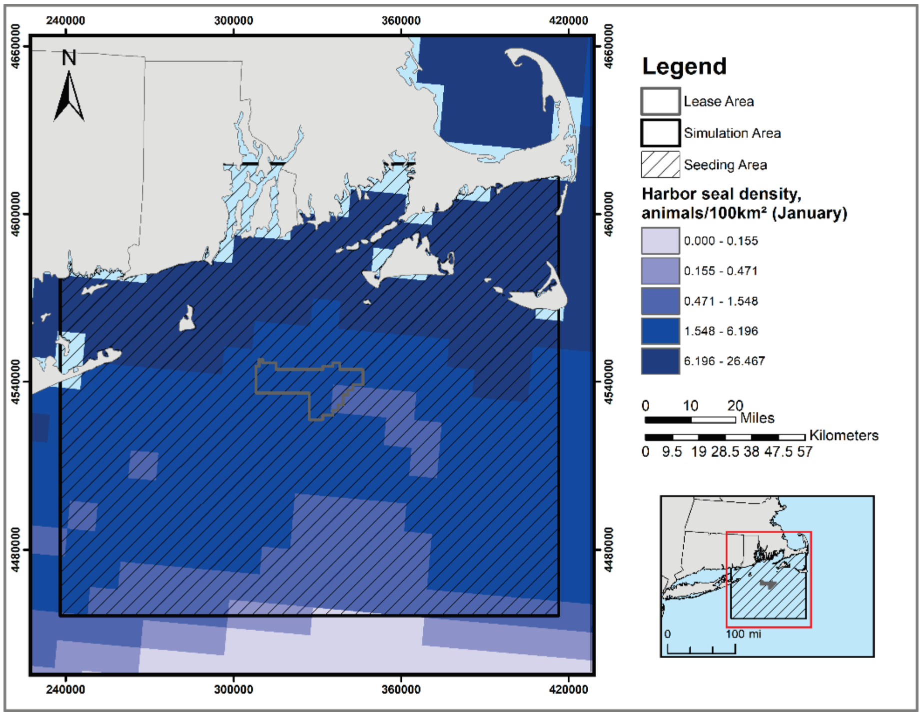

Figure I-16. Map of harbor seal animat seeding range for January, the month with the highest density

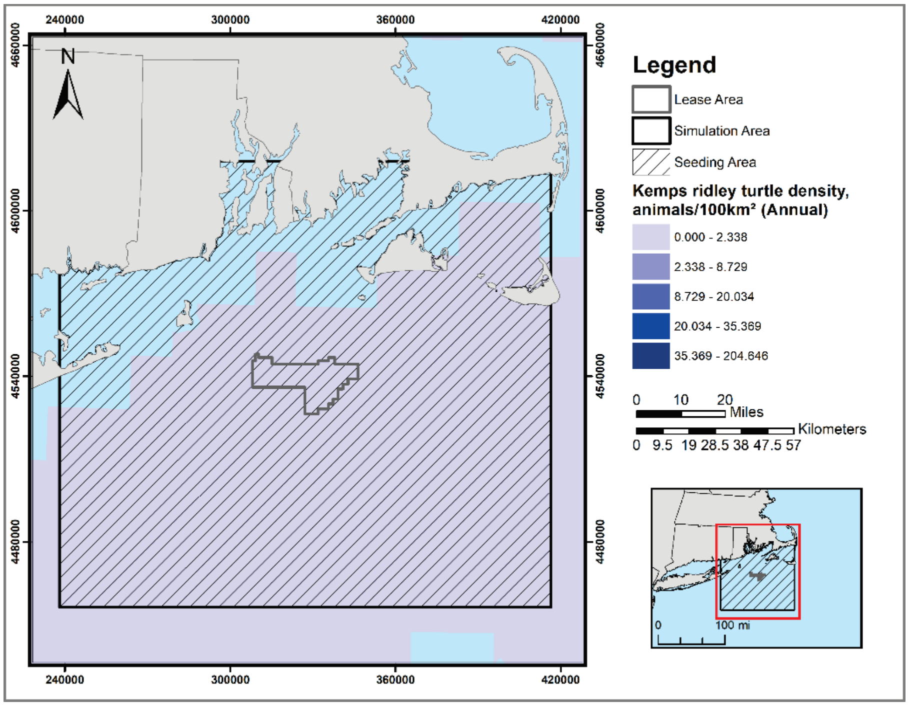

Figure I-17. Map of Kemps ridley sea turtle animat seeding range with annual density from DoN (2017).

