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VINEYARD WIND

Draft
Construction and Operations Plan

Volume III
Appendices

Vineyard Wind Project

October 22, 2018

Submitted by
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Submitted to
Bureau of Ocean Energy Management
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Sterling, Virginia 20166

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October 22, 2018

Appendix III-M

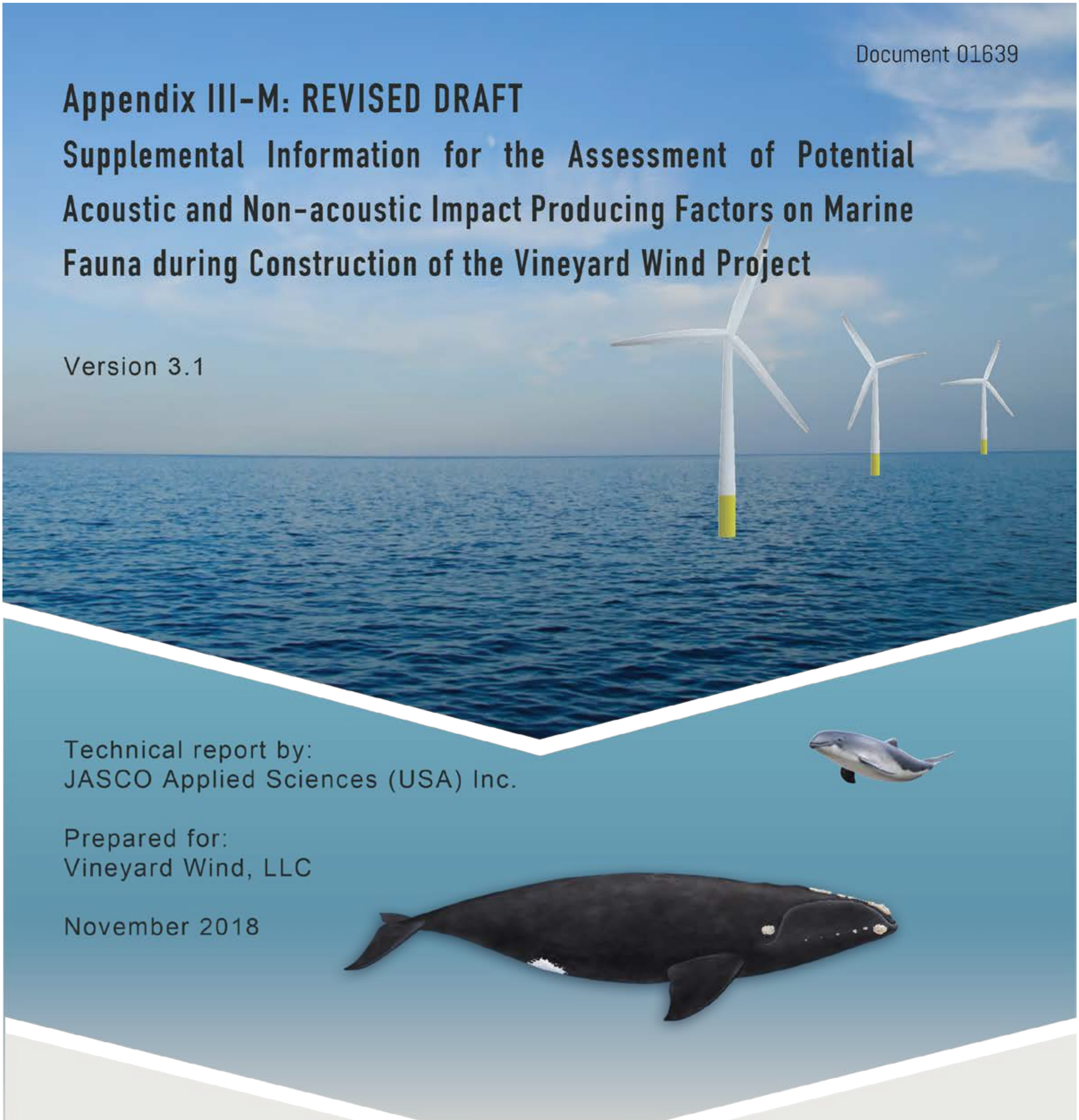
DRAFT - Supplemental Information for the Assessment of Potential Impacts to Marine Mammals and Sea Turtles During Construction, Operation, and Decommissioning of the Vineyard Wind Project

Document 01639

Appendix III-M: REVISED DRAFT

Supplemental Information for the Assessment of Potential Acoustic and Non-acoustic Impact Producing Factors on Marine Fauna during Construction of the Vineyard Wind Project

Version 3.1



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November 2018

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Disclaimer:

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

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Acronyms and Abbreviations

AMAPPS	Atlantic Marine Assessment Program for Protected Species
BMP	best management practice
BOEM	Bureau of Ocean Energy Management
CalTran	California Department of Transportation
COP	Construction and Operations Plan
CRESLI	Coastal Research and Education Society of Long Island
dB	decibel
ESA	Endangered Species Act
ESP	electrical service platform
FR	Federal Register
Hz	hertz
IPF	impact producing factor
JASMINE	JASCO’s Animal Simulation Model Including Noise Exposure
L_{E}	sound exposure levels
L_{p}	sound pressure levels
L_{pk}	peak thresholds
µPA	microPascal
MA WEA	Massachusetts Wind Energy Area
MA/RI WEA	Massachusetts/Rhode Island Wind Energy Area
MMPA	Marine Mammal Protection Act
NARW	North Atlantic Right Whale
NEFSC	Northeast Fisheries Science Center
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PTS	permanent threshold shift
rms	root mean square
SAR	stock assessment report
SEFSC	Southeast Fisheries Science Center
SPL	sound pressure level
TNASS	Trans North Atlantic Sightings Survey
TTS	temporary threshold shift
U.S.C.	United States Code
USCG	United States Coast Guard
USEPA	United States Environmental Protection Agency
WDA	Wind Development Area
WTG	wind turbine generator

Executive Summary

Vineyard Wind, LLC (Vineyard Wind) is proposing to construct a commercial wind energy project (the Project) within Bureau of Ocean Energy Management (BOEM) Lease Area OCS-A 0501, which is located off the coast of Massachusetts. Vineyard Wind intends to install wind turbine generators (WTGs) and electrical service platforms (ESPs) in the northeast portion of the Lease Area, referred to as the Wind Development Area (WDA). The Construction and Operations Plan (COP) provides a detailed description of the Project, including a tentative schedule outlined in Section 1.5.3 of Volume I of the COP (July 2018). The Project COP was submitted for review to BOEM on December 19, 2017. Pursuant to this review, BOEM provided technical comments to Vineyard Wind, and requested additional detail on specific acoustic and non-acoustic impacts to marine fauna during Project construction. For additional information on species presence and environmental baseline for marine mammals and sea turtles, please see Sections 6.7 and 6.8 of Volume III of the COP.

This supplemental document was prepared to address BOEM's request for further information on acoustic and non-acoustic impact producing factors (IPFs) of the Project. These IPFs include noise from pile driving, habitat modification, and vessel traffic during construction. The marine species evaluated include marine mammals and other marine fauna, such as sea turtles, that may occur in or near the WDA and surrounding area. The assessment uses the most recent science available in the peer-reviewed literature relative to sound propagation, animal movement modeling, and potential impacts to and responses by marine species that may be present in the vicinity of the Project.

JASCO Applied Sciences (JASCO) conducted acoustic modeling of underwater sound generated during piling installation (Appendix A). The sound energy from pile driving is transmitted into the water from both the pile wall and through marine sediments. Acoustic models predict the levels of this sound energy, and ranges to acoustic thresholds in water that may result in injury to marine fauna, or that have the potential to elicit behavioral response.

The basic modeling approach is to characterize the sound source, and then determine how the sounds propagate in specific construction areas in multiple seasons and how they are potentially received by marine species. The modeling results inform an analysis of the potential effects of pile driving on marine species that may be present near the WDA during construction. In this study, a conservative modeling approach was adopted to account for both adjustments to Project plans and environmental variability. Two scenarios were modeled in the study: Maximum Design and Most Likely. Each of these scenarios were modeled to assess the installation of one- and two-piles per day. These scenarios include the two potential WTG and ESP foundation types in the Project Envelope: monopiles (larger diameter steel piles) and jackets (steel structures that include either three or four smaller diameter piles connected with welded steel tubular cross bracing). The Maximum Design scenario considers the installation of up to 90 monopiles and 12, four-pile jackets. The Most Likely scenario considers the installation of up to 100 monopiles and two, four-pile jackets. Both scenarios were modeled over a construction period that excluded the months of January to April when endangered North Atlantic Right Whales (NARW) (*Eubalaena glacialis*) are likely to be present in relatively high numbers. This reflects Vineyard Wind's self-imposed prohibition on pile driving in these months for the protection of this species.

Acoustic characteristics of the output signal from the piling activities proposed for the Project scenarios were predicted using finite difference and wave equation source models. The resultant sound fields were then modeled to determine total sound propagation in the WDA and surrounding area. Ranges to various sound level isopleths were estimated for permitting, monitoring, and mitigation purposes; and the sound fields were combined with JASCO's Animal Simulation Model Including Noise Exposure (JASMINE) to estimate potential injurious and behavioral exposure levels for marine species near the proposed construction activities. Animal aversion to sound and mechanism for recovery (or resetting) was included in JASMINE for sensitive species including the NARW and the Harbor Porpoise (*Phocoena phocoena*). The use of sound reduction technology mitigation was assessed for multiple levels of attenuation. Although many scenarios were assessed to determine a range of potential impacts, the final determinations herein are reflective of the Maximum Design scenario, which is a conservative approach.

Acoustic thresholds used in this study represent the best available science on the effects of sound on marine mammals (NMFS 2018; Wood, Southall, & Tollit, 2012) and sea turtles (Popper et al., 2014). The NMFS (2018) Technical Guidance document includes acoustic criteria for potential onset of temporary and permanent threshold shift in marine mammals. Wood et al. (2012) used a frequency weighted metric to assess probability of behavioral response to impulsive sounds. The Wood et al. criteria are also limited to marine mammals. The Guidelines established by Popper et al. (2014) represent the consensus efforts of a scientific working group to establish sound exposure guidelines for sea turtles, fishes and fish eggs and larvae, across the complete range of taxa and sound types, considering mortality and injury.

Project pile driving sounds are predicted to attenuate to background levels over several kilometers (km) assuming an unobstructed straight line. Seabed surface features and marine infrastructure will increase the attenuation of sound; therefore, modeled ranges to sound levels that could potentially elicit behavioral response are considered conservative. Additionally, in all cases where comparative analyses were completed for ranges and exposures to assess the impact of sound reduction mitigation, the mean of the maximum number was used. This is also a conservative approach.

Overall, the predicted exposure results expressed as potential impacts to species' abundance indicate very low (negligible) impact rating to mid- and high-frequency cetaceans and pinnipeds, regardless of the scenario or number piles driven per day, for both potential injury and behavioral disruption. While individual animals may be exposed, the number of animals affected is small relative to the size and health of their populations. Of this group, only Sperm Whales (*Physeter macrocephalus*) are endangered, but due to their low density in the WDA and preference for deep water, the predicted impact to this species is negligible (0% of population). A small number of pinnipeds (< 2 Harp Seals [*Pagophilus groenlandicus*] and < 1 animal for each of Gray [*Halichoerus grypus*] and Harbor Seals [*Phoca vitulina*]) were predicted to receive injurious levels of sound without attenuation of the piling source. Without attenuation, ~13 Harbor Porpoises were predicted to receive injurious levels of sound based on exposures exceeding the unweighted, peak sound pressure (PK) threshold. With attenuation ranging from 6–12 dB, the number of Harbor Porpoise predicted to receive injurious levels of sound decreases to < 2–6 animals, and injurious impacts to pinnipeds are < 1 animal for each species. These estimates do not include modeled aversive behavior. When aversion was included in the Harbor Porpoise modeling, zero animals received sound at injury threshold levels.

Low-frequency cetaceans are more likely to exceed the sound exposure level (SEL) exposure threshold. This occurs because the hearing frequency of this group overlaps with the highest energy frequency bands produced during pile driving. In the Maximum Design scenario with two piles installed per day, without attenuation, the predicted potential risk of injurious exposures expressed as a percentage of species abundance is very low (e.g., 0.10% of Minke Whale [*Balaenoptera acutorostrata*], 0.37% of Fin Whale [*Balaenoptera physalus*], 0.13% of Sei Whale [*Balaenoptera borealis*] population), and low (e.g., 1.66% of NARW and 1.56% of Humpback Whale [*Megaptera novaeangliae*] population). However, sound attenuation mitigation is proposed for the Project, which significantly reduces the number of predicted exposures as a percentage of abundance for all species, including mysticetes. For the critically endangered NARW, modeled sound attenuation by 12 dB reduces the number of predicted animals potentially exposed to injurious levels of sound to less than 0.10 animals in the Maximum Design scenario, and less than 0.06 (nearly zero) animal in the Most Likely scenario, 0.03% and 0.02% of the species' population respectively.

This result is consistent for all low-frequency cetaceans. With a targeted sound reduction of approximately 12 dB using sound attenuatuion technologies outlined in Table 31, the number of modeled animals as a percentage of abundance, potentially exposed to injurious levels of sound is reduced to nearly zero in all scenarios, for all species. Therefore the impact risk rating for low-frequency cetaceans is very low to negligible. These exposure predictions and ratings for low-frequency cetaceans do not account for aversion, which is commonly seen in mysticetes exposed to anthropogenic sound, nor do they account for other proposed mitigation measures, including ramp-up, zone clearance and monitoring. Therefore, they are conservative estimates. An example model run was conducted for NARW that included aversion. Even without attenuation, the aversion model predicted that the number of NARW that could potentially receive injurious levels of sound was nearing zero.

Assuming 12 dB of attenuation, the largest percentage of a population potentially exposed to behavioral harassment thresholds is just over 2% of NARW. Model exposure estimates for other species have much larger absolute values of potential exposures, so this result is driven by the very low abundance of NARW. Nonetheless, the percentage calculated represents a small portion of the NARW population and very small portions for all other species. Potential exposures at injurious levels are even smaller portions of some populations and effectively zero for most. Assuming no attenuation, the percentage of the NARW population potentially exposed at behavioral harassment levels rises to just over 5%, while most other species remain below 2%. These values and the lower values associated with potential injurious exposures represent small portions of the species populations.

Based on this approach to assessing potential exposures in the context of marine mammal population or stock sizes, impacts to the species present in the region are expected to be negligible.

Using the NMFS injury criteria (unweighted 180 dB L_{p}) with sound exposure estimates, < 1 Loggerhead Turtle (*Caretta caretta*) is predicted to be exposed to an injurious sound level threshold. When attenuation is considered, the number of modeled Loggerhead Turtles estimated to receive injurious exposures decreased to ~0.1. For both Maximum Design and Most Likely scenarios, ~0.1 Leatherback (*Dermochelys coriacea*) and Kemp's Ridley Sea Turtles (*Lepidochelys kempii*) were predicted to receive injurious levels of sound, without attenuation. With attenuation, the predicted number approaches zero. When using the Popper et al. (2014) criteria (210 dB L_{E}, or 207 dB L_{pk}) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014), fewer than one, or approaching zero, animals were predicted to receive injurious levels of sound, with or without attenuation. The calculated radius, using the Popper et al. (2014) criteria, within which, if present, turtles might experience the NMFS injury thresholds with attenuation of 6 and 12 dB, is 67–487 m (220–1598 feet) and 34–153 m (112–502 feet) respectively.

The behavioral criteria used by the NMFS for sea turtles is an unweighted 166 dB SPL (NSF, 2011). This level of sound is predicted to propagate to a range of approximately 4 km (2.5 miles) from the piling source. Exposure results predict approximately three Loggerhead Turtles would receive sound levels sufficient to result in a behavioral response for the modeled scenarios without attenuation. With attenuation, the predicted number of Loggerhead Turtles expected to experience a behavioral response is ~2 for 6 dB of attenuation and ~1 for 12 dB of attenuation. Models predict that fewer than one each of Leatherback and Kemp's Ridley Sea Turtles may potentially receive sound levels above the behavioral threshold without attenuation, and even less with attenuation.

Mitigation measures implemented during pile driving can decrease the potential impacts to marine species by reducing the zone of potential impact and therefore the likelihood of injurious sound exposure. Mitigation measures under consideration to achieve these sound reductions for the Project include but are not limited to: equipment selection that is optimized for sound reduction (Integrated Pile Installer), underwater noise abatement systems (e.g., AdBm encapsulated bubble sleeve), and/or bubble curtains. Various studies have demonstrated that these mitigation measures are capable of attenuating sounds by approximately 10 to 23 dB (Christopherson & Lundberg, 2013; Reinhall, Dardis, & Dahl, 2015). A California Department of Transportation (CalTrans) study tested several sound reduction systems and found that they resulted in 10–15 dB of attenuation in good conditions (Buehler, Oestman, Reyff, Pommerenck, & Mitchell, 2015). Attenuation levels also vary by equipment type, frequency band, and location. Various levels of attenuation ranging from 0–12 dB were modeled for the Project (Appendix A). Given the limitations of effectiveness predictability, Vineyard Wind will implement sound attenuating mitigation measures targeting the more attainable, up to approximately 12 dB sound level decrease, to reduce the potential for impact to marine species.

Vineyard Wind will implement mitigation measures to reduce the potential for negative impacts to marine fauna. While protection of marine mammals is a top priority, environmental and human health and safety is the very highest priority in working in the offshore environment; therefore, exceptions to mitigation may be made under certain circumstances. Mitigation measures proposed to reduce potential acoustic and non-acoustic impacts include:

Monitoring & mitigation measure	Description	Anticipated regulatory requirement	Enhanced mitigation	Additional information
Mitigation for All Marine Mammals and Sea Turtles During Pile Driving				
Seasonal Restrictions[1]	▪ Vineyard Wind will establish a restriction on pile driving between January 1 and April 30	--	✓	▪ No pile driving activities January - April
Sound Reduction Technology	▪ Vineyard Wind will implement attenuation mitigation to reduce sound levels by a target of approximately 12 dB - A noise attenuation technology will be implemented (e.g., Noise Mitigation System [NMS], Hydro-sound Damper [HSD], Noise Abatement System [AdBm], bubble curtain, or similar), and a second back-up attenuation technology (e.g. bubble curtain or similar) will be on-hand, if needed pending results of field verification	--	✓	▪ Integrated equipment dampening methods ▪ External sound dampening
Sound Field Verification	▪ Sound levels will be recorded for each of the pile types for comparison with model results	✓	✓	▪ One each of the monopiles and jacket piles will be recorded and characterized
Low Visibility Construction Operations	▪ Pile driving will not be initiated when the clearance zone cannot be visually monitored	--	✓	▪ As determined by the lead PSO on duty
Protected Species Observers (PSOs)	▪ A minimum of two PSOs will maintain watch during daylight hours when pile driving is underway ▪ PSOs may not perform another duty while on watch ▪ PSOs may not exceed four consecutive watch hours; must have a minimum two hour break between watches; and may not exceed a combined watch schedule of more than 12 hours in a 24-hour period ▪ All PSOs will have training certificates that meet or exceed BOEM/BSEE criteria or have NMFS approval, or will be pre-approved by NMFS ▪ PSOs will be deployed on the installation vessel ▪ PSOs will check the NMFS Sighting Advisory System for NARW activity ▪ Clearance and monitoring zones will be monitored around the pile center for marine mammals ▪ PSOs will record behavioral activity of animals observed	✓	✓	n/a
Pre-piling Clearance Timing	▪ Clearance zone(s) must be clear for the following time period prior to pile driving - Mysticete whales and sea turtles[2] for 30 minutes - Odontocetes and Pinnipeds for 15 minutes	✓	✓	▪ Use reticle binoculars and/or range sticks
Soft-start	▪ Soft-start will be implemented during pile driving	✓	✓	n/a

Monitoring & mitigation measure	Description	Anticipated regulatory requirement	Enhanced mitigation	Additional information
Passive Acoustic Monitoring (PAM)	▪ A PAM system will be utilized – the system will be identified prior to construction and in consultation with BOEM and NOAA Fisheries ▪ The PAM system will not be located on the installation vessel to avoid interference ▪ A team of trained PAM operators will monitor for acoustic detections ▪ The system will be in operation in accordance with the pre-piling clearance timing	--	✓	n/a
Clearance Zones (radius from pile center)	▪ Monopile and Jacket Installation: - Mysticete Whales: 500 m - Odontocetes, Pinnipeds, and Sea Turtles: 50 m	✓	✓	▪ Proposed clearance zones are based on modeled distances to the NMFS Level A harassment thresholds (both PK and SEL), visual observation capability, and practical offshore implementation. ▪ Clearance zone distances assume longer than expected exposure durations for SEL criteria.
Monitoring Zone (radius from pile center)	▪ PSOs will monitor to the extent practicable - During Monopile Installation: 2,750 m - During Jacket Installation: 2,200 m	✓	✓	▪ Monitoring zones are based on the NMFS Level B harassment criteria (160 dB SPL) and reflect the average distance of two modeled sites.
Shut downs	▪ If a marine mammal or sea turtle is observed approaching the clearance zone, the PSO will request a temporary cessation of pile driving. Where shut-down is not possible to maintain installation feasibility, reduced hammer energy will be requested and implemented where practicable ▪ After shut down, piling can be initiated once the clearance zone is clear for the minimum species-specific time period, or if required to maintain installation feasibility	✓	--	n/a

Monitoring & mitigation measure	Description	Anticipated regulatory requirement	Enhanced mitigation	Additional information
Vessel Strike Avoidance	▪ 100 m (328 feet) will be maintained between all transiting vessels and whales ▪ If a whale is observed within 100 m (328 feet), the transiting vessel will shift engine to neutral and will not re-engage engines until the whale has moved out of the vessel path and beyond 100 m (328 feet) ▪ Transiting vessels will maintain a separation distance of 50 m (164 feet) from pinnipeds and dolphins, except for bow-riding dolphins and pinnipeds that approach the vessel ▪ Vineyard Wind will report sightings of injured or dead protected species			n/a
Additional Pile Driving Mitigation for NARW				
May 1 to May 14	▪ An extended PAM clearance zone of 10 km (radius from pile center) will be implemented for NARW ▪ PAM will be operated 24/7 ▪ Prior to piling, an aerial or boat survey will be conducted across the extended 10 km clearance zone - Aerial surveys will not begin until the lead PSO on duty determines adequate visibility and at least 1 hour after sunrise (on days with sun glare) - Boat surveys will not begin until the lead PSO on duty determines there is adequate visibility - If a NARW is sighted during the survey, piling operations will not be conducted that day unless an additional survey is conducted to confirm the zone is clear of NARW	--	✓	n/a
May 1 to December 31	▪ 60 minute pre-piling monitoring time period ▪ Clearance zone: minimum 1000 m	--	✓	n/a
November 1 to December 31	▪ An extended PAM clearance zone of 10 km (radius from pile center) will be implemented for NARW ▪ An aerial survey, as described above may also be utilized to confirm zone is clear ▪ PAM will be operated 24/7	--	✓	n/a
Additional Vessel Speed Mitigation for NARW				
November 1 to May 14	▪ Vessels will travel at less than 10 knots within the WDA ▪ When transiting to or from the WDA (this will not apply to any transitting in Nantucket Sound, which has been demonstrated by best available science to not provide consistent habitat for NARW) Vineyard Wind will either travel at less than 10 knots or will implement visual surveys or PAM to ensure the transit corridor is clear of NARW	--	✓	n/a

Monitoring & mitigation measure	Description	Anticipated regulatory requirement	Enhanced mitigation	Additional information
DMA	▪ Vineyard Wind will reduce speeds within a DMA to 10 knots unless visual surveys or PAM are conducted, which demonstrate that NARW are not present in the transit corridor, or the animals can be avoided	--	✓	n/a
Year-round	▪ An observer who has undergone marine mammal training will be stationed on vessels transiting to and from the WDA if traveling over 10 knots ▪ 500 m (1640 feet) will be maintained between all transiting vessels and NARW	--	✓	n/a

[1] This restriction is intended to minimize the amount of pile driving that occurs when the migratory NARW is likely to be in the Offshore Project Area and thus limit sound exposure for this endangered species. Density data from Roberts et al. (2016) and survey data (both visual and acoustic) from Kraus et al. (2016) suggest that the highest density of NARWs in the WDA occurs annually in March. Over 93% of the sightings in the Kraus et al. (2016) study occurred from January through April, with no NARWs sighted from May through August.

[2] Consistent with sea turtle clearance times for seismic activity in the Atlantic and Gulf of Mexico - 30 minutes (BOEM 2012, BOEM-NTL-2016-G02).

Acoustic model predictions assume that biological receivers are mobile for the duration of the sound exposure and that sound attenuation will be applied during pile driving.

In addition to acoustic-related IPFs, there is the potential for other non-acoustic environmental impacts arising from the Project. Consistent with the analysis provided in the COP, supplemental evaluations identify potential non-acoustic impacts to marine mammals and sea turtles, including habitat modification and vessel traffic during construction and operation. Analyses of these impacts were most recently conducted by BOEM in the Programmatic Environmental Impact Statement for Alternative Energy Development and Production (BOEM 2016) and in the Commercial Wind Lease Issuance and Site Assessment Activities Environmental Assessments (BOEM 2012). All the potential non-acoustic IPFs are extensively regulated by multiple agencies (e.g., BOEM, USCG, and USEPA). Based on the evaluation, impacts from installation and operation activities are expected to be low, and after mitigation measures are implemented, the residual risk of impacts is expected to be significantly reduced.

1. Introduction

Vineyard Wind, LLC (Vineyard Wind) is proposing to construct a commercial wind energy project (the Project) in Lease Area OCS-A 0501, which is located off the coast of Massachusetts. Vineyard Wind intends to install wind turbine generators (WTGs) and electrical service platforms (ESPs) in the northeast portion of the Lease Area, referred to as the Wind Development Area (WDA) (Figure 1). The Construction and Operations Plan (COP) provides a detailed description of the Project, including a tentative schedule outlined in Section 1.5.3 of Volume I of the COP (July 2018), and the environmental baseline as it pertains to marine mammals and sea turtles. The Project COP was submitted for review to the Bureau of Ocean Energy Management (BOEM) on December 19, 2017. Pursuant to this review, BOEM provided technical comments to Vineyard Wind on February 2, 2018, with a request for supplemental information relating to the potential for additional acoustic and non-acoustic impacts to marine mammals and sea turtles during Project construction.

This supplemental submission was prepared to address BOEM's request for further information on acoustic and non-acoustic impact producing factors (IPFs) of the Project. These IPFs include noise from pile driving, habitat modification, and vessel traffic. The marine species evaluated include marine mammals and other marine fauna, such as sea turtles, that may occur in or near the WDA and surrounding area. The assessment uses the most recent science available in the peer-reviewed literature relative to sound propagation, animal movement modeling, and potential impacts to, and responses by, marine species that may be present in the modeled exposure area.

This supplement is intended to inform BOEM's preparation of an environmental impact statement (EIS) to support review under the National Environmental Policy Act (NEPA), and agency decision on the Vineyard Wind Project. The document is written to complement the existing materials provided in Sections 6.5-6.8 of Volume III of the COP, particularly sub-sections describing potential impacts of the Project related to increased noise, habitat changes, and vessel traffic. During the development of this supplemental submission, Vineyard Wind met with BOEM and the National Oceanic and Atmospheric Administration (NOAA) to understand their respective considerations under NEPA, the Marine Mammal Protection Act (MMPA), and the Endangered Species Act (ESA). Vineyard Wind will separately seek authorization under the MMPA to conduct construction activities.

This document is organized into separate sections for IPFs that describe consequential potential risks to marine mammals, sea turtles, and other marine fauna species that may be present in the WDA and surrounding region during the construction of the Project. Appendix A of this supplemental submission provides a complete analysis of acoustic sources and propagation modeling with respect to pile driving. The acoustic analysis report includes modeled sound levels, main frequency bands for the two foundation types under consideration (monopiles and jacket piles), and the estimated duration, number of strikes, and pile-driving energy required to install each pile. Vineyard Wind provided the requisite information on pile-driving energy, number of strikes, and duration for the acoustical analysis. Figure 1 shows an overview of the WDA, with the Project footprint and acoustic modeling sites highlighted. Information provided in this report supersedes that provided in Volume III of the COP, as it incorporates information and modeling results that were not available at the time the previous document was submitted.

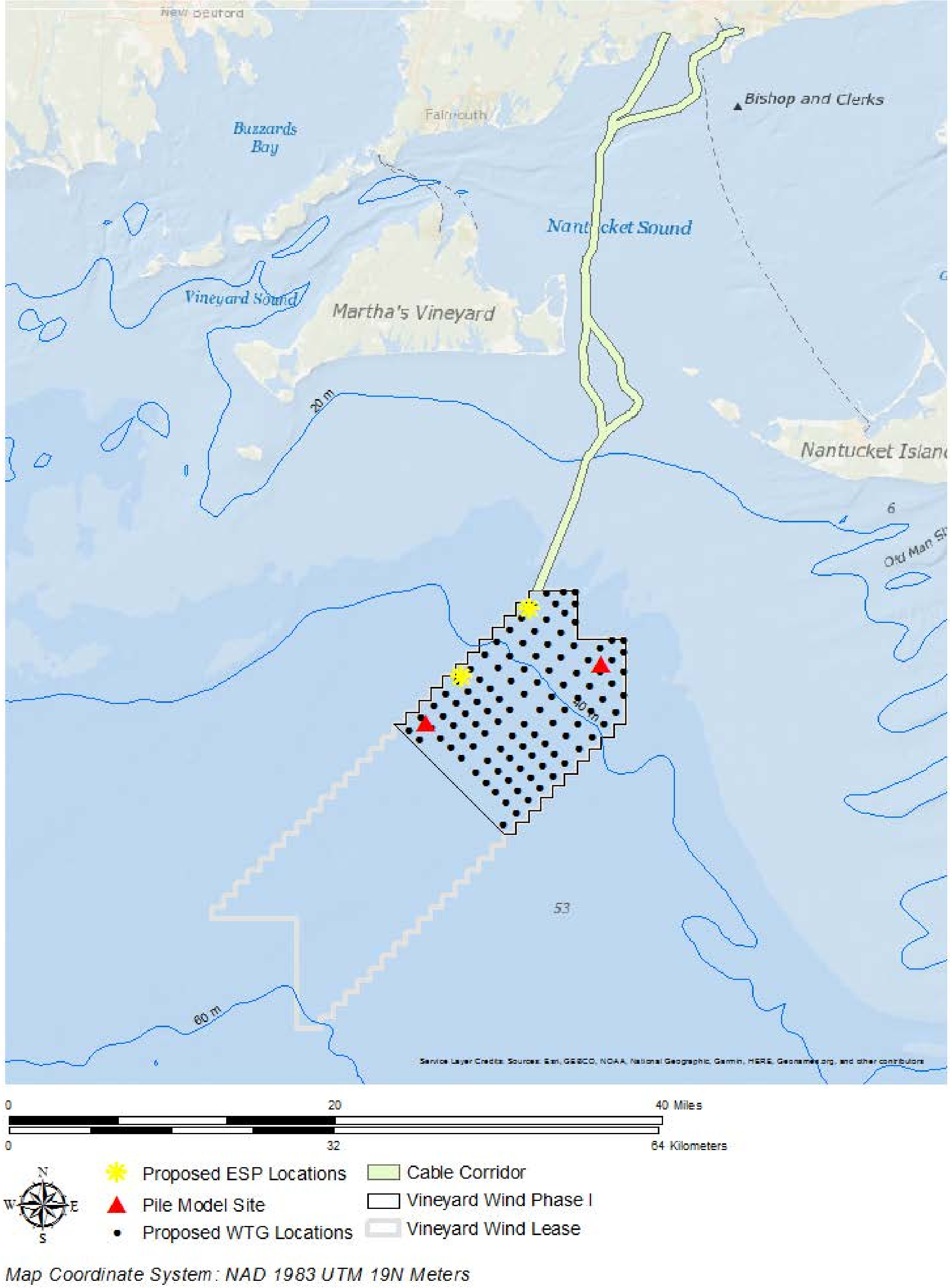

Figure 1. Overview of the WDA with proposed pile locations and modeling sites for impact pile driving.

2. Acoustic Impacts Modeling

2.1. Pile driving as a Source of Sound

When piles are driven with impact hammers they 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 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). 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. These parameters were considered in the acoustic modeling detailed in Appendix A.

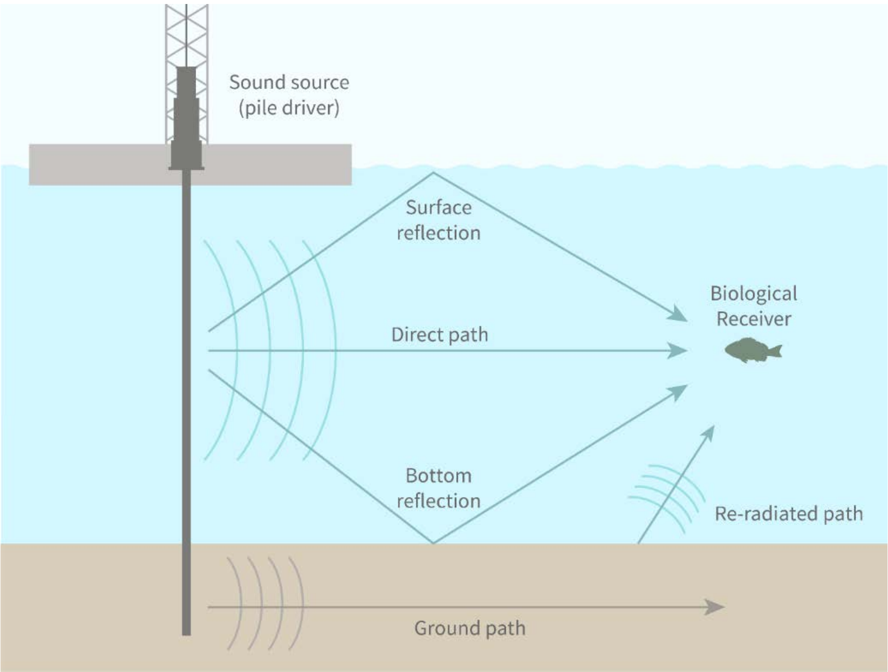

Figure 2. Sound propagation paths associated with pile driving (adapted from Buehler et al., 2015).

Mitigation of pile driving sound focuses on reducing potential impacts to marine fauna such as marine mammals, sea turtles and pelagic fish (described in Sections 6.5–6.8 of Volume III of the COP). The main goal for mitigating potential impacts from pile driving sound on marine aquatic ecology is to minimize, as much as possible, the sound levels from the pile driving source. Doing so reduces the zone of potential impact, thus reducing the likelihood of sound exposure to the biological receiver. Attenuation results for piling mitigation with sound reduction up to 12 dB are assumed in the model for this Project. These reductions may be achieved with various proven technologies outlined in the Project mitigation table (Table 31). Mitigation measures under consideration to achieve these sound reductions for the Project include: equipment selection that is optimized for sound reduction (Integrated Pile Installer) and underwater noise abatement systems (e.g., Hydro-sound Damper, AdBm encapsulated bubble sleeve and/or bubble curtains) deployed near to the pile and farther from the source.

2.2. Acoustic Modeling: Scope and Assumptions

Vineyard Wind is proposing to install up to 100 WTGs and two electrical service platforms (ESPs) in the WDA[1]. Two types of foundations are included in the Project Envelope and were considered in the acoustic modeling study:

- Monopile foundations varying in size with a maximum of 10.3 meter (m) (33.8 feet [ft]) diameter piles, and
- Jacket-style foundation using three-four, 3 m (9.8 ft) diameter (jacket) piles.

The 10.3 m (33.8 ft) monopile foundation is the largest potential pile diameter proposed for the Project and represents the Maximum Design scenario for monopile foundations. Piles for monopile foundations will be constructed for specific locations with maximum diameters ranging from ~8 m (26.2 ft) up to 10.3 m (33.8 ft) and an expected median diameter < 9 m (29.5 ft) . Jacket foundations each require the installation of three to four, 3 m (9.8 ft) diameter jacket securing piles, known as jacket piles. The piles for the monopile foundations are all 95 m (311.7 ft) in length and will be driven to a penetration depth of 20–45 m (65.6–147.6 ft). The 3 m (9.8 ft) jacket piles for the jacket foundations are 65 m (213.3 ft) (WTGs) or 80 m (262.5 ft) (ESPs) maximum length and will be driven to a penetration depth ranging from 30–75 m (98.4–246 ft) (Tables 3.1-3 and 3.1-4 of Volume I of the COP). An IHC S-4000 hammer was modeled for driving piles for the monopile foundations and an IHC S-2500 for driving the 3 m (9.8 ft) jacket piles. Representative hammering schedules of increasing hammer energy with increasing penetration depth were modeled resulting in, generally, higher intensity sound fields as the hammer energy and penetration increases.

Two installation scenarios were considered: 1) the Maximum Design scenario consisting of 90, 10.3 m (33.8 ft) WTG monopile foundations, 10 WTG jacket foundations, and two ESP jacket foundations; and 2) the Most Likely scenario, which is the maximum of the Most Likely installation configuration consisting of 100 10.3 m (33.8 ft) WTG monopile foundations and two ESP jacket foundations[2] (Table 1). Both scenarios assumed four piles for each jacket.

Table 1. Modeling scenarios

Scenario	WTG monopiles (pile size: 10.3 m [33.8 ft])	WTG jacket foundations (pile size 3 m [9.8 ft], 4 piles per jacket)	ESP jacket foundations (pile size 3 m [9.8 ft], 4 piles per jacket)	Total # piles	Total # locations
Maximum Design	90	10	2	138	102
Most Likely	100	--	2	108	102

Both scenarios were modeled assuming the installation of one monopile per day, and for comparison, two monopiles per day distributed across the same calendar period (Tables 2 and 3). One jacket foundation per day (i.e., four piles) was assumed for both scenarios. It was also assumed that no concurrent pile driving will be performed. The pile driving schedules for modeling were provided by Vineyard Wind's engineers, and created based on the number of expected suitable weather days available per month in which pile driving may occur. The number of suitable weather days per month was obtained from historical weather data.

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[1] 106 potential turbine locations were assessed in the COP, to allow flexibility for the Project. However, the maximum number of turbines to be installed is up to 100.

[2] Alternatively, Vineyard Wind may install a single ESP, which may have up to eight piles, and therefore be treated as two, four pile jacket installations.

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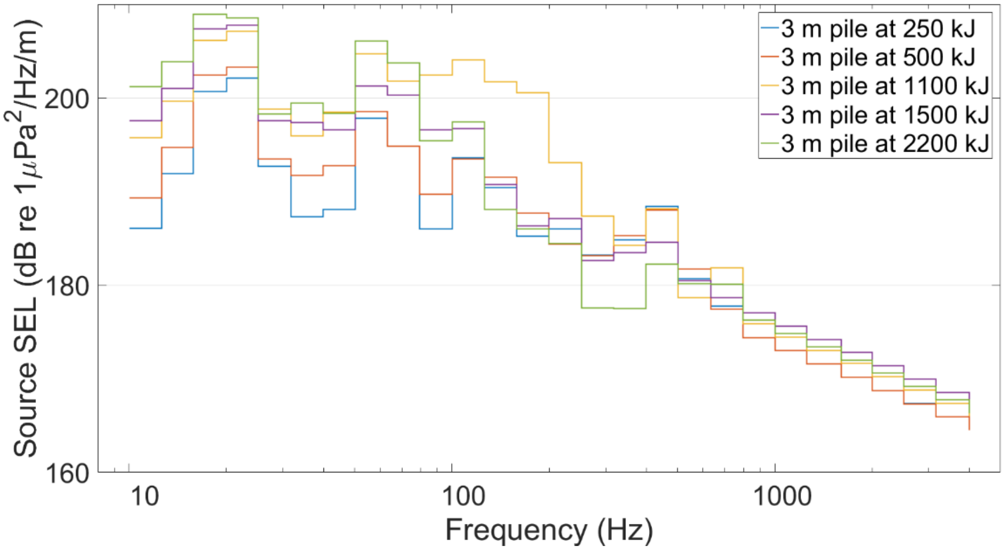

Figure 3. Decidecade-band spectral source levels for jacket pile (3 m [9.8 ft]) installation using IHC S-2500 hammer operating at 250 kJ to 2200 kJ.

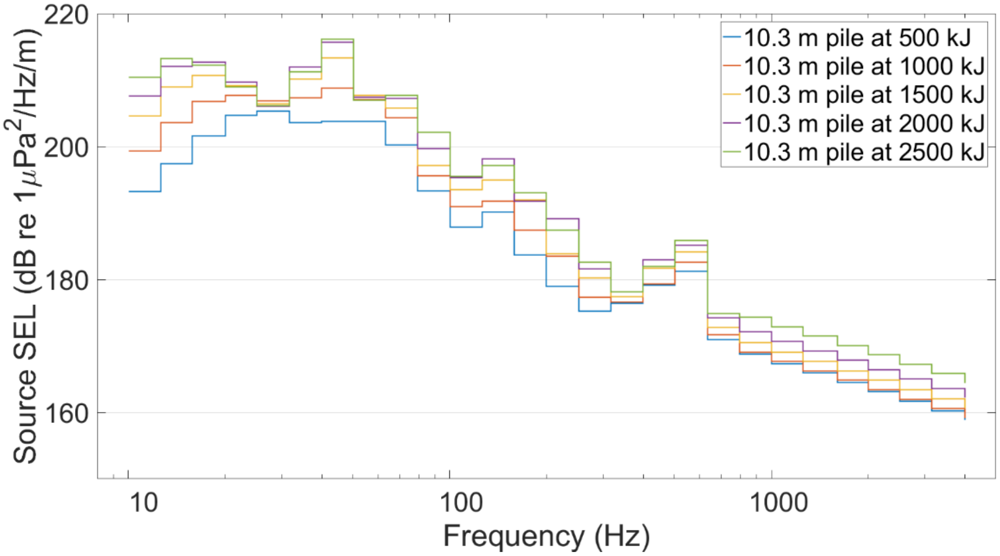

Figure 4. Decidecade-band spectral source levels for monopile (10.3 m [33.8 ft]) installation using IHC S-4000 hammer operating at 500 kJ to 2500 kJ.

3. Acoustic Impact Analysis Methods Overview

To estimate potential effects (e.g., injury, behavioral disturbance) of noise generated during the Project to marine fauna, JASCO performed the following modeling steps:

1. Modeled the spectral and temporal characteristics of the sound output from the proposed pile driving activities using the industry-standard GRLWEAP (wave equation analysis of pile driving) model, and JASCO's Pile Driving Source Model (PDSM). Source model set-up and initialization data was based on pile-driving operational parameters provided by Vineyard Wind.
2. Acoustic propagation modeling using JASCO's Marine Operations Noise (MONM) and Full Wave Range Dependent Acoustic (FWRAM) Models that combined the outputs of the source model with the spatial and temporal environmental context (e.g., location, oceanographic conditions, seabed type) to estimate sound fields (converted to exposure radii for monitoring and mitigation). The lower frequency bands were modeled using MONM-RAM, which is based on the parabolic equation method of acoustic propagation modeling, and the higher frequencies were modeled using MONM-Bellhop, which is a Gaussian-beam ray-theoretic acoustic propagation model.
3. Animal movement modeling integrated the estimated sound fields with species-typical behavioral parameters (e.g., dive patterns, aversion) in the JASCO Animal Simulation Model Including Noise Exposure (JASMINE) model to estimate received sound levels for the animals that may occur in the operational area.
4. Estimated the number of potential injurious and behavioral level exposures based on pre-defined acoustic thresholds/criteria (NMFS 2018).

4. Acoustic Impact Assessment – Marine Mammals

Scientific knowledge of how anthropogenic sound sources may or may not affect marine mammals is rapidly evolving, with significant research investment by industry, government, and academia into improving the understanding of the impacts of sound from pile driving and other industrial operations on marine mammals and the potential for reducing these impacts through mitigation procedures. This analysis employs robust acoustic impact assessment methods that consider pile-specific parameters, environmental conditions relevant to the location and affecting sound propagation, local animal densities, and biological behaviors of the species present in the area.

4.1. Species that May be Present in the Project Area

Of the approximately 133 species of known marine mammals, 26 are known to occur at least occasionally within the WDA. Thirteen cetaceans and three pinniped species are thought to occur in the Massachusetts Wind Energy Area (MA WEA) and the Massachusetts/Rhode Island Wind Energy Area (MA/RI WEA). The remaining 10 species are all considered extralimital strays, and unlikely to occur. Four cetacean species are listed as endangered, with the North Atlantic Right Whale (NARW) (*Eubalaena glacialis*) considered the rarest of all marine mammal species in the Atlantic Ocean. Both common and uncommon species are included in the assessment. Uncommon species include: Sperm Whales (*Physeter macrocephalus*) and Risso’s Dolphins (*Grampus griseus*), which are found in deeper waters than the WDA, and Harp Seals (*Pagophilus groenlandicus*), which are typically found farther north than the WDA (Hayes et al., 2017). In addition, there are two pilot whale species (Long-Finned and Short-Finned Pilot Whales [*Globicephala melas* and *Globicephala macrorhynchus*) with distributions that overlap in the latitudinal range of the Offshore Project Area (Hayes et al., 2017; Roberts et al., 2016). Because it is difficult to discriminate the two species at sea, sightings and thus the densities calculated from them, are generally reported together as *Globicephala* spp. (Hayes et al., 2017; Roberts et al., 2016). Both Long- and Short-Finned Pilot Whales are treated as one uncommon species in the model. Except for NARW, species that are extralimital, or unlikely to occur in the WDA, are not considered further in the environmental analysis. Marine mammal species resident in the WDA and evaluated in this study are shown in Table 5.

Table 5. Summary of marine mammal species considered in the acoustic exposure analysis.

Species of interest		Hearing group	Estimated auditory bandwidth[1]	Area population status[2]	Referenced materials
Common name	Latin binomial				
Fin whale*	*Balaenoptera physalus*	LF	15 Hz to 10 kHz	Common	(Cranford & Krysl, 2015)
Humpback whale	*Megaptera novaeangliae*	LF	20 Hz to 10 kHz	Common	(Houser, Helweg, & Moore, 2001)
Minke whale	*Balaenoptera acutorostrata*	LF	50 Hz to 10 kHz	Common	
North Atlantic right whale*	*Eubalaena glacialis*	LF	10 Hz to 22 kHz	Common	(Parks, Ketten, O'Malley, & Arruda, 2007)
Sei whale*	*Balaenoptera borealis*	LF	15 Hz to 3.5 kHz	Uncommon	(Baumgartner et al., 2008; McDonald et al., 2005)
Atlantic white sided dolphin	*Lagenorhynchus acutus*	MF	1–100 kHz	Common	
Bottlenose dolphin	*Tursiops truncatus*	MF	150 Hz to 135 kHz	Common	
Long-finned pilot whale	*Globicephala melas*	MF	0.5–80 kHz	Uncommon	(Pacini et al., 2011)
Short-finned pilot whale	*Globicephala macrorhynchus*	MF	0.5–80 kHz	Rare	(Schlundt, Dear, Bowles, Reidarson, & Finneran, 2011)
Risso's dolphin	*Grampus griseus*	MF	1–100 kHz	Uncommon	(Nachtigall et al., 1995; Nachtigall et al., 2005)
Short beaked dolphin	*Delphinus delphis*	MF	1–100 kHz	Common	
Sperm whale*	*Physeter macrocephalus*	MF	0.5–60 kHz	Uncommon	
Harbor porpoise	*Phocoena phocoena*	HF	250 Hz to 180 kHz	Common	(Kastelein 2002)
Gray seal	*Halichoerus grypus*	PW	50 Hz to 30 kHz	Common	
Harbor seal	*Phoca vitulina*	PW	0.5–40 kHz	Common	(Kastelein et al., 2009)
Harp seal	*Pagophilus groenlandicus*	PW	0.75–30 kHz	Uncommon	(Terhune & Ronald, 1972)

[1] Estimates of species auditory bandwidth are from many different sources included in the report bibliography

[2] Categories: common–abundant wherever it occurs in the region; uncommon–may or may not be widely distributed but does not occur in large numbers; rare–present in such small numbers throughout the region that it is seldom seen

* Endangered listing

4.2. Density Estimates

Quantifying the number of animals or the percentage of a population that is at risk of acoustic exposure requires an estimate of the number of animals in that area. Occurrence and abundance estimates are determined from visual and/or acoustic surveys that identify, count, and log the position of species in various waters. From these data, models can be created to provide estimates of occurrence likelihood (surface density) along transect lines and between lines.

Marine mammal density estimates (animals/km^2) used in this assessment were obtained using the Duke University Marine Geospatial Ecological Laboratory model results (Roberts et al., 2016). Jason Roberts supplied an unpublished updated model for NARW densities (Roberts, Mannocci, & Halpin, 2017) that incorporates more sighting data than (Roberts et al., 2016), including sightings from the Atlantic Marine Assessment Program for Protected Species (AMAPPS) 2010–2014, which included some aerial surveys over the MA WEA and MA/RI WEA (NEFSC and SEFSC, 2011a; NEFSC and SEFSC, 2011b; NEFSC and SEFSC, 2011c; NEFSC and SEFSC, 2012; NEFSC and SEFSC, 2013; NEFSC and SEFSC, 2014; NEFSC and SEFSC, 2015; NEFSC and SEFSC, 2016). Density estimates for pinnipeds were calculated using Roberts et al. (2015) density data.

Visual survey studies conducted by BOEM in the Offshore Project Area were reviewed to assess agreement with the Roberts et al. (2016; 2015; 2017) density estimates for NARW and other species (Kraus et al., 2016). Notably, there were no aerial sightings of NARW for the months of May to October, and only four sightings in December across all survey years (October 2011-June 2015) (Kraus et al., 2016). There are no piling activities planned for the Project during January to April, when most of the sightings occurred in the study. Based on a review of the Kraus et al. (2016) survey information, and a comparison with previous efforts to calculate densities using an alternative approach, it was determined that no changes were needed to the Roberts et al. (2016; 2015; 2017) density estimates used in the model.

4.2.1. Uncommon species

Uncommon species, including Sperm Whale, Risso’s Dolphin, Long-finned Pilot Whale, and Harp Seal, are unlikely to be exposed to sound from pile driving due to the relatively short duration of each pile driving event and these species’ unusual occurrence in the WDA. Kraus et al. (2016) reported sightings of only one Sperm Whale in the fall and three groups totaling eight Sperm Whales in the summer over a five year aerial survey study specifically focused on the MA WEA and MA/RI WEA. These sightings occurred in two different years. Only two sightings totaling two Risso’s Dolphins were recorded by Kraus et al. (2016) during the same period. It is difficult to discriminate Long- and Short-finned Pilot Whales at sea, and therefore the densities calculated from sightings of both species are generally reported together as Pilot Whales (*Globicephala* spp.) (Hayes et al., 2017; Roberts et al., 2016). While a small number of the Pilot Whales occurring in the Offshore Project Area could be Short-finned Pilot Whales, it is likely that most of the affected animals from this genus will be Long-finned Pilot Whales. Pilot Whales were observed 11 and three times in the spring and summer, respectively, during aerial surveys of the MA/RI WEA during 2011–2015 (Kraus et al., 2016).

Harp Seals were not observed during any of the AMAPPS surveys. Harp Seals typically breed on pack ice and migrate southward in the fall to areas of Nova Scotia; however, Harp Seals have been observed in US waters (Harris, Lelli, & Jakush, 2002), and Harp Seals have been occasionally recorded on land south of the MA WEA and MA/RI WEA in areas of New York, usually in groups of one or two individuals (CRESLI, 2018). Approximately 11 individuals have been observed by the Coastal Research and Education Society of Long Island (CRESLI) near Long Island since 2008 (CRESLI, 2018). Harp Seals strand in Massachusetts, with a total of 96 recorded strandings from 2007 to 2011 (Hayes et al., 2017). Despite their rarity, uncommon species were included in the modeling effort, with Pilot Whales reported in one category.

4.2.2. Monthly densities

Mean monthly densities for all animals were calculated using a 13 km (8 mile) buffered polygon around the WDA perimeter and overlaying it on the abundance maps from Roberts et al. (2016; 2015; 2017) Figure 5). The 13 km (8 mile) buffer defines the maximum area around the WDA with the potential to result in behavioral disturbance for the 10.3 m (33.8 ft) monopile installation using Wood et al. (2012) thresholds (Table 13). This buffer encompasses and extends well beyond the range of behavioral disturbance for all hearing groups using the NOAA (2005) unweighted thresholds.

The mean density for each month was calculated using the mean of all 10 x 10 km (6.2 x 6.2 mile) grid cells partially or fully within the buffer zone polygon. Mean values from the density maps were converted from units of abundance (animals/100km^2 [38.6 miles^2]) to units of density (animals/km^2). Densities were computed for months May-December to coincide with planned pile driving activities. In cases where monthly densities were unavailable, annual (pilot whales) and seasonal (pinnipeds) mean densities were used instead. Table 6 shows the monthly marine mammal density estimates for each species evaluated in the acoustic analysis.

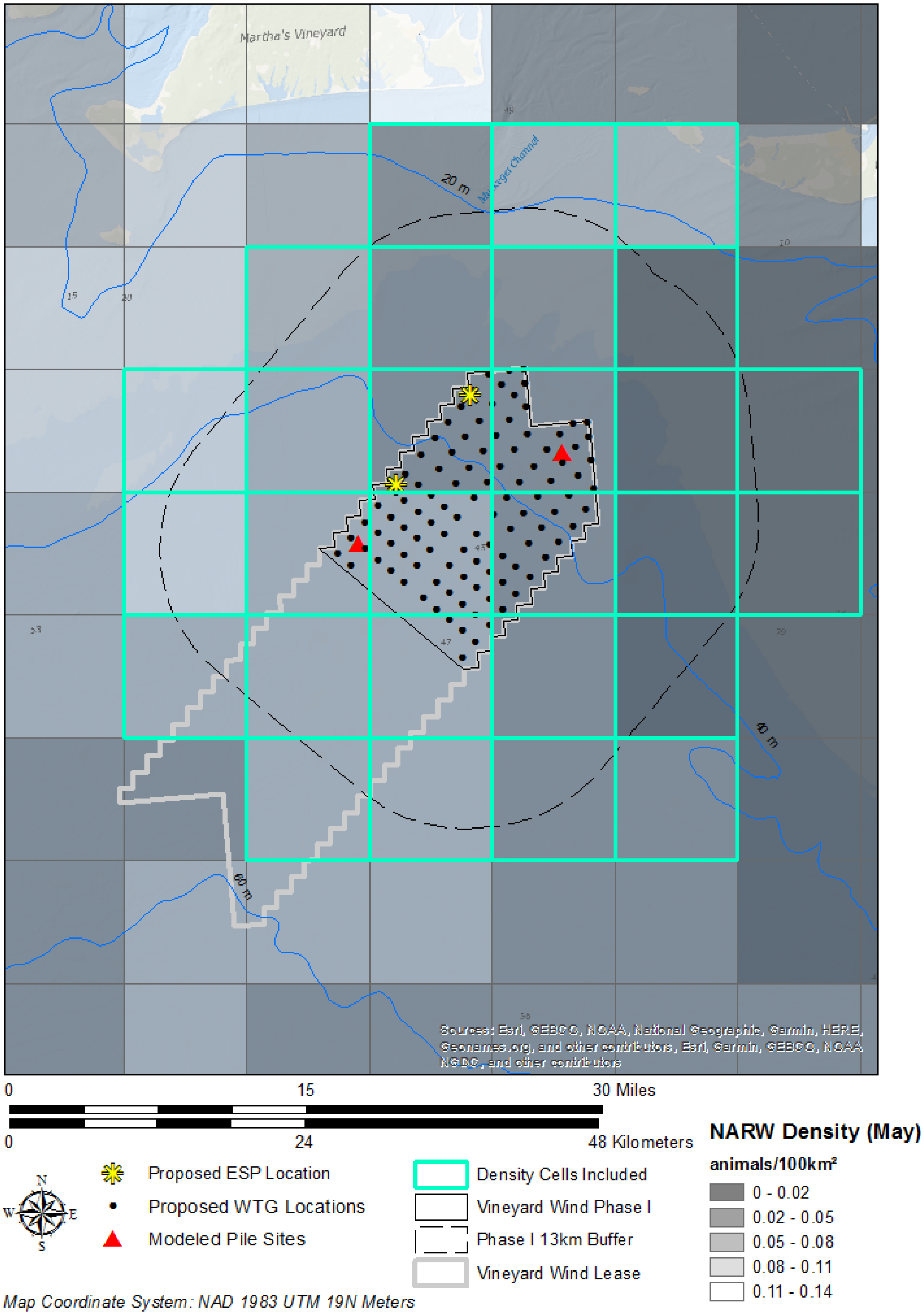

Figure 5. Density map showing Roberts et al. (2016) grid cells. Highlighted cells indicate those used to calculate mean monthly species estimates in the vicinity of the Project.

Table 6. Mean monthly Atlantic marine mammal density estimates for the Offshore Project Area (Roberts et al., 2016).

Species of interest	Monthly densities (animals/100 km^2 [38.6 miles^2])‡												Annual	May to Dec
Common name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	Mean
Fin whale*	0.219	0.164	0.150	0.219	0.311	0.299	0.294	0.277	0.202	0.175	0.220	0.281	0.234	0.257
Humpback whale	0.106	0.102	0.158	0.072	0.111	0.120	0.099	0.120	0.167	0.157	0.163	0.099	0.123	0.130
Minke whale	0.036	0.041	0.044	0.071	0.101	0.115	0.108	0.071	0.041	0.037	0.038	0.037	0.062	0.069
North Atlantic right whale*	0.205	0.309	0.543	0.582	0.287	0.308	0.002	0.002	0.006	0.001	0.001	0.267	0.209	0.109
Sei whale*	0.010	0.010	0.011	0.029	0.048	0.022	0.005	0.001	0.001	<0.001	<0.001	0.009	0.012	0.011
Atlantic white sided dolphin	2.158	0.815	0.727	1.752	3.716	3.243	2.144	1.715	2.342	2.828	3.715	4.060	2.435	2.970
Bottlenose dolphin	0.479	0.227	0.109	0.302	1.555	3.601	3.071	3.233	4.697	2.907	2.232	0.779	1.933	2.759
Pilot whales†	0.389	0.389	0.389	0.389	0.389	0.389	0.389	0.389	0.389	0.389	0.389	0.389	0.389	0.389
Risso’s dolphin	0.001	0.001	0.001	0.001	0.001	0.003	0.005	0.006	0.005	0.004	0.002	0.002	0.003	0.004
Short beaked dolphin	1.531	0.646	0.678	1.510	4.809	5.862	3.525	3.536	3.699	4.751	5.372	3.995	3.326	4.444
Sperm whale*	0.006	0.006	0.007	0.009	0.009	0.010	0.009	0.007	0.004	0.005	0.006	0.005	0.007	0.007
Harbor porpoise	10.876	6.992	5.582	10.738	6.844	2.996	0.608	0.293	0.726	2.453	0.841	6.247	4.600	2.626
Gray seal	4.395	4.395	4.395	4.395	4.395	1.040	1.040	1.040	4.395	4.395	4.395	4.395	3.556	3.137
Harbor seal	4.395	4.395	4.395	4.395	4.395	1.040	1.040	1.040	4.395	4.395	4.395	4.395	3.556	3.137
Harp seal	4.395	4.395	4.395	4.395	4.395	1.040	1.040	1.040	4.395	4.395	4.395	4.395	3.556	3.137

* Endangered listing

† Long- and Short-finned Pilot Whales are grouped together to estimate the total density of both uncommon species

‡ Roberts et al. (2015) reports densities for all seal species as a single value for two periods (June to August and September to May)

4.3. Acoustic Criteria – Injury and Behavioral Disruption

The Marine Mammal Protection Act (MMPA) (16 U.S.C. 1362) prohibits the take of marine mammals. MMPA defines the term “take” 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 pile driving operations. These are:

- Level A: any act of pursuit, torment, or annoyance which 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.

To assess the potential impacts of the Project-associated pile driving noise, it is necessary to first establish acoustic exposure criteria for which takes could result. In 2016, the NMFS issued a Technical Guidance document that provides acoustic thresholds for onset of permanent threshold shift (PTS) in marine mammal hearing for most sound sources, that was then updated in 2018 (NMFS 2016, 2018). The NMFS also provided guidance on the use of weighting functions when applying injury criteria. The NMFS Guidance recommends the use of a dual criterion for assessing injurious exposures, including a peak (unweighted/flat) sound level metric (PK) and a cumulative sound exposure level (SEL) metric with frequency weighting. Both acoustic criteria and weighting function application are divided into functional hearing groups (low-, mid-, and high-frequency) that species are assigned to, based on their respective hearing ranges.

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

Table 7. Summary of relevant acoustic terminology used by US regulators and in this report.

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

The SEL_{cum} metric as used by the NMFS describes the sound energy received by a receptor over a period of 24 hours. Accordingly, following the ISO standard, this will be denoted as SEL in this report, with the exception of tables and equations where L_E will be used alongside SEL to account for its use in mathematical equations.

4.3.1. 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 (Au & Hastings, 2008; Richardson, Greene, Malme, & Thomson, 1995; Southall et al., 2007; Wartzok & Ketten, 1999). While hearing measurements are available for a small number of species based on captive animal studies, direct measurements of many odontocetes and all mysticetes do not exist. As a result, hearing ranges for many odontocetes are grouped with similar species, and predictions for mysticetes are based on other methods including: anatomical studies and modeling (Cranford & Krysl, 2015; Houser et al., 2001; Parks, Clark, & Tyack, 2007; Tubelli, Zosuls, Ketten, & Mountain, 2012), vocalizations (Au & Hastings, 2008; see reviews in Richardson et al., 1995; Wartzok & Ketten, 1999), taxonomy, and behavioral responses to sound (Dahlheim & Ljungblad, 1990; see review in Reichmuth, Mulsow, Finneran, Houser, & Supin, 2007) In 2007, Southall et al. proposed that marine mammals be divided into hearing groups. This division was updated in 2016 and 2018 by the NMFS using more recent best available science (Table 8).

Table 8. Marine mammal hearing groups (NMFS 2018; Sills, Southall, & Reichmuth, 2014).

Hearing group	Generalized hearing range*
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 39 kHz
Phocid pinnipeds in air (PPA)**	50 Hz to 36 kHz

*The generalized hearing range for all species within a group. Individual hearing will vary.

**Based on the distance from shore (23 km [14 miles] offshore of Martha's Vineyard and Nantucket), sound will not reach NOAA thresholds for behavioral disturbance of pinnipeds in air (90 dB root mean square [rms] re 20 µPa for Harbor Seals and 100 dB [rms] re 20 µPa for all other seal species) at land-based sites where pinnipeds may spend time out of the water. They are not considered further in this study.

4.3.2. Marine mammal auditory weighting functions

The potential for anthropogenic sounds 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 & 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 (L_E)) (Erbe, McCauley, & Gavrilov, 2016; Finneran, 2016; Southall et al., 2007). Marine mammal auditory weighting functions published by Finneran (2016) are included in the NMFS (2018) Technical Guidance for use in conjunction with corresponding PTS (injury) onset acoustic criteria (Table 9).

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

4.3.3. 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 the hearing apparatus independent of duration so an additional metric of peak pressure (PK) is needed to assess acoustic exposure injury risk. PTS is 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, so PTS onset is typically 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 hours (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 9).

Table 9. Summary of relevant PTS onset acoustic thresholds (NMFS 2018).

Hearing group	PTS onset thresholds* (received level)	
	Impulsive	Non-impulsive
Low-frequency (LF) cetaceans	L_{pk}, flat: 219 dB $L_{\text{E, LF}}$, 24h: 183 dB	$L_{\text{E, LF}}$, 24h: 199 dB
Mid-frequency (MF) cetaceans	L_{pk}, flat: 230 dB $L_{\text{E, MF}}$, 24h: 185 dB	$L_{\text{E, MF}}$, 24h: 198 dB
High-frequency (HF) cetaceans	L_{pk}, flat: 202 dB $L_{\text{E, HF}}$, 24h: 155 dB	$L_{\text{E, HF}}$, 24h: 173 dB
Phocid pinnipeds in water (PW)	L_{pk}, flat: 218 dB $L_{\text{E, PW}}$, 24h: 185 dB	$L_{\text{E, PW}}$, 24h: 201 dB

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

L_{pk}, flat–peak sound pressure is flat weighted or unweighted and has a reference value of 1 µPa

L_{E} - denotes cumulative sound exposure over a 24-hour period and has a reference value of 1 µPa^{2}s

The subscript associated with cumulative sound exposure level thresholds indicates the designated marine mammal auditory weighting.

4.3.4. Behavioral disruption 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. However, it is recognized that the context in which the sound is received affects the nature and extent of responses to a stimulus (Ellison & Frankel, 2012; Southall et al., 2007). Because of the complexity and variability of marine mammal behavioral responses to acoustic exposure, the NMFS has not yet released technical guidance on behavior thresholds for use in calculating animal exposures (NMFS 2018). The NMFS currently uses a step function to assess behavioral impact (NOAA, 2005). A 50% probability of inducing behavioral responses at a SPL of 160 dB re 1 µPa was derived from the HESS (1999) report which, in turn, was based on the responses of migrating mysticete whales to airgun sounds (Malme, Miles, Clark, Tyack, & Bird, 1984; Malme, Miles, Clark, Tyak, & Bird, 1983). The HESS team recognized that behavioral responses to sound may occur at lower levels, but significant responses were only likely to occur above a SPL of 140 dB re 1 µPa. An extensive review of behavioral responses to sound was undertaken by Southall et al. (2007, their Appendix B). Southall et al. (2007) found varying responses for most marine mammals between a 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 porpoise 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 behavioral response to impulsive pile-driving sounds (Table 10).

Table 10. Behavioral exposure criteria used in this analysis. Probability of behavioral response frequency-weighted sound pressure level (SPL dB re 1 µPa). Probabilities are not additive. Adapted from Wood et al. (2012).

Marine mammal group	Probability of response to frequency-weighted SPL (dB re 1 µPa)			
	120	140	160	180
Beaked whales and harbor porpoises	50%	90%		
Migrating mysticete whales	10%	50%	90%	
All other species		10%	50%	90%

4.4. Predicted Sound Fields

The sound a source produces is characterized in time, spectral content, and space. As the sound travels away from the source, it is also shaped by interactions with the environment in which it propagates (see Appendix A). For this reason, the sound field produced by a source is specific to the source and the location. Understanding the potential for sound exposure to impact animals requires an understanding of the sound field to which they could be exposed. Sound fields produced during pile driving were modeled by first characterizing the sound signal produced during pile driving using the industry-standard GRLWEAP (wave equation analysis of pile driving) model and JASCO's Pile Driving Source Model (PDSM). The source signal was then propagated along radial planes using JASCO's parabolic equation models MONM and FWRAM, and radial planes assembled in to three-dimensional sound fields (see Appendix A). These three-dimensional, per-strike sound fields were then used with animal movement modeling (see below) to obtain estimates of animal exposure probability.

Two sites were selected to provide representative propagation and sound fields for the Offshore Project Area (Figure 1). Source locations were selected to span the region from shallow to deep water and varying distances to dominant bathymetric features (i.e., slope and shelf break). Water depth and environmental characteristics (e.g., bottom-type) are similar throughout the WDA (Vineyard Wind, 2016), and therefore minimal difference was found in sound propagation results for the two sites (Appendix A). Because of this similarity in results, and for summary purposes, the tables in the main body of the report include the mean maximum values of the two sites. Detailed results are included in Appendix A.

Table 11. Sites used in propagation modeling.

Site	Location (UTM Zone 19N)		Water depth (m)*	Sound source	Source type
	Easting	Northing			
P1	382452	4548026	38 (124.7 ft)	Monopile, Jacketed pile	Impulsive
P2	365240	4542200	46 (151 ft)		

*vertical datum for water depth is Earth Gravitational Model 1996 (EGM96)

4.4.1. Distances to exposure thresholds

Though not used for exposure estimates, ranges to exposure criteria thresholds are often reported. For each sound level threshold, two statistical estimates are calculated: the maximum range (R_{max}), and the 95% range ($R_{95\%}$). The R_{max} is simply the distance to the farthest occurrence of the threshold level, at any depth. The $R_{95\%}$ for a given sound level is the radius of a circle, centered on the source, encompassing 95% of the sound at levels above threshold. Use of $R_{95\%}$ reduces the sensitivity to extreme outlying values (the farthest 5% of ranges) so is helpful in estimating ranges used for monitoring and mitigation purposes (detailed description in Appendix A).

4.4.1.1. Injury criteria radii

Table 12 lists the radial distances to sound exposure (SEL) and peak levels (PK) using the NMFS (2018) frequency weighting for marine mammals. For PK, the greatest distances expected are shown, typically occurring at the highest hammer energies. The distances to SEL are calculated using the hammer energy schedules for driving one monopile or four jacket piles (Appendix A). The summary table includes the mean maximum distance from two modeling sites. Results for each of these sites are provided in Appendix A.

Table 12. Radii distances ($R_{95\%}$ in meters) to injury thresholds (NMFS 2018) at two modeling sites for marine mammal functional hearing groups estimated for each scenario foundation type. The largest mean maximum radii of two modeling sites is shown with 0, 6, and 12 dB sound attenuation.

Foundation type	Hearing group	Level A (L_{pk})			Level A ($L_{E,24hr}$)		
		No attenuation	6 dB	12 dB	No attenuation	6 dB	12 dB
10.3 m (33.8 ft) monopile	LFC	34	17	8.5	5,443	3,191	1,599
	MFC	10	5	2.5	56	43	0
	HFC	235	119	49	101	71	71
	PPW	38	19	10	450	153	71
Four, 3 m (9.8 ft) jacket piles	LFC	7.5	4	2.5	12,975	7,253	3,796
	MFC	2.5	1	0.5	71	71	56
	HFC	51	26	13.5	1,389	564	121
	PPW	9	5	2.5	2,423	977	269

4.4.1.2. Behavioral criteria radii

The NOAA (2005) behavioral threshold for all hearing groups is an unweighted 160 dB SPL. For comparison, Wood et al. (2012) uses Southall et al. (2007) auditory weighting with a probability of response step function (Table 10) applied to SPL. Maximum distances are shown as obtained using the hammer energy schedule to drive one monopile and one jacket pile – i.e., the most conservative hammer size and energy combination is presented in the summary table (Table 13) for both criteria. The mean maximum with probability of response ranges are presented for Wood et al. (2012). Various levels of attenuation ranging from 6–12 dB were modeled for the Project (Appendix A). Table 13 includes no attenuation and sound reductions of 6 dB and 12 dB.

Table 13. Radii distances ($R_{95\%}$ in meters) to sound pressure level behavioral thresholds for marine mammals based on NOAA (2005) and Wood et al. (2012). Ranges are calculated using the average maximum hammer energy at two modeling sites for marine mammal functional hearing groups estimated for each scenario foundation type with 0, 6 dB and 12 dB sound reduction.

Foundation type	Hearing group	Level B unweighted (NOAA, 2005)			Level B frequency-weighted mean 50% probability of response (Wood et al., 2012)		
		No attenuation	6 dB	12 dB	No attenuation	6 dB	12 dB
10.3 m (33.8 ft) monopile	LFC*	6,316	4,121	2,739	6,183	4,007	2,681
	MFC				1,747	821	289
	HFC**				38,333	22,140	13,245
	PW				3,012	2,046	1,120
Four, 3 m (9.8 ft) jacket piles	LFC*	4,104	3,220	2,177	4,498	3,302	2,092
	MFC				2,695	1,406	539
	HFC**				55,800	34,918	21,760
	PW				3,480	2,400	1,187

* The mysticetes found in the WDA during planned operations are likely foraging even if they are migrating (e.g., Leiter et al., 2017). The migrating mysticete category in Wood et al. (2012) was not used to select ranges included in the table.

** The high frequency species known to occupy habitat in the WDA is the harbor porpoise. This species is highly sensitive to underwater anthropogenic sound. Wood et al. (2012) applies a lower threshold criterion for this species to account for this sensitivity.

4.5. Animal Movement and Exposure Modeling

The JASCO Animal Simulation Model Including Noise Exposure (JASMINE) was used to predict the probability of exposure of animals to sound arising from the Project's pile driving operations. Sound exposure models like JASMINE use simulated animals (animats) to sample the predicted 3D sound fields with movement rules derived from animal observations (Appendix B). The output of the simulation is the exposure history for each animat within the simulation. As shown in Figure 6, sound fields are inputted into JASMINE and animats are programmed to behave like the marine animals that may be present in the Offshore Project Area. The parameters used for forecasting realistic behaviors (e.g., diving, foraging, aversion, surface times, etc.) are determined and interpreted from marine species studies (e.g., tagging studies) where available, or reasonably extrapolated from related species (Appendix B). An individual animat's sound exposure levels are summed over a specified duration, such as 24 hours, to determine its total received energy, and then compared to the threshold criteria described in Sections 4.3.3 and 4.3.4. Appendix B details the piling schedule used in the JASMINE simulations.

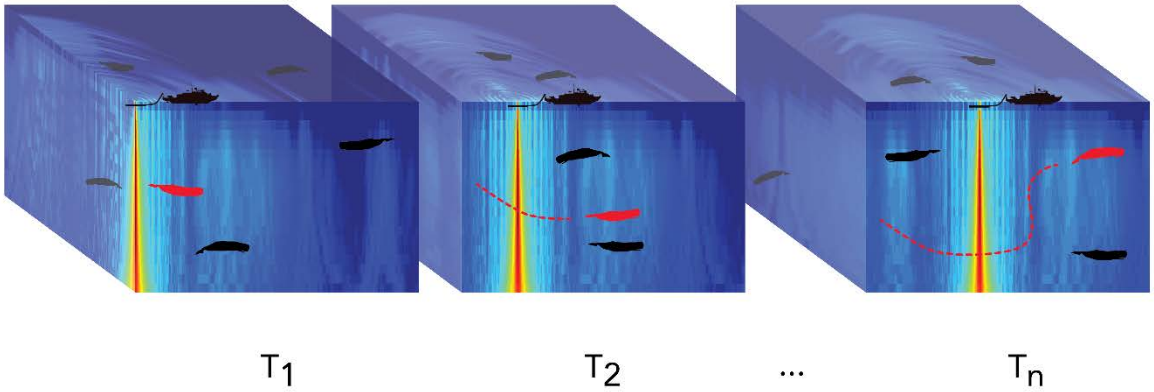

Figure 6. Cartoon of animats in a moving sound field. Example animat (red) shown moving with each time step. The acoustic exposure of each animat is determined by where it is in the sound field, and its exposure history is accumulated as the simulation steps through time.

4.5.1. Exposure estimates

With the inclusion of more jacket foundations, and therefore more pile driving in the WDA, exposure estimates for the Maximum Design scenario (Tables 14 and 15) are higher than the Most Likely scenario (Tables 16 and 17). In all scenarios, the maximum number of jacket foundations modeled per day was one (four jacket piles). Whether one or two monopile foundations are installed per day makes little difference to the projected injurious exposures (Table 14 versus Table 15, and Table 16 versus Table 17). Over the course of the Project, the same total amount of pile driving is conducted whether one monopile or two is installed per day, so the finding that injurious exposures are similar indicates that animals are primarily impacted by the total amount of piling to which they are exposed. For behavioral disruptions, exposure estimates for one monopile foundation per day are somewhat higher than for two monopiles foundations per day (Table 14 versus Table 15, and Table 16 versus Table 17). This is because the ensonified volume that may result in behavioral disruption is larger than the volume that may result in injury. Because behavioral disruption is assessed on the maximum single exposure, a behavioral disruption may be registered in response to both piles driven in a day but the animat is only counted once. With two monopile foundations per day there are half as many days of pile driving so there is likewise a reduced number of predicted behavioral response exposures. The following estimates of potential exposures (Table 14–Table 17) to underwater sounds are the result of JASMINE model runs without animat aversion. When animats are programmed to avert in the model, exposures are generally lower. This effect is illustrated in Table 18.

4.5.1.1. Scenario 1 – Maximum Design (90 monopiles, 12 jacket foundations)

The real-world number of individual cetaceans expected to exceed the exposure criteria (NMFS, 2018; NOAA, 2005) for the Project's pile driving activities (limited to months of May-December) using the Maximum Design scenario (summarized in Table 1) with no attenuation, and attenuation levels of 6 dB and 12 dB are shown in Table 14 (one pile per day) and Table 15 (two piles per day). The sound reduction target of up to 12 dB is highlighted in the tables. It is noted that the estimated numbers of individuals exceeding thresholds are conservative because the 24 hr evaluation window allows individuals to be counted on multiple days, or interpreted as different individuals each 24 hrs.

Table 14. The number of marine mammals estimated to experience sound levels above-threshold exposure criteria for the Project (NMFS 2018) using Maximum Design scenario parameters, one pile per day, and 0, 6, and 12 dB attenuation.

Species	No attenuation			6 dB			12 dB		
	Injury (L_{pk})	Injury (L_{E})	Behavior max. SPL ($L_{\text{p,24hr}}$)	Injury (L_{pk})	Injury (L_{E})	Behavior max. SPL ($L_{\text{p,24hr}}$)	Injury (L_{pk})	Injury (L_{E})	Behavior max. SPL ($L_{\text{p,24hr}}$)
Fin whale*	0.29	19.89	58.59	0.12	4.90	39.03	0.02	0.34	25.68
Humpback whale	0.09	20.03	33.16	0.02	6.63	22.05	0.01	0.73	14.40
Minke whale	0.10	2.44	15.76	0.03	0.20	10.85	0	0.06	7.02
North Atlantic right whale*	0.08	6.47	20.12	0.03	1.36	13.25	0	0.09	8.74
Sei whale*	0.02	0.88	2.52	0	0.21	1.68	0	0.02	1.15
Atlantic white sided	0	0	728.87	0	0	464.19	0	0	287.05
Bottlenose dolphin	0.31	0	146.69	0	0	88.71	0	0	57.35
Pilot whales	0	0	0	0	0	0	0	0	0
Risso's dolphin	0	0	0.89	0	0	0.58	0	0	0.37
Short beaked dolphin	0.96	0	972.37	0.06	0	640.36	0.06	0	424.70
Sperm whale*	0	0	0	0	0	0	0	0	0
Harbor porpoise	12.84	0.39	343.47	6.14	0.25	217.83	2.24	0	133.43
Gray seal	0.53	0.58	248.54	0.11	0.29	156.23	0.04	0.07	94.28
Harbor seal	0.67	0.72	269.27	0.28	0.20	170.63	0.25	0.07	108.91
Harp seal	1.20	1.89	276.33	0.57	0.71	173.35	0	0.04	106.50

* Endangered species

Table 15. The number of marine mammals estimated to experience sound levels above-threshold exposure criteria for the Project (NMFS 2018) using Maximum Design scenario parameters, two piles per day, and 0, 6, and 12 dB attenuation.

Species	No attenuation			6 dB			12 dB		
	Injury (L_{pk})	Injury (L_{E})	Behavior max. SPL ($L_{\text{p},24hr}$)	Injury (L_{pk})	Injury (L_{E})	Behavior max. SPL ($L_{\text{p},24hr}$)	Injury (L_{pk})	Injury (L_{E})	Behavior max. SPL ($L_{\text{p},24hr}$)
Fin whale*	0.34	21.42	49.00	0.12	5.32	35.04	0	0.49	24.26
Humpback whale	0.11	20.33	28.50	0.02	7.05	19.96	0	0.80	13.54
Minke whale	0.08	2.57	14.27	0.02	0.21	10.25	0	0.05	6.89
North Atlantic right whale*	0.07	6.54	16.45	0.02	1.39	11.75	0.01	0.10	7.96
Sei whale*	0.01	0.89	2.04	0	0.21	1.44	0	0.02	1.00
Atlantic white sided dolphin	0.26	0	653.02	0.13	0	442.69	0	0	281.77
Bottlenose dolphin	0.15	0	95.31	0	0	62.48	0	0	40.47
Pilot whales	0	0	0	0	0	0	0	0	0
Risso's dolphin	0	0	0.70	0	0	0.49	0	0	0.34
Short beaked dolphin	0.54	0	760.27	0.27	0	540.25	0.06	0	374.64
Sperm whale*	0	0	0	0	0	0	0	0	0
Harbor porpoise	11.95	0.48	265.66	6.14	0.25	181.70	2.68	0.09	119.39
Gray seal	1.07	0.99	167.83	0.24	0.43	116.96	0.04	0.21	77.68
Harbor seal	1.92	1.35	188.87	0.78	0.70	132.62	0.13	0.32	88.90
Harp seal	1.07	2.29	191.19	0.30	0.44	130.92	0.13	0.04	87.53

* Endangered species

4.5.1.2. Scenario 2 – Most Likely (100 monopiles, two jacket foundations)

The real-world number of individual cetaceans expected to exceed the exposure criteria (NMFS, 2018; NOAA, 2005) for the Project's pile driving activities (limited to months of May-December) using the Most Likely scenario (summarized in Table 1) with no attenuation, and attenuation levels of 6 dB and 12 dB are shown in Table 16 (one pile per day) and Table 17 (two piles per day). The sound reduction target of up to 12 dB is highlighted in the tables. Again, it is noted that the estimated numbers of individuals exceeding thresholds are conservative because the 24 hr evaluation window allows individuals to be counted on multiple days, or that there are new individuals each 24 hrs

Table 16. The number of marine mammals estimated to experience sound levels above-threshold exposure criteria for the Project (NMFS 2018) using Most Likely scenario parameters, one pile per day, and 0, 6, and 12 dB attenuation.

Species	No attenuation			6 dB			12 dB		
	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)
Fin whale*	0.30	13.83	54.65	0.13	3.31	34.91	0.03	0.26	22.72
Humpback whale	0.09	14.81	30.23	0.03	4.78	19.22	0.01	0.61	12.50
Minke whale	0.11	1.63	14.10	0.04	0.13	9.44	0	0.06	6.21
North Atlantic right whale*	0.07	3.74	17.37	0.04	0.72	10.82	0	0.04	7.09
Sei whale*	0.01	0.60	2.26	0	0.14	1.44	0	0.02	0.98
Atlantic white sided dolphin	0	0	644.45	0	0	388.72	0	0	241.73
Bottlenose dolphin	0.34	0	152.00	0	0	90.73	0	0	59.11
Pilot whales	0	0	0	0	0	0	0	0	0
Risso's dolphin	0	0	0.86	0	0	0.54	0	0	0.34
Short beaked dolphin	0.96	0	917.58	0.01	0	583.60	0.01	0	382.55
Sperm whale*	0	0	0	0	0	0	0	0	0
Harbor porpoise	11.23	0.20	307.44	5.33	0.19	186.30	1.91	0	111.55
Gray seal	0.31	0.04	239.36	0.01	0.02	145.18	0	0	85.92
Harbor seal	0.56	0.30	256.08	0.28	0.01	156.87	0.27	0	99.09
Harp seal	1.17	0.67	263.02	0.59	0.59	159.01	0	0	95.45

* Endangered species

Table 17. The number of marine mammals estimated to experience sound levels above-threshold exposure criteria for the Project (NMFS 2018) using Most Likely scenario parameters, two piles per day, and 0, 6, and 12 dB attenuation.

Species	No attenuation			6 dB			12 dB		
	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)
Fin whale*	0.35	15.53	44.00	0.13	3.78	30.48	0	0.42	21.14
Humpback whale	0.11	15.14	25.03	0.03	5.25	16.89	0	0.68	11.54
Minke whale	0.08	1.77	12.45	0.03	0.14	8.77	0	0.04	6.07
North Atlantic right whale*	0.06	3.82	13.42	0.02	0.76	9.21	0.01	0.06	6.25
Sei whale*	0.01	0.61	1.75	0	0.13	1.19	0	0.01	0.83
Atlantic white sided dolphin	0.29	0	560.43	0.14	0	364.90	0	0	235.88
Bottlenose dolphin	0.17	0	94.34	0	0	61.31	0	0	40.18
Pilot whales	0	0	0	0	0	0	0	0	0
Risso’s dolphin	0	0	0.65	0	0	0.45	0	0	0.31
Short beaked dolphin	0.49	0	681.82	0.24	0	472.32	0.01	0	326.91
Sperm whale*	0	0	0	0	0	0	0	0	0
Harbor porpoise	10.28	0.29	225.25	5.33	0.19	148.14	2.38	0.09	96.72
Gray seal	0.91	0.48	150.67	0.16	0.17	102.03	0	0.15	67.68
Harbor seal	1.93	0.99	167.74	0.83	0.56	115.10	0.14	0.28	77.11
Harp seal	1.03	1.11	169.48	0.29	0.30	112.38	0.15	0	74.62

* Endangered species

4.5.2. Aversion

The exposure estimates tables included above (Tables 14–17) do not account for aversion or mitigation beyond attenuation (e.g., pile driving shut-down or power down). Aversion is a common response of marine mammals 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 levels elicit response at closer ranges; both proximity and received levels are important factors in aversion response (Dunlop et al., 2017). Some marine mammals are well known for their aversion from anthropogenic sound (e.g., Harbor Porpoise), although it is assumed that most species will avert from noise. For this modeling study, aversion parameters to sound level were implemented for Harbor Porpoise and NARW, in recognition of their critically endangered status..

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 that included aversion in the animal movement model, based on the Wood et al. (2012) response probability, were calculated for both the Harbor Porpoise and the NARW for all modeling scenarios contemplated in this study. The most conservative exposure results are associated with the unattenuated Maximum Design scenario, installing two piles per day. For comparative purposes, the results are shown with and without aversion (Table 18).

Conducting example aversion runs such as these, further illustrates the potential range of exposures that may result during the Project. Details of the aversion approach used in JASMINE are provided in Appendix B.

Table 18. Comparison of exposure estimates (NMFS, 2018; NOAA, 2005) for Harbor Porpoise and NARW when aversion is included in animal movement models relative to models without aversion.

Species	No attenuation – no aversion			No attenuation – with aversion		
	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)
Harbor porpoise	12.84	0.39	343.47	0.18	0	15.5
North Atlantic right whale	0.08	6.47	20.12	0	0.40	8

4.5.3. Population impacts

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

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

Abundance numbers used to calculate the percentage of population estimated to receive threshold levels of sound are shown in Table 19. Both the SAR abundance data (Hayes et al., 2018; Waring et al., 2016) and the habitat-based abundance data (Roberts et al., 2016, 2017) are included for comparison purposes. Since the densities used in estimating potential exposures were derived from Roberts et al. (2015, 2016, 2017), it is most appropriate to use the abundance estimates from that same source when calculating the percent of population or stock potentially exposed. Thus, Roberts et al. (2016, 2017) abundance estimates were used to calculate the percentage of each population or stock potentially exposed to injurious or behavioral response levels for the two scenarios (Maximum Design and Most Likely), with scenarios that include one monopile foundation driven per day or two monopile foundations driven per day in each scenario (Tables 20–23) based on the exposure estimates in Tables 14 and 17 for all species except pinnipeds. SAR abundance data for pinnipeds were used to calculate the percentage of population exposed to threshold criteria for these species as abundance estimates were not available in Roberts et al. (2015). The sound reduction target of up to 12 dB is highlighted in the tables.

Table 19. Stock abundance estimates for modeled species The best estimate of abundance, N_{best}, is shown from Stock Assessment Reports (Hayes et al., 2018; Waring et al., 2016) and from the Duke University models (Roberts et al., 2015, 2016, 2017).

Species	N_{best}	
	Hayes et al. (2018); Waring et al. (2016)	Roberts et al. (2015, 2016, 2017)^
Fin whale*	1,618	4,859
Humpback whale	335	1,773†
Minke whale	2,591	3,014†
North Atlantic right	458	394†
Sei whale*	357	453†
Atlantic white sided	48,819	37,180
Bottlenose dolphin	77,532	97,476
Pilot whales$	5,636	27,597
Risso's dolphin	18,250	7,732
Short beaked dolphin	70,184	86,098
Sperm whale*	2,288	4,199
Harbor porpoise	79,833	60,281†
Gray seal	27,131	N/A
Harbor seal	75,834	N/A
Harp seal	7,400,000‡	N/A

^ Estimates are for entire Atlantic EEZ

* Endangered species

† Maximum over seasonal abundances

‡ Abundance estimate for western North Atlantic Harp Seals in Canadian waters

$ It is likely that most of the affected animals from this genus will be Long-finned Pilot Whales. Hayes, Josephson, Maze-Foley, and Rosel (2018) provides stock assessments for each genus and the estimate for Long-finned Pilot Whales are presented here. Roberts et al. (2016) combines Long- and Short-finned Pilot Whales

Population impacts for injurious exposure, and impacts from behavioral disruption as a percentage of abundance are shown in Tables 20–23 for the two scenarios (Maximum Design envelope and Most Likely), with scenarios that include one monopile foundation driven per day or two monopile foundations driven per day. The sound reduction target of up to 12 dB is highlighted in the tables.

Table 20. Estimated injurious and behavioral threshold acoustic exposures as a percentage of species' abundance for the Maximum Design scenario with one pile per day, and 0, 6, and 12 dB attenuation.

Species	Number of Exposures as a Percentage of Abundance								
	No attenuation			6 dB			12 dB		
	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)
Fin whale*	0.01	0.35	1.02	0	0.08	0.68	0	0.01	0.45
Humpback whale	0.01	1.54	2.56	0	0.51	1.70	0	0.06	1.11
Minke whale	0	0.09	0.59	0	0.01	0.41	0	0	0.26
North Atlantic right whale*	0.02	1.64	5.11	0.01	0.35	3.36	0	0.02	2.22
Sei whale*	0	0.13	0.36	0	0.03	0.24	0	0	0.16
Atlantic white sided	0	0	1.96	0	0	1.25	0	0	0.77
Bottlenose dolphin	0	0	0.15	0	0	0.09	0	0	0.06
Pilot whales	0	0	0.00	0	0	0	0	0	0
Risso's dolphin	0	0	0.01	0	0	0.01	0	0	0.00
Short beaked dolphin	0	0	1.13	0	0	0.74	0	0	0.49
Sperm whale*	0	0	0.00	0	0	0	0	0	0
Harbor porpoise	0.01	0	0.39	0.01	0	0.25	0	0	0.15
Gray seal	0	0	0.92	0	0	0.58	0	0	0.35
Harbor seal	0	0	0.36	0	0	0.23	0	0	0.14
Harp seal	0	0	0	0	0	0	0	0	0

* Endangered species

Table 21. Estimated injurious and behavioral threshold acoustic exposures as a percentage of species' abundance for the Maximum Design scenario with two piles per day, and 0, 6, and 12 dB attenuation.

Species	Number of Exposures as a Percentage of Abundance								
	No attenuation			6 dB			12 dB		
	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)
Fin whale*	0.01	0.37	0.86	0	0.09	0.61	0	0.01	0.42
Humpback whale	0.01	1.56	2.19	0	0.54	1.54	0	0.06	1.04
Minke whale	0	0.10	0.53	0	0.01	0.38	0	0	0.26
North Atlantic right whale*	0.02	1.66	4.18	0.01	0.35	2.98	0	0.03	2.02
Sei whale*	0	0.13	0.29	0	0.03	0.21	0	0	0.14
Atlantic white sided	0	0	1.76	0	0	1.19	0	0	0.76
Bottlenose dolphin	0	0	0.10	0	0	0.06	0	0	0.04
Pilot whales	0	0	0.00	0	0	0	0	0	0
Risso's dolphin	0	0	0.01	0	0	0.01	0	0	0
Short beaked dolphin	0	0	0.88	0	0	0.63	0	0	0.44
Sperm whale*	0	0	0.00	0	0	0	0	0	0
Harbor porpoise	0.01	0	0.30	0.01	0	0.21	0	0	0.14
Gray seal	0	0	0.62	0	0	0.43	0	0	0.29
Harbor seal	0	0	0.25	0	0	0.17	0	0	0.12
Harp seal	0	0	0	0	0	0	0	0	0

* Endangered species

Table 22. Estimated injurious and behavioral threshold acoustic exposures as a percentage of species' abundance for the Most Likely scenario with one pile per day, and 0, 6, and 12 dB attenuation.

Species	Number of Exposures as a Percentage of Abundance								
	No attenuation			6 dB			12 dB		
	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)
Fin whale*	0.01	0.24	0.96	0	0.06	0.61	0	0	0.40
Humpback whale	0.01	1.14	2.33	0	0.37	1.48	0	0.05	0.96
Minke whale	0	0.06	0.51	0	0	0.34	0	0	0.22
North Atlantic right whale*	0.02	0.95	4.41	0.01	0.18	2.75	0	0.01	1.80
Sei whale*	0	0.09	0.33	0	0.02	0.21	0	0	0.14
Atlantic white sided	0	0	1.73	0	0	1.05	0	0	0.65
Bottlenose dolphin	0	0	0.16	0	0	0.09	0	0	0.06
Pilot whales	0	0	0	0	0	0	0	0	0
Risso's dolphin	0	0	0.01	0	0	0.01	0	0	0
Short beaked dolphin	0	0	1.07	0	0	0.68	0	0	0.44
Sperm whale*	0	0	0	0	0	0	0	0	0
Harbor porpoise	0.01	0	0.37	0.01	0	0.22	0	0	0.13
Gray seal	0	0	0.88	0	0	0.54	0	0	0.32
Harbor seal	0	0	0.34	0	0	0.21	0	0	0.13
Harp seal	0	0	0	0	0	0	0	0	0

* Endangered species

Table 23. Estimated injurious and behavioral threshold acoustic exposures as a percentage of species' abundance for the Most Likely scenario with two piles per day, and 0, 6, and 12 dB attenuation.

Species	Number of Exposures as a Percentage of Abundance								
	No attenuation			6 dB			12 dB		
	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)	Injury (L_{pk})	Injury (L_E)	Behavior max. SPL ($L_{p,24hr}$)
Fin whale*	0.01	0.27	0.77	0	0.07	0.54	0	0.01	0.37
Humpback whale	0.01	1.17	1.93	0	0.40	1.30	0	0.05	0.89
Minke whale	0	0.06	0.45	0	0	0.32	0	0.00	0.22
North Atlantic right whale*	0.02	0.97	3.41	0.01	0.19	2.34	0	0.02	1.59
Sei whale*	0	0.09	0.25	0	0.02	0.17	0	0	0.12
Atlantic white sided	0	0	1.51	0	0	0.98	0	0	0.63
Bottlenose dolphin	0	0	0.10	0	0	0.06	0	0	0.04
Pilot whales	0	0	0	0	0	0	0	0	0
Risso's dolphin	0	0	0.01	0	0	0.01	0	0	0
Short beaked dolphin	0	0	0.79	0	0	0.55	0	0	0.38
Sperm whale*	0	0	0	0	0	0	0	0	0
Harbor porpoise	0.01	0	0.27	0.01	0	0.18	0	0	0.12
Gray seal	0	0	0.56	0	0	0.38	0	0	0.25
Harbor seal	0	0	0.22	0	0	0.15	0	0	0.10
Harp seal	0	0	0	0	0	0	0	0	0

* Endangered species

5. Acoustic Impact Assessment – Sea Turtles

Based on physiology, it is likely that TTS can occur in sea turtles as it does in other vertebrates. However, no studies have been conducted on TTS in sea turtles to confirm this hypothesis. It is also unknown if lost or damaged sensory cells in sea turtles can regrow after a loss, as occurs in fish. Because of their rigid external anatomy, it is possible that sea turtles are highly protected from impulsive sound effects such as pile driving (Popper et al., 2014). Data on the behavioral response of sea turtles to acoustic exposure have been collected in a small number of research studies.

A full evaluation of potential stressors to sea turtles is presented in Section 6.8 of Volume III of the COP. This section discusses potential acoustic risks posed to sea turtles from the Project and provides supplemental research, analysis, and evaluation of the stressors presented in Section 6.8 of Volume III of the COP. Specifically, potential behavioral response to pile driving-related noise is presented.

5.1. Species that May be Present in the Project Area

All the sea turtle species that may be present in the WDA are listed as threatened or endangered. Four species of sea turtles may occur in the Offshore Project Area: Loggerhead Turtle (*Caretta caretta*), Kemp’s Ridley Sea Turtle (*Lepidochelys kempii*), Green Sea Turtle (*Chelonia mydas*), and Leatherback Sea Turtle (*Dermochelys coriacea*). Many species of sea turtle prefer coastal waters, however both the Loggerhead and Leatherback Turtles are known to occupy deepwater habitats, and are considered common during summer and fall in the WDA. Kemp's Ridleys are thought to be regular visitors during those seasons. Green Sea Turtles are rare in the Offshore Project Area, generally preferring tropical and subtropical habitats, and are not considered further.

5.2. Density Estimates

There are limited density estimates for sea turtles in the WDA. For this analysis, sea turtle densities were obtained from the US Navy Operating Area Density Estimate (NODE) database on the Strategic Environmental Research and Development Program Spatial Decision Support System (SERDP-SDSS) portal (DoN, 2007; DoN, 2012). These numbers were adjusted by the Sea Mammal Research Unit (SMRU, 2013), available in the Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP) (Halpin et al., 2009). These data are summarized seasonally (winter, spring, summer, and fall) and provided as a range of potential densities per square kilometer within each grid square. Leatherback and Loggerhead Sea Turtles were the most commonly observed turtle species during aerial surveys by Kraus et al. (2016) in the MA/RI and MA WEAs, with an additional six identified Kemp’s Ridley Turtle sightings over five years.

In OBIS-SEAMAP, because density is provided as a range, the maximum density will always exceed zero, even though turtles are unlikely to be present in winter. Maximum densities were assumed for all seasons. Thus, the winter densities of sea turtles in the WDA was very likely overestimated. The WDA is on the northernmost border of the Mid-Atlantic North region defined in NEFSC & SEFSC (2011c) for sea turtle distribution. Furthermore, as described in the COP, the presence of sea turtles in the WDA will be limited mainly to summer and fall months due to seasonal habitat use whereby sea turtles use warmer water habitats in the winter months (DoN, 2017; Dodge, Galuardi, Miller, & Lutcavage, 2014; Hawkes, Broderick, Coyne, Godfrey, & Godley, 2007). 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/RI and MA WEAs. South of the MA WEA, in the New York Bight, Normandeau and APEM (2016, 2018) conducted aerial surveys for sea turtles in 2016 and 2017 using high-resolution photography to aid in species identification. In that region, most of the sea turtles recorded were Loggerhead Sea Turtles by an order of magnitude. Sea turtle densities used in animal movement modeling are listed in Table 24.

Table 24. Sea turtle density estimates for the Project area. Density estimates are derived from SERDP-SDSS NODE database (density estimate from http://seamap.env.duke.edu/serdp).

Common name	Density (animals/100 km^2 [38.6 miles^2])			
	Spring	Summer	Fall	Winter
Leatherback sea turtle	0.0274	0	0.0274	0.0274
Loggerhead sea turtle	0.1117	0.1192	0.1111	0.1111
Kemp's ridley sea turtle	0.0105	0.0105	0.0105	0.0105

5.3. Acoustic Analysis Methods

Acoustic analysis for sea turtles uses the same methods outlined for marine mammals in Section 3, with the exception of frequency weighting. Weighting functions do not exist for sea turtles and are therefore not used to evaluate potential impacts to fish and sea turtles. There is also limited guidance for acoustic impact evaluation.

5.4. Acoustic Criteria – Injury and Behavior

Very little data are available to inform thresholds for impacts to sea turtles from exposure to sound generated during pile driving activities. NOAA also has not established formal acoustic thresholds for behavioral harassment or injury for sea turtles. The ANSI-accredited report by Popper et al. (2014) follows a similar approach as Southall et al. (2007) in suggesting the dual criteria of peak pressure and accumulated sound energy for evaluating potential injury. Both the BOEM and NMFS have adopted the following thresholds based on the literature:

- Potential mortal injury – 210 dB cumulative sound exposure level (L_E), or greater than 207 dB peak sound level (L_{pk}) (Popper et al., 2014).
- Behavioral harassment – 166 dB re 1 µPa rms (L_p).

These thresholds were developed based on NMFS criteria for marine mammals of 160 dB rms for Level B harassment and 180 dB rms re 1 µPa for Level A harassment (prior to NMFS (2018) guidance discussed in Section 6.7 of Volume III of the COP), and refined by the results of McCauley et al. (2000). Popper et al. (2014) does not define sound levels that may result in behavioral response, but does indicate a high likelihood of response near an impulsive source (tens of meters), moderate response at intermediate ranges (hundreds of meters), and low response far from the source (thousands of meters) (Popper et al., 2014). Both the NMFS criteria (SPL of 166 and 180 dB re 1 µPa) and the Popper et al. (2014) criteria were evaluated in this analysis.

5.5. Predicted Sound Fields

The ranges for potential injury and temporary threshold shifts for sea turtles for multiple pile types and various scenarios were modeled using the same methods as those used for marine mammals (Section 4.4). Included in the assessment of thresholds for potential injury or mortality and behavioral responses of sea turtles were 10.3 m (33.8 ft) monopile foundations and four 3 m (9.8 ft) diameter jacket piles (Appendix A). Table 25 provides a summary of threshold radii estimated for the larger diameter 10.3 m (33.8 ft) piles, applying various attenuation cases for comparison purposes. The values are calculated using the most conservative hammer energy radii, averaged over both modeling sites.

Table 25. Ranges ($R_{95\%}$ in meters) to thresholds for sea turtles (Popper et al., 2014) due to impact hammering of a 10.3 m (33.8 ft) pile in 24 hours, using an IHC S-4000 hammer with 0, 6, and 12 dB sound attenuation.

Impact	Metric	Threshold (dB)	No attenuation	6 dB	12 dB
Mortality and Potential Mortal Injury	L_E,24hr	210	1,115	487	153
	L_{pk}	207	151	67	34
Behavioral Response	L_p	166	4,121	2,944	1,912

5.6. Animal Movement and Exposure Modeling

The same animal movement modeling and exposure modeling procedures are used for sea turtles as were used for marine mammals (Appendix B). Movement parameters specific to the turtle species are shown in Appendix B.

5.7. Exposure Estimates

The numbers of sea turtle animat exposures are adjusted for the species' real-world density provided in Table 24. Real-world density estimates were obtained from the NODE database for the Atlantic region. The actual number of adult sea turtles (juvenile estimates are not available) predicted to exceed the exposure criteria for both the Maximum Design and Worst Case Likely scenario estimates with and without attenuation are shown in Tables 26–29.

Table 26. Maximum Design, one pile per day real-world expected individual sea turtles above exposure with 0, 6, and 12 dB attenuation. Evaluated for the NMFS injury and behavior criteria and Popper et al. (2014) injury criteria.

Sea turtles	NMFS criteria						Popper et al. (2014) criteria					
	No Attenuation		6 dB		12 dB		No Attenuation		6 dB		12 dB	
	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury SEL (L_E)	Injury PK (L_{pk})	Injury SEL (L_E)	Injury PK (L_{pk})	Injury SEL (L_E)	Injury PK (L_{pk})
Kemp's Ridley*	0.12	0.54	0.03	0.31	0.01	0.16	0.01	0.01	0	0.01	0	0.01
Leatherback*	0.16	0.64	0.05	0.38	0.01	0.20	0.01	0.02	0	0.02	0	0.01
Loggerhead	0.66	2.94	0.22	1.72	0.10	0.89	0.07	0.07	0	0.07	0	0.01

* Endangered species

Table 27. Maximum Design, two piles per day real-world expected individual sea turtles above exposure with 0, 6, and 12 dB attenuation. Evaluated for the NMFS injury and behavior criteria and Popper et al. (2014) injury criteria.

Sea turtles	NMFS criteria						Popper et al. (2014) criteria					
	No Attenuation		6 dB		12 dB		No Attenuation		6 dB		12 dB	
	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury SEL (L_E)	Injury PK (L_{pk})	Injury SEL (L_E)	Injury PK (L_{pk})	Injury SEL (L_E)	Injury PK (L_{pk})
Kemp's Ridley*	0.09	0.30	0.03	0.19	0.01	0.11	0.01	0.01	0	0.01	0	0
Leatherback*	0.13	0.45	0.05	0.29	0.02	0.16	0.01	0.01	0	0.01	0	0
Loggerhead	0.96	3.34	0.32	2.13	0.11	1.26	0.13	0.09	0.04	0.08	0.01	0.04

* Endangered species

Table 28. Most Likely design, one pile per day real-world expected individual sea turtles above exposure with 0, 6 and 12 dB attenuation. Evaluated for the NMFS injury and behavior criteria and Popper et al. (2014) injury criteria.

Sea turtles	NMFS criteria						Popper et al. (2014) criteria					
	No Attenuation		6 dB		12 dB		No Attenuation		6 dB		12 dB	
	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury SEL (L_E)	Injury PK (L_{pk})	Injury SEL (L_E)	Injury PK (L_{pk})	Injury SEL (L_E)	Injury PK (L_{pk})
Kemp's Ridley*	0.11	0.53	0.04	0.31	0.01	0.15	0.01	0.01	0	0.01	0	0
Leatherback*	0.14	0.58	0.05	0.34	0.01	0.18	0.01	0.02	0	0.01	0	0
Loggerhead	0.60	2.62	0.21	1.50	0.10	0.80	0.07	0.07	0	0.07	0	0

* Endangered species

Table 29. Most Likely design, two piles per day real-world expected individual sea turtles above exposure with 0, 6, and 12 dB attenuation. Evaluated for the NMFS injury and behavior criteria and Popper et al. (2014) injury criteria.

Sea turtles	NMFS criteria						Popper et al. (2014) criteria					
	No Attenuation		6 dB		12 dB		No Attenuation		6 dB		12 dB	
	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury max. SPL (L_p)	Beh. max. SPL (L_p)	Injury SEL (L_E)	Injury PK (L_{pk})	Injury SEL (L_E)	Injury PK (L_{pk})	Injury SEL (L_E)	Injury PK (L_{pk})
Kemp’s Ridley*	0.09	0.28	0.03	0.18	0.01	0.11	0.01	0.01	0	0.01	0	0
Leatherback*	0.11	0.38	0.04	0.24	0.01	0.14	0.01	0.01	0	0.01	0	0
Loggerhead	0.94	3.07	0.33	1.96	0.11	1.21	0.14	0.10	0.04	0.09	0.02	0.04

* Endangered species

6. Model Uncertainty

All modeled assessment approaches contain an inherent level of uncertainty that is different for each model input or parameter. For some parameters, such as the pile-driving sound source, there is high variability but little to no uncertainty. The dates and location of the Project are fixed within a defined spatial area and short temporal range (summer/fall). Pile types are used as standard practice in wind energy projects globally. The source and propagation models are first-principles models based on an understanding of the physics of sound production by the source and propagation of sound through the water. These types of models have been extensively tested during their development and use. Uncertainty in these models arises from the choice of parameter values, such as uncertainty in the sound speed profile and the geoacoustic parameters of the ocean bottom substrate.

The marine mammal density data used in this assessment is the Duke University Marine Geospatial Ecological Laboratory model (Duke model) (Roberts et al., 2016). The Duke model is a habitat-based density model that involved integrating 23 years of aerial and shipboard marine mammal surveys and linking these data to environmental covariates obtained from remote sensing and ocean models. The most recent survey included in the Duke model was conducted in 2009. The model uses traditional distance-sampling methods to calculate densities. The Atlantic Ocean is a highly studied region relative to other parts of the world, with surveys conducted on a regular basis and in the Offshore Project Area. There is a reasonably high confidence in the site-specific visual surveys conducted by BOEM, NOAA, and other researchers in this area, with the exception of pinnipeds (Roberts pers. comm.). Where data are extrapolated, uncertainty is moderated to by using the mean values to calculate estimated exposures.

6.1. Estimated Effects

The effects of sound exposure on individual animals is not well understood. Exposure estimates are produced in the modeling process and, to predict potential impacts, the exposure estimates must be compared to species-specific threshold criteria. Research ethics precludes exposing protected animals like marine mammals and sea turtles to injury so no data are available as a direct assessment of injury due to sound exposure. For this reason, lower-level sound exposures that produce a temporary hearing loss have been studied and used as the basis on which permanent hearing loss (injury) thresholds are extrapolated. Individuals vary in their susceptibility to hearing loss and there is uncertainty in the extrapolation from temporary hearing loss to permanent hearing loss primarily because the growth functions in the extrapolation process necessarily come from terrestrial mammals. Because of the context-dependent nature of behavioral response, there is a great deal of variability in behavior and behavioral reactions to sound. Behavioral studies exist, but usually only represent a few individuals, for a short time, and with limited data available regarding the status and context of the animal. To account for this variability, conservative assumptions are used to maximize the number of exposure estimates rather than quantifying a limiting variable that would reduce the estimates. Conservative assumptions limit the impact of uncertainty in values like acoustic thresholds and density estimates by overestimating exposures. Conservative assumptions of the modeling include, but are not limited to the following:

- Cumulative exposure estimates assume an animal is exposed for the maximum possible number of strikes and duration of pile driving; however, typical pile-driving activities are not expected to achieve the maximum of either of these values.
- Exposure estimates assume the Maximum Design and Most Likely scenarios, with both scenarios including the maximum monopile size of 10.3 m (33.8 ft). It is likely that this maximum diameter pile will not be used for all monopiles.
- Acoustic threshold radii estimates quantified soft-start mitigation, but exposure estimates do not quantify animal response to soft-start.
- Impact of clearance zones was not considered.
- Exposure estimates do not consider aversion of most species, or short-term displacement that are both likely to reduce injurious level exposures over the life of the Project.

7. Other Sound Sources

7.1. Vessel Noise

Effects from vessel noise are variable and dependent on the species of marine mammal, the marine mammal's location and activity, the novelty of the sound, vessel behavior, habitat, and other factors (Ellison, Southall, Clark, & Frankel, 2012). Vessel noise associated with the Project is likely to be similar in frequency characteristics to the existing commercial traffic sound. The Navigation Risk Assessment prepared for Vineyard Wind indicates that construction activities will likely result in an increase from normal traffic levels in the area. NARWs are known to continue to feed in Cape Cod Bay despite disturbance from passing vessels (Brown, Marx, & Nichols, 2000), indicating some level of habituation to the sound levels of local traffic. Regardless, Vineyard Wind has committed to several mitigation measures that will reduce the potential impact of vessel noise on marine mammals and sea turtles, including monitoring for the presence of marine mammals and turtles, the establishment of transit setback distances, adherence to vessel strike avoidance measures, monitoring of the sighting advisory system, and the slow-down of vessels when animals are observed. Vessel slowdown reduces sound levels of ships and therefore exposure for marine fauna. These measures are expected to decrease the risk of impact to low.

7.2. Project Operations

In general, reported sound levels of operational wind turbines is low (Madsen, Wahlberg, Tougaard, Lucke, & Tyack, 2006). Operational noise levels measured at the Block Island Wind farm are barely detectable at a range of 50 m (164 ft) (J. H. Miller & Potty, 2017). European studies of operational sound levels provide some insight into the expected risk to marine mammals, however, sound behavior is largely dependent on site-specific environmental factors. Tougaard and Henrikson (2009) found that sound from three different wind turbine types in European waters was only measurable above ambient sound levels at frequencies below 500 hertz (Hz). The total sound pressure level was in the range 109 to 127 dB re 1 μPa, measured at distances between 14 and 20 m (46 and 65.6 ft) from the turbines. For the Offshore Project Area, Kraus et al. (2016) recorded ambient sound in the frequency range of 70.8 to 224 Hz in the MA WEA and MA/RI WEA from 2011 to 2015. Sound levels ranged from 96 dB to 103 dB re 1 μPa during 50% of recording time. Sound pressure levels were 95 dB re 1 μPa or less 40% of the time and greater than 104 dB re 1 μPa 10% of the time. BOEM recordings of operational sound from turbines during the Real-time Opportunity for Development Environmental Observations (RODEO) project, indicate that expected levels at 50 m (164 ft) from the source are approximately 90 dB re 1μPa rms (SPL) at a frequency of ~71 kHz (J. H. Miller & Potty, 2017).

Studies of Harbor Porpoises, one of the most noise sensitive species, have found porpoises to be present all year-round near exploration drilling rig and production platforms in the North Sea (Todd, Lepper, & Todd, 2007; Todd, Pearse, Tregenza, Lepper, & Todd, 2009). This work has also shown that the short-term activity of porpoises is unaffected by routine oil and gas operations such as drilling, tender-boat operations, and cementing and casing (Todd et al., 2009). Sound levels associated with these activities were recorded in the US Beaufort and Chukchi Seas (M. E. Austin, Hannay, & Bröker, 2018). Recorded sound levels of exploration drilling were significantly higher (169–175 dB re 1 μPa) than those recorded by Tougaard and Henrikson (2009) at WTGs. Based on the results from both Tougaard and Henrikson (2009) and Kraus et al. (2016), the operational sounds generated by the Project turbines is expected to be similar to the ambient sound found within the MA WEA and MA/RI WEA.

Vineyard Wind has used the best available data to make the determination that operational sound levels generated by the Project are expected to be a low risk to marine mammals.

8. Non-Acoustic IPFs

To supplement the analysis provided in the COP, the following non-acoustic IPFs (habitat modification and vessel traffic) are further elaborated in this document. This section provides additional research, analysis, and evaluation of the IPFs (stressors) presented in the Section 6.7 of Volume III of the COP.

8.1. Habitat Modification

There are few studies that have measured the responses of marine species to habitat modification resulting from offshore wind farm construction and operation, and none have yet assessed longer term impacts at the population level (Bailey, Brookes, & Thompson, 2014). Researchers have concluded, from the limited studies that do exist, that the most significant negative impacts of offshore wind farm construction are likely to occur as a result of avoidance of construction noise or structures rather than direct mortality (Bailey et al., 2014).

In contrast to construction, offshore wind energy projects may benefit fish by acting as artificial reefs, and consequently marine mammals by increasing prey availability through fish aggregation and production and improving prey species abundance and diversity during long-term operation (Bailey et al., 2014; Inger et al., 2009; Lindeboom et al., 2011; Petersen and Malm, 2006; Runyon, 2018; Scheidat et al., 2011; Wilhelmsson and Malm, 2008). Once operational, there are data to suggest that marine mammals may be attracted to the Project infrastructure. Russell et al. (2014) conducted a tagging study of Harbor and Grey Seals living near two active wind energy project areas on the British and Dutch coasts of the North Sea. The tag data strongly suggested that the associated wind energy structures were used for foraging, and the directed movements showed that animals could effectively navigate to and between structures (Russel et al., 2014). Studies of Harbor Porpoise activity within operational wind farms showed that relatively more porpoises were found in the wind farm area compared to reference sites, with statistically positive linkage to the wind energy project (Todd et al., 2007). Researchers studying this behavior have concluded that the likely explanation for these findings were related to increased food availability and the exclusion of fishing activities (Scheidat et al., 2011). Fujii (2015, 2016) observed that feeding habits of major fish species were closely associated with an offshore oil platform in the North Sea.

Increased prey is not limited to fish aggregation and production. Lighting on offshore platforms may generate sufficient downward illumination to affect the local distribution of phototaxic prey invertebrate including zooplankton (Keenan et al., 2007; McConnell et al., 2010). Sea turtles, particularly Loggerheads, are commonly observed resting in and around artificial reefs and shipwrecks (Nuttall & Wood, 2012; Patterson III, Addis, & Dance, 2009). By hiding under overhanging structures, sea turtles are less exposed to the influence of currents and, more importantly, less vulnerable to potential predators. Artificial sites, like wind energy infrastructure, may provide important resting and foraging habitat, particularly during inter-nesting periods. Sea turtles may also use artificial structures to remove bio-fouling from their carapaces (Barnette). Bergström et al. (2014) summarized probable impacts of wind energy project construction and operation on marine mammals, fish, and benthos, and concluded that there is a moderate level of certainty of significant positive habitat gain for fish arising from wind energy project habitat modification. Other studies suggest that there are little to no differences in species' presence inside and outside wind farms post-construction and during operation (Tougaard et al., 2009).

A negative effect of habitat gain could emerge if the infrastructure functions as introduction habitat for invasive species (Brodin & Andersson, 2009; Bulleri & Airoldi, 2005; Page et al., 2008;). The opportunistic use of artificial substrata (oil and gas platforms) by non-indigenous coral species in the Gulf of Mexico is well-documented, with growing concern related to a spread of these species to the Atlantic as marine infrastructure increases (Sammarco et al., 2010). Over the lifetime of the Project's operation, habitat gain and the resulting increase in biodiversity and prey species may be masked or offset somewhat by loss induced by invasive species. Additionally, more structurally complex habitats that might develop in artificial infrastructure are likely to have greater species diversity and abundance, including predatory species that might prey on juvenile sea turtles. This hypothesis is focused mainly on artificial reefs sited near to nesting beaches (Barnette), and therefore is not as applicable for enhanced habitat created further offshore in the WDA.

Where certain vessels and/or vessel-based activities are excluded from portions of the area for periods of time, the Project may provide shelter for sea turtles, fish, and marine mammals. When commercial and recreational fisheries are allowed, the introduction of infrastructure in an area frequented by these users can pose another risk to these marine fauna, that is the potential for entanglement. Increased fishing activities near Project platforms can result in the accumulation of monofilament and anchor lines on these structures, which then present a threat to sea turtles that may utilize the artificial reefs as resting habitat (Barnette). Potential negative impacts, particularly during the relatively limited construction period, are likely outweighed by the long-term benefits of habitat gain over the operational lifetime.

Modeling of sound producing activities during Project construction, including vessel traffic, but particularly pile driving installation activities, indicates that there is potential for marine mammals and fish to experience sound exposure at levels that may cause behavioral response, including aversion and avoidance. Expected habitat displacement or avoidance of vessels and pile driving activities during WTG and ESP installation is based on modeled sound levels and studies of other wind energy projects. This model prediction is consistent with research data that indicates significant avoidance behavior and displacement during pile driving (Bailey et al., 2014; Bergström et al., 2014; Brandt, Diederichs, Betke, & Nehls, 2011; Brasseur et al., 2010; Carstensen, Henriksen, & Teilmann, 2006; Dähne et al., 2013; Richardson et al., 1995; Tougaard & Henrikson, 2009).

Research suggests that this displacement is temporally limited to the construction phase (Bergström et al., 2014). The proposed Project configuration of WTGs includes a typical grid spacing of 1,400–1,800 m (0.87–1.1 miles) between WTGs (with a minimum distance between nearest turbines of 1,200 m [0.75 miles]), allowing access and transit through the WDA during construction. Based on the results of other wind energy project monitoring studies, re-occupation of habitat in the Offshore Project Area is expected at equivalent or higher levels relative to the region around the Project post-construction and during operation.

8.2. Vessel Traffic

A Navigational Risk Assessment was conducted for the Project, which determined that construction activities would result in an increase from normal operations in the area. The average number of vessels in the WDA during construction is anticipated to be approximately 24, with a maximum of approximately 46 vessels onsite at any given time (Section 4.2.4 and Table 4.2-1 of Volume I of the COP). It is anticipated that there will be a moderate increase in traffic between the primary staging port and minimal to moderate traffic increases between the WDA and secondary staging ports (Appendix III-I of Volume III - Navigational Risk Assessment of the COP). The volume of traffic will vary monthly depending on weather and Project activities. During maximum periods of activity, up to 46 construction vessels would be traveling in and out of the staging port while up to three to four vessels would travel to secondary ports daily. Over the course of construction, the Project anticipates an average of 10 daily trips between both the primary and secondary ports and the WDA, compared to the current amounts of 25 vessels daily (measured per AIS 2011 lease block area).

Ports used by the Project include the likely primary port of New Bedford, and secondary ports identified in Rhode Island, Massachusetts, Connecticut, Canada, and Europe. Any vessels transiting from Canada and Europe would follow the major navigation routes. International vessel transits are not included in the daily count, but the volume of traffic from international ports is well within the realm of normal international shipping traffic based on the information gathered for the Navigational Risk Assessment.

The Navigational Risk Assessment states that coastal vessel traffic around the MA WEA and MA/RI WEA is already very high (Appendix III-I of Volume I of the COP). Within the MA WEA, the WDA experiences moderate levels of vessel traffic, with pleasure craft, passenger ferries, high speed craft, and commercial fishing vessels comprising this traffic in that order of frequency. The Offshore Project Area experiences increased vessel traffic during the summer months; however, there is no significant disruption of normal traffic patterns anticipated. Marine mammals in the Offshore Project Area are regularly subjected to commercial shipping noise and would potentially be habituated to vessel noise as a result of this exposure (BOEM 2014). This habituation may also apply to sea turtles and fish. As noise from vessel traffic associated with construction is likely to be similar to background vessel traffic noise, additional vessel noise risk to marine mammals and sea turtles would be low relative to pile driving noise.

There are many different classes of vessels proposed for use during the construction of the Project. The speed of these vessels varies from 6 – 30 knots maximum transit speed. Operational speeds are generally lower than transit speeds. The approximate speeds of Project vessels used for construction and operations are listed in Table 4.2-1 of Volume I of the COP. Many of the larger vessels associated with the construction of the Project will transit at speeds that are different from the normal vessel traffic (i.e., generally slower), and/or may remain “parked” or moored at a location while the Project is constructed.

Several mitigation measures (Table 31) are in place for the project to limit or negate vessel strike avoidance and all Project vessels will watch for marine mammals and sea turtles during construction and operation activities. However, data suggest that visual mitigation measures are not 100% effective for turtles (McDiarmid, 2012). Sea turtles spend most of their life below the sea surface, and individuals on the sea surface, particularly subadults and juveniles, generally are not demonstrative and may be difficult to visually detect, particularly beyond 500 m (1,640 ft) and during periods of elevated seas or low visibility.

Vineyard Wind will implement monitoring and mitigation measures requiring vessel slow down (Table 31) when marine mammals and sea turtles are observed within specified distances, which will minimize the risk of vessel strikes. Reductions in vessel speed have been shown to reduce the risk of collision-related mortality for NARWs (Conn & Silber, 2013; Laist, Knowlton, & Pendleton, 2014) and is also inherently protective of other marine fauna.

9. Project Monitoring and Mitigation Measures

Mitigation measures implemented during pile driving can decrease potential impacts to marine mammals, sea turtles, and fish by reducing the zone of potential impact and therefore the likelihood of injurious and behavioral sound interaction. Vineyard Wind will comply with all applicable monitoring and mitigation regulations and any permit conditions placed on the Project by regulatory agencies. In addition to regulatory compliance, Vineyard Wind is voluntarily applying various enhanced monitoring and mitigation measures to negate or limit the potential for acoustic and non-acoustic impacts to marine fauna during construction and operation of the Project. A full description of these techniques, potential best management practices (BMPs), and mitigation strategies under consideration, such as vessel speed restrictions and monitoring zones, are detailed in the mitigation menu in Section 6.7.2.1.3 of Volume III of the COP. This menu is intended to describe mitigation options that can be implemented independently or in combination to effectively reduce risks to marine mammals.

Important factors to consider when selecting mitigation techniques include safety, practical application, and effectiveness for the Project. One measure that Vineyard Wind has voluntarily agreed to implement is a seasonal restriction on pile driving in order to reduce the sound level exposure of NARWs. Density data from Roberts et al. (2016) and survey data (both visual and acoustic) from Kraus et al. (2016) suggest that the highest density of NARWs in the WDA occurs annually during the month of March. Over 93% of the sightings occurred in the months of January through April, with no NARWs observed from May through August (Kraus et al., 2016). The lowest number of acoustic recordings of this species is in August, with relatively low detections from June through November. Based on this information, Vineyard Wind has decided to refrain from any pile-driving activities from January through April in an effort to reduce impacts from construction-related activities.

A second key mitigation measure is the use of sound attenuation technology. Options under consideration for the Project include: equipment selection that is optimized for sound reduction (Integrated Pile Installer), underwater noise abatement systems (e.g., AdBm encapsulated bubble sleeve), and/or bubble curtains. Various studies have demonstrated that these mitigation measures are capable of attenuating sounds by approximately 10 to 23 dB (Michael A. Bellmann, 2014; Christopherson & Lundberg, 2013; Reinhall et al., 2015). Attenuation levels vary by equipment type, frequency band, and location. A California Department of Transportation (CalTrans) study tested several sound reduction systems and found that they resulted in 10–15 dB of attenuation in good conditions (Buehler et al., 2015). In a study conducted by Dähne et al. (2017), two big bubble curtains were shown to attenuate pile driving sounds between 7-10 dB when used independently and up to 12 dB when used concurrently. Various levels of attenuation ranging from 6–12 dB were modeled for the Project (Appendix A). Given the limitations of effectiveness predictability in various environments, attenuation mitigation efforts focused on the more attainable 6 and 12 dB reductions. As an illustration of the effect of sound attenuating technology on acoustic exposure radii calculations, percentage reductions are shown in Table 30.

Table 30. Percentage reduction in ranges to marine mammal exposure criteria with attenuation

Metric	Percentage range reduction	
	6 dB	12 dB
Level B (NOAA 2005)	49	75
PK (L_{pk})	49	73
SEL (L_E)	45	68

9.1. Summary of Project Mitigation Measures

Table 31 is a summary of the acoustic and non-acoustic monitoring and mitigation measures currently proposed for the Project. The table does not include standard compliance or mitigation measures that may be stipulated by BOEM or NOAA in permit conditions. While protection of marine mammals is a top priority, environmental and human health and safety is the very highest priority in working in the offshore environment; therefore, exceptions to mitigation may be made under certain circumstances.

Table 31. Proposed monitoring and mitigation plans for construction and operations

Monitoring & mitigation measure	Description	Anticipated regulatory requirement	Enhanced mitigation	Additional information
Mitigation for All Marine Mammals and Sea Turtles During Pile Driving				
Seasonal Restrictions[1]	▪ Vineyard Wind will establish a restriction on pile driving between January 1 and April 30	--	✓	▪ No pile driving activities January - April
Sound Reduction Technology	▪ Vineyard Wind will implement attenuation mitigation to reduce sound levels by a target of approximately 12 dB - A noise attenuation technology will be implemented (e.g., Noise Mitigation System [NMS], Hydro-sound Damper [HSD], Noise Abatement System [AdBm], bubble curtain, or similar), and a second back-up attenuation technology (e.g. bubble curtain or similar) will be on-hand, if needed pending results of field verification	--	✓	▪ Integrated equipment dampening methods ▪ External sound dampening
Sound Field Verification	▪ Sound levels will be recorded for each of the pile types for comparison with model results	✓	✓	▪ One each of the monopiles and jacket piles will be recorded and characterized
Low Visibility Construction Operations	▪ Pile driving will not be initiated when the clearance zone cannot be visually monitored	--	✓	▪ As determined by the lead PSO on duty
Protected Species Observers (PSOs)	▪ A minimum of two PSOs will maintain watch during daylight hours when pile driving is underway ▪ PSOs may not perform another duty while on watch ▪ PSOs may not exceed four consecutive watch hours; must have a minimum two hour break between watches; and may not exceed a combined watch schedule of more than 12 hours in a 24-hour period ▪ All PSOs will have training certificates that meet or exceed BOEM/BSEE criteria or have NMFS approval, or will be pre-approved by NMFS ▪ PSOs will be deployed on the installation vessel ▪ PSOs will check the NMFS Sighting Advisory System for NARW activity ▪ Clearance and monitoring zones will be monitored around the pile center for marine mammals ▪ PSOs will record behavioral activity of animals observed	✓	✓	n/a

Monitoring & mitigation measure	Description	Anticipated regulatory requirement	Enhanced mitigation	Additional information
Pre-piling Clearance Timing	▪ Clearance zone(s) must be clear for the following time period prior to pile driving - Mysticete whales and sea turtles[2] for 30 minutes - Odontocetes and Pinnipeds for 15 minutes	✓	✓	▪ Use reticle binoculars and/or range sticks
Soft-start	▪ Soft-start will be implemented during pile driving	✓	✓	n/a
Passive Acoustic Monitoring (PAM)	▪ A PAM system will be utilized – the system will be identified prior to construction and in consultation with BOEM and NOAA Fisheries ▪ The PAM system will not be located on the installation vessel to avoid interference ▪ A team of trained PAM operators will monitor for acoustic detections ▪ The system will be in operation in accordance with the pre-piling clearance timing	--	✓	n/a
Clearance Zones (radius from pile center)	▪ Monopile and Jacket Installation: - Mysticete Whales: 500 m - Odontocetes, Pinnipeds, and Sea Turtles: 50 m	✓	✓	▪ Proposed clearance zones are based on modeled distances to the NMFS Level A harassment thresholds (both PK and SEL), visual observation capability, and practical offshore implementation. ▪ Clearance zone distances assume longer than expected exposure durations for SEL criteria.
Monitoring Zone (radius from pile center)	▪ PSOs will monitor to the extent practicable - During Monopile Installation: 2,750 m - During Jacket Installation: 2,200 m	✓	✓	▪ Monitoring zones are based on the NMFS Level B harassment criteria (160 dB SPL) and reflect the average distance of two modeled sites.
Shut downs	▪ If a marine mammal or sea turtle is observed approaching the clearance zone, the PSO will request a temporary cessation of pile driving. Where shut-down is not possible to maintain installation feasibility, reduced hammer energy will be requested and implemented where practicable ▪ After shut down, piling can be initiated once the clearance zone is clear for the minimum species-specific time period, or if required to maintain installation feasibility	✓	--	n/a

Monitoring & mitigation measure	Description	Anticipated regulatory requirement	Enhanced mitigation	Additional information
Vessel Strike Avoidance	▪ 100 m (328 feet) will be maintained between all transiting vessels and whales ▪ If a whale is observed within 100 m (328 feet), the transiting vessel will shift engine to neutral and will not re-engage engines until the whale has moved out of the vessel path and beyond 100 m (328 feet) ▪ Transiting vessels will maintain a separation distance of 50 m (164 feet) from pinnipeds and dolphins, except for bow-riding dolphins and pinnipeds that approach the vessel ▪ Vineyard Wind will report sightings of injured or dead protected species			n/a
Additional Pile Driving Mitigation for NARW				
May 1 to May 14	▪ An extended PAM clearance zone of 10 km (radius from pile center) will be implemented for NARW ▪ PAM will be operated 24/7 ▪ Prior to piling, an aerial or boat survey will be conducted across the extended 10 km clearance zone - Aerial surveys will not begin until the lead PSO on duty determines adequate visibility and at least 1 hour after sunrise (on days with sun glare) - Boat surveys will not begin until the lead PSO on duty determines there is adequate visibility - If a NARW is sighted during the survey, piling operations will not be conducted that day unless an additional survey is conducted to confirm the zone is clear of NARW	--	✓	n/a
May 1 to December 31	▪ 60 minute pre-piling monitoring time period ▪ Clearance zone: minimum 1000 m	--	✓	n/a
November 1 to December 31	▪ An extended PAM clearance zone of 10 km (radius from pile center) will be implemented for NARW ▪ An aerial survey, as described above may also be utilized to confirm zone is clear ▪ PAM will be operated 24/7	--	✓	n/a
Additional Vessel Speed Mitigation for NARW				
November 1 to May 14	▪ Vessels will travel at less than 10 knots within the WDA ▪ When transiting to or from the WDA (this will not apply to any transitting in Nantucket Sound, which has been demonstrated by best available science to not provide consistent habitat for NARW) Vineyard Wind will either travel at less than 10 knots or will implement visual surveys or PAM to ensure the transit corridor is clear of NARW	--	✓	n/a
DMA	▪ Vineyard Wind will reduce speeds within a DMA to 10 knots unless visual surveys or PAM are conducted, which demonstrate that NARW are not present in the transit corridor, or the animals can be avoided	--	✓	n/a

Monitoring & mitigation measure	Description	Anticipated regulatory requirement	Enhanced mitigation	Additional information
Year-round	▪ An observer who has undergone marine mammal training will be stationed on vessels transiting to and from the WDA if traveling over 10 knots ▪ 500 m (1640 feet) will be maintained between all transiting vessels and NARW	--	✓	n/a

[1] This restriction is intended to minimize the amount of pile driving that occurs when the migratory NARW is likely to be in the Offshore Project Area and thus limit sound exposure for this endangered species. Density data from Roberts et al. (2016) and survey data (both visual and acoustic) from Kraus et al. (2016) suggest that the highest density of NARWs in the WDA occurs annually in March. Over 93% of the sightings in the Kraus et al. (2016) study occurred from January through April, with no NARWs sighted from May through August.

[2] Consistent with sea turtle clearance times for seismic activity in the Atlantic and Gulf of Mexico - 30 minutes (BOEM 2012, BOEM-NTL-2016-G02).

9.2. Sound Field Verification

Exposure estimates indicate that mitigation measures achieving a sound attenuation of 6 dB are protective for species of concern, including the NARW. Vineyard Wind has committed to investigating mitigative technologies capable of reducing sound levels by up to approximately 12 dB. To assess the efficacy of mitigation measures and to determine the distance to pre-defined acoustic thresholds, Vineyard Wind proposes to conduct a sound field verification (SFV) when construction commences. Sound levels will be measured at distances from the pile at one monopile location and one jacket pile location. The results of the *in situ* SFV will be compared to the modeling results presented in this report. These results will also inform Project mitigation measure implementation for the remainder of the construction – such as determining monitoring or clearance zones. Monitoring and clearance zones depend on the potential for impact and the number of expected exposures. For some metrices, PK and SPL, the distance necessary to monitor is easy to determine because impacts are predicted from single instances of exposure. Because animals move, it is much more difficult to determine a meanginful area over which animal exclusion is desired for accumulating metrics, SEL. Assuming static animals may lead to impractical and unnecessarily large areas to monitor. Understanding how the acoustic energy accumulates for animals moving through the area, e.g. animal movement modeling, can lead to a better defined and more practical monitoring area. Specific details on equipment type and deployment strategy will be provided to BOEM and NOAA in advance of the SFV.

10. Results Summary

Exposure estimates were calculated for the Maximum Design and Most Likely scenarios for marine mammals and sea turtles. Estimates of population impacts were obtained as the percentage of species' abundance to gage potential impacts from injurious exposure and behavioral disruption. This approach is conservative because potentially injurious or behavioral response exposures are equated with Level A and Level B take even though exposure to threshold levels of sound does not always mean that harassment has occurred. Estimates were generated assuming one monopile foundation is driven per day and two monopile foundations driven per day, and up to one jacket foundation per day, each with unattenuated sound fields and assuming targets of up to approximately 6 and 12 dB of broadband sound attenuation. Additional assumptions made when generating exposure estimates include the following:

- No pile driving will occur from January 1 through April 30.
- Pile driving activity is distributed from May through December, with monthly activity levels adjusted according to historical weather data.
- Pile driving will be initiated during daylight hours only.
- The conservative assumptions in the NMFS (2018) acoustic guidance such as no hearing recovery between pile strikes, measures of TTS as proxy for estimating PTS onset, and auditory weighting for functional hearing groups, were included in the model.
- Clearance of animals near the WDA before commencement of pile driving was not considered in the exposure estimates.
- Exposure estimates will be further evaluated through an MMPA permitting process in collaboration with NOAA to ensure that the exposures meet the permitting criteria. Further evaluation may include refinements in technical aspects of the Project and application of practicable mitigation.

10.1. Marine Mammals

With the inclusion of more jacket foundations, and therefore more pile driving in the WDA, exposure estimates for the Maximum Design scenario (Tables 14 and 15) are higher than the Most Likely scenario (Tables 16 and 17). In all scenarios, the maximum number of jacket foundations modeled per day was one (four jacket piles). Whether one monopile foundation is installed per day or two makes little difference with respect to projected injurious exposures (Table 14 versus Table 15, and Table 16 versus Table 17). The same total amount of pile driving is conducted whether one monopile or two is installed per day, so the finding that injurious exposures are similar indicates that animals are primarily impacted by one piling event per day. For behavioral disruptions, exposure estimates for one monopile foundation per day are somewhat higher than for two monopiles foundations per day (Table 14 versus Table 15, and Table 16 versus Table 17). The reason is that ensonified volume that may result in behavioral disruption is larger than the volume that may result in injury. Because behavioral disruption is assessed on the maximum single exposure, a behavioral disruption may be registered in response to both piles driven in a day but the animat is only counted once. With two monopile foundations per day there are half as many days of pile driving so there is likewise a reduced number of predicted behavioral response exposures.

Overall, the predicted exposures expressed as potential impacts to species populations indicate very low (negligible) risk to mid- and high-frequency cetaceans and pinnipeds — regardless of the scenario, number piles driven per day, and for both potential injury and behavioral disruption (Tables 20 and 23). While individual animals may be exposed, and possibly injured, the number of animals affected is small relative to the size and health of their populations. Of this group, only Sperm Whales are endangered, but due to their low density in the Offshore Project Area and preference for deep water, their predicted impacts approach zero.

A small number of pinnipeds (< 2 Harp Seals and < 1 animal for each of Gray and Harbor Seals) were predicted to receive injurious levels of sound without attenuation of the piling source. Without attenuation, ~13 Harbor Porpoises were predicted to receive injurious levels of sound based on exposures exceeding the unweighted, peak sound pressure (PK) threshold. With attenuation ranging from 6–12 dB, the number of Harbor Porpoise predicted to receive injurious levels of sound decreases to < 2–6 animals, and injurious impacts to pinnipeds are < 1 animal for all species. These estimates do not include modeled aversive behavior. When aversion was included in the Harbor Porpoise modeling, zero animals received sound at injury threshold levels.

Low-frequency cetaceans are more likely to exceed the SEL exposure threshold. This occurs because the hearing frequency of this group overlaps with the highest energy frequency bands produced during pile driving. In the case of NARWs, over six individuals are predicted to receive potentially injurious sound exposure for the Maximum Design scenario with no noise attenuation or other mitigation measures. For the Most Likely scenario with no noise attenuation or other mitigation, the number of individuals is almost four. While this is a low number of individuals, the total population of NARW is small (~450, Table 19) and they are critically endangered. With approximately 6 dB sound attenuation, the number of individuals predicted to receive a potentially injurious exposure decreases to just over one individual for the Maximum Design scenario and < 1 for the Most Likely scenario. Achieving up to approximately 12 dB of attenuation further decreases the number of predicted animals potentially exposed to injurious levels of sound to less than two animals in the Maximum Design scenario, and less than one animal in the Most Likely scenario, 0.03% and 0.02% of the species' population, respectively.

The NARW results are similar to those seen for all low-frequency cetaceans. In the Maximum Design scenario with two piles installed per day, without attenuation, the predicted potential risk of injurious exposures expressed as a percentage of species abundance is very low (e.g., 0.10% of Minke Whale, 0.37% of Fin Whale, 0.13% of Sei Whale population), and low (e.g., 1.66% of NARW and 1.56% of Humpback Whale population). However, sound attenuation mitigation is proposed for the Project, which significantly reduces the number of predicted exposures as a percentage of abundance for all species, including mysticetes. For the critically endangered NARW, modeled sound attenuation by 12 dB reduces the number of predicted animals potentially exposed to injurious levels of sound to less than two animals in the Maximum Design scenario, and less than one animal in the Most Likely scenario, 0.03% and 0.02% of the species' population,respectively respectively. For all other species, with a targeted sound reduction of up to approximately 12 dB, the number of modeled animals potentially exposed to injurious levels of sound is reduced to small numbers in all scenarios, for all species (Tables 14-17, and therefore the impact risk rating is very low.

These exposure predictions do not account for aversion, which is commonly seen in mysticetes exposed to anthropogenic sound, nor do they account for other proposed mitigation measures, including ramp-up, zone clearance, and monitoring. Therefore, they are conservative estimates. An example model run was conducted for NARW that included aversion. Even without attenuation, the aversion model predicted that the number of NARW that could potentially receive injurious levels of sound was nearing zero. With aversion and attenuation ranging from approximately 6–12 dB, no NARW were predicted to reach the NMFS (2018) injury thresholds.

Individual exposure numbers are also considered in the context of species' abundance. As with individual exposure estimates, the model-predicted numbers for injurious exposures as a percentage of species' abundance are very low for all mid- and high-frequency cetaceans and pinniped species, with or without attenuation, in all Maximum Design and Most Likely scenarios. These results are similar for behavioral response, with the highest percentage of exposures to Atlantic White Sided Dolphin (maximum 1.96%). With sound attenuation planned for the Project, the injury and behavioral response impact rating for mid- and high-frequency marine mammal species is very low or negligible.

10.2. Sea Turtles

Using the NMFS injury criteria (unweighted 180 dB L_p) with sound exposure estimates, < 1 Loggerhead Turtle is predicted to be exposed to an injurious sound level threshold. When attenuation is considered, the number of modeled Loggerhead Turtles estimated to receive injurious exposures decreased to ~0.1. For both Maximum Design and Most Likely scenarios, ~0.1 Leatherback and Kemp's Ridley Sea Turtles were predicted to receive injurious levels of sound, without attenuation. With attenuation, the predicted number approaches zero. When using the Popper et al. (2014) criteria (210 dB L_E, or 207 dB L_{pk}) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014), fewer than one, or approaching zero, animals were predicted to receive injurious levels of sound, with or without attenuation. The calculated radius, using the Popper et al. (2014) criteria, within which, if present, turtles might experience the NMFS injury thresholds with attenuation of 6 and 12 dB, is 67–487 m and 34–153 m respectively.

The behavioral criteria used by the NMFS for sea turtles is an unweighted 166 dB SPL (NSF, 2011). This level of sound is predicted to propagate to a range of approximately 4 km (2.5 miles) from the piling source. Exposure results predict ~3 Loggerhead Turtles would receive sound levels sufficient to result in a behavioral response for the modeled scenarios without attenuation. With attenuation, the predicted number of Loggerhead Turtles expected to experience a behavioral response is ~2 for 6 dB of attenuation and ~1 for 12 dB of attenuation. Models predict that fewer than one each of Leatherback and Kemp's Ridley Sea Turtles may potentially receive sound levels above the behavioral threshold without attenuation, and even less with attenuation.

There are no estimates for the total populations of Leatherback or Kemp's Ridley Sea Turtles. The NEFSC & SEFSC (2011c) estimated that the Loggerhead Turtle population in the Northeast Atlantic Ocean is approximately 588,000 when only positively identified Loggerhead Turtles are considered in abundance estimates, and as high as 801,000 when a proportion of unidentified sea turtles in surveys is considered in estimates. Thus, the conservative estimate of three individual Loggerhead Turtles experiencing behavioral response to pile driving constitutes potential effects to only 0.0005% to 0.0003% of their estimated population.

11. Discussion

To estimate the potential impact of acoustic exposure from the proposed Project, the sound fields generated by pile driving were computed and combined with simulations of the animal species that may be present in the vicinity of the survey area. Movement parameters such as swimming speeds and depths as well as the frequency of dives, derived from tagging studies, are input to the model. Animats with these species-specific programmed behaviors represent receivers that sample the complex sound fields. The sound fields were computed using pile driving source models and sound propagation models. Sound exposure level SEL and Sound Pressure Level (SPL) were estimated in decidecade frequency bands applicable to pile driving. Because animals have finite hearing ranges and different sensitivity at different frequencies (i.e., low-, mid-, and high-frequency cetaceans), transmission loss was frequency-filtered or weighted to account for different hearing sensitivity of the species' groups. Ranges to various isopleths were estimated to allow for planning of monitoring and mitigation procedures.

Modeling results indicate that for all species modeled in the study, when sound reduction mitigation measures are employed, the likelihood of injury occurring is very low to negligible. In addition to sound attenuation, additional mitigation measures implemented during this program will further decrease the likelihood of injury occurring.

11.1. Marine Mammal Behavioral Response

Low-frequency cetaceans have the potential to be particularly sensitive to the low frequencies of pile-driving noise and may perceive sound at longer distances than mid- and high-frequency cetaceans (Finneran, 2016; Kastelein, Hoek, & Gransier, 2013), though perception does not necessarily result in harassment, as defined under the MMPA. The acoustic analysis of pile-driving sound propagation for the Project (Appendix A) results in a maximum mean distance to behavioral harassment of 2,177 m (1.35 miles) for four 3 m (9.8 ft) pile jackets and 2,739 m (1.7 miles) for 10.3 m (33.8 ft) monopiles with 12 dB sound reduction (Table 13). These are unweighted distances (NOAA 2005) that do not account for the actual hearing sensitivity of different hearing groups. Actual behavioral disturbance for LFC, MFC and PPW are limited to shorter distances when comparing a 50% probability of response, because their hearing sensitivity makes them less sensitive to certain acoustic frequencies. HFC may be responsive at longer distances, because of their documented increased sensitivity to anthropogenic sounds (e.g., Harbor Porpoise).

11.2. Sea Turtle Behavioral Response

Information on sea turtle responses to high-intensity, impulsive sounds are based on observations of captive sea turtles exposed to seismic airgun sounds. While pile driving is an impulsive source, it is not the same as an airgun. Additionally, captured and restrained animals may react differently than animals in a natural, uncaged condition without the prior stress of capture, and small sample sizes in the limited number of acoustic exposure studies with sea turtles are not sufficient to evaluate statistical significance of sound received levels that would generate behavioral reactions. However, these are the best available data to date for the potential response of sea turtles to sounds generated by pile driving.

11.2.1. Startle response

McCauley et al. (2000) suggest that sea turtles display a general alarm response at approximately 2 km (1.2 miles) from a seismic vessel operating airguns. At seismic air gun levels of 166 dB re 1µPa rms, caged sea turtles (one Green Sea Turtle and one Loggerhead Sea Turtle) noticeably increased their swimming activity in comparison to when the airgun was not operating (McCauley et al., 2000). DeRuiter and Larbi Doukara (2012) observed wild Loggerhead Sea Turtles basking near the surface during a seismic survey. They present a relationship between the probability of a dive, often preceded by a startle response, with the range to the airguns. Approximately 75% of sea turtles dove when within 20 m (65.6 ft) of an active air gun, and 50% dove at 220 m (721.8 ft), with a median response distance of 130 m (426.5 ft). The modeled sound level at 130 m (426.5 ft) was 191 dB re 1µPa peak, suggesting a higher tolerance for sound levels that those found by McCauley et al. (2000).

11.2.2. Area avoidance

Noise from pile driving may cause temporary, localized displacement of sea turtles. McCauley et al. (2000) suggest that sea turtles display behavior indicative of avoidance within 1 km (0.62 miles) of an operating seismic vessel. Above 175 dB re 1µPa rms, McCauley et al. (2000) described sea turtle behavior as erratic, suggesting that they were agitated. They suggest that, because they observed increasing swimming behavior with increasing received sound level, the 175 dB re 1µPa rms indicates the point at which sea turtles would exhibit avoidance behavior. Acoustic measurements during pile-driving events in the construction of the Block Island Wind Farm measured peak pressure levels of 188 dB at 500 m (1,640 ft) from the source (J. H. Miller & Potty, 2017). Hence, it is likely that sea turtles would avoid this area if they exhibit similar behavioral patterns to those observed by McCauley et al. (2000).

In McCauley et al. (2000), sea turtles captured and put into cages were exposed to an approaching and departing air gun signal. The sample size was two turtles, one Green Sea Turtle and one Loggerhead Sea Turtle on different days, with two hours of exposure for one animal and one hour of exposure for the other. O'Hara and Wilcox (1990) tested Loggerhead Sea Turtle responses to air guns fired at different pressures. The guns had source sound levels of about 220 dB re 1µPa at 1 m (3.3. ft). At lower pressures of 70 kg/cm^3, they found no response; however, at 140 kg/cm^3, they found a significant difference in the distribution of the turtles suggestive of avoidance. Weir (2007) summarized sea turtle sightings recorded during two 3D seismic surveys. Turtle sighting occurred closer to the source during guns-off periods compared to full-array operations, suggestive of avoidance during seismic gun operations.

11.2.3. Habituation

Some habituation and/or adaptation to pile-driving noise may occur. For example, Moein et al. (1994) found that 10 Loggerhead Sea Turtles captured in nets in the York River and placed in an enclosure with a 3 m (9.8 ft) line attached to the carapace to monitor location had decreased response, which suggested habituation to the sound of seismic air guns over multiple exposures. However, this study also does not represent pile-driving noise, involves captured sea turtles in enclosures, and has small sample sizes. Nevertheless, the received levels of sound reported in Moein et al. (1994), 175, 177, and 179 dB (no units were reported) are within the same range as those modeled for pile driving, and this is one of the few studies of sea turtle response to elevated sound levels; thus, to be conservative, it is considered possible that similar results may occur in the WDA.

11.2.4. Ambient sound

The risk to sea turtles from pile-driving sound must also be considered in the context of existing ambient sound. Other anthropogenic sound sources can, to a certain extent, mask pile-driving sound. For example, during construction of a Belgian offshore wind farm, the combined effect of the bathymetry and the noise generated by shipping was predicted to be of greater relevance to marine animals, as the sound emitted from a single pile-driving strike did not add to the soundscape for at least half of the time (Thomsen et al., 2015).

Kraus et al. (2016) recorded ambient sound in the frequency range of 70.8 to 224 Hz in the MA WEA and MA/RI WEA from 2011 to 2015. Sound levels ranged from 96 dB re 1 µPa to 103 dB during 50% of recording time. Sound pressure levels were 95 dB re 1 µPa or less 40% of the time, and greater than 104 dB re 1 µPa 10% of the time. In Long Island Sound, Samuel, Morreale, Clark, Greene, and Richmond (2005) recorded sound levels ranging from 70 to greater than 120 dB re 1 µPa. Over a busy holiday weekend, they found that 50% of sound levels were at pressures between 90 and 100 dB, and 5% were greater than 120 dB.

12. Conclusion

The acoustic modeling examined three thresholds for potential sound impacts on marine mammals from pile driving. Sound level exposure estimates were then calculated by comparing pre-determined exposure threshold criteria with computed sound fields generated by the sound source associated with two pile driving scenarios, each with one and two-pile per day activity levels. Exposure estimates were purposely conservative regarding onset thresholds of auditory injury and hearing curves for marine mammal hearing groups and assume that all individuals within a prescribed threshold radius are exposed. In addition, for comparison tables, the mean maximum values were reported and used to calculate animal exposures.

Based on the acoustic modeling results, it can be conservatively estimated that both injurious and behavioral threshold exposure levels may be exceeded for some individual marine mammals during pile driving in the WDA. It is important to note that a sound level above these thresholds indicates a potential for injury or a behavioral response to noise – it does not necessarily equate to an adverse effect on an individual marine mammal or a population.

Modeling results indicate that for most species, including NARW, the likelihood of injury occurring is low to negligible, particularly when mitigation measures to reduce sound are applied. Overall, the predicted exposure results expressed as potential impacts to species' abundance indicate very low (negligible) impact rating to mid- and high-frequency cetaceans and pinnipeds, regardless of the scenario, or number of piles driven per day, for both potential injury and behavioral disruption. While individual animals may be exposed, the number of animals affected is small relative