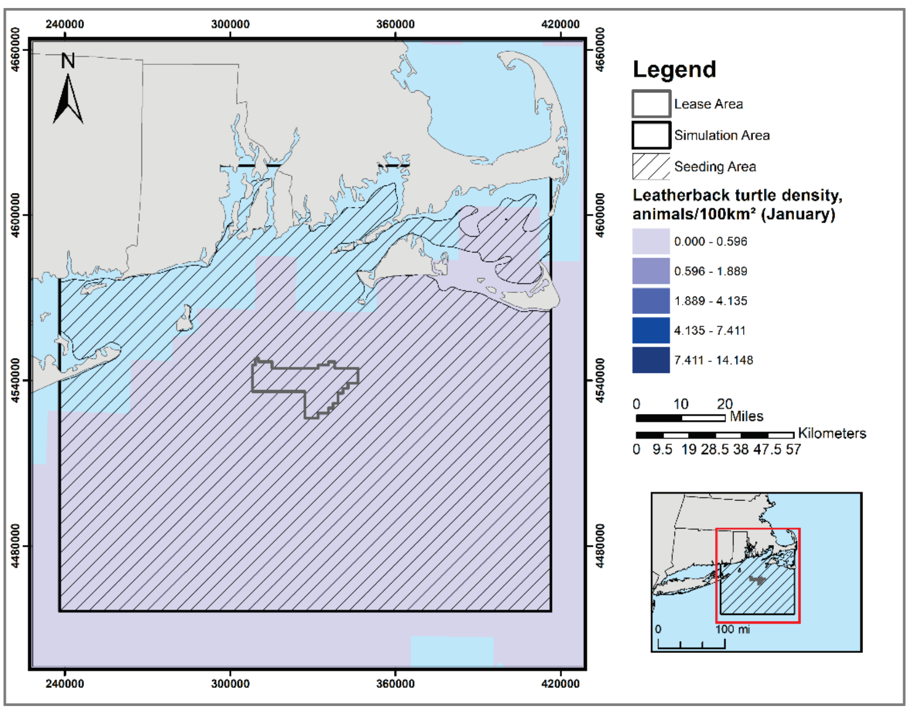

Figure I-18. Map of leatherback sea turtle animat seeding range with density from DoN (2017) for spring, the season with the highest density.

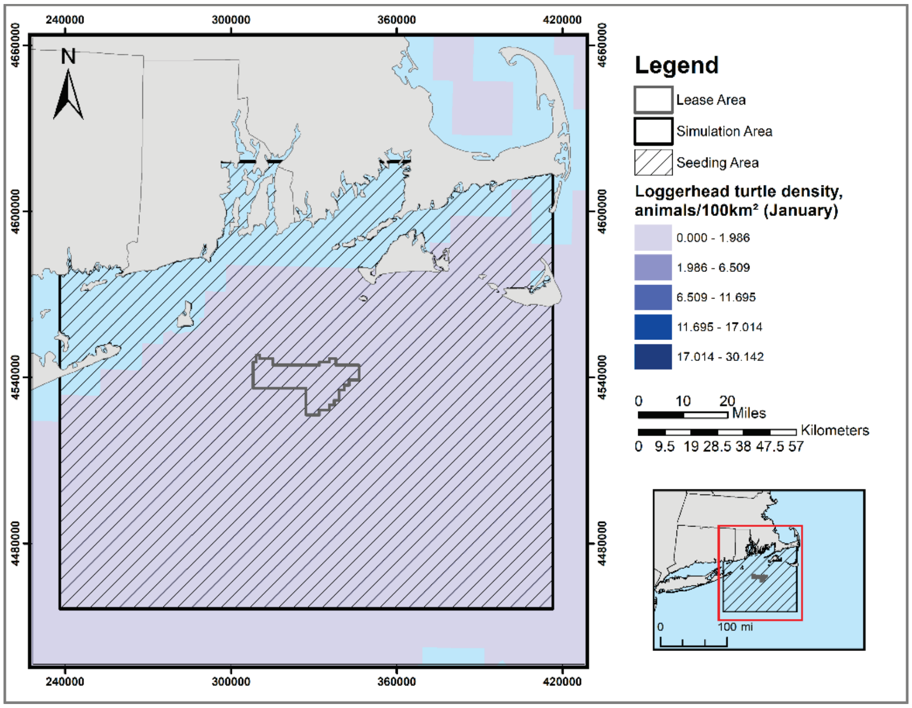

Figure I-19. Map of loggerhead sea turtle animat seeding range with density from DoN (2017) for summer, the season with the highest density.

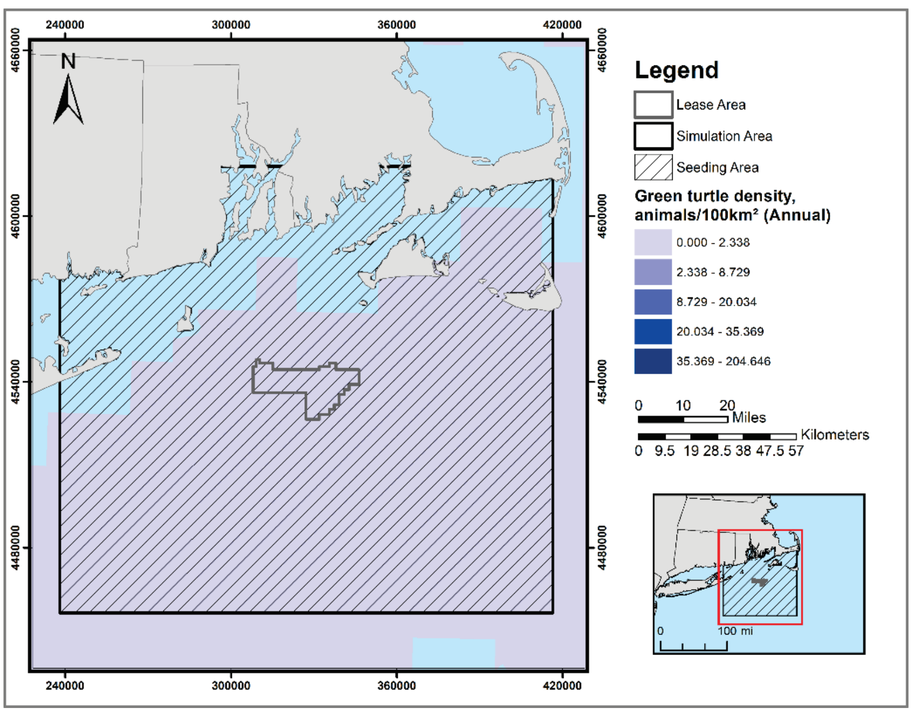

Figure I-20. Map of green sea turtle, showing Kemp's ridley sea turtle annual density from DoN (2017) as an estimate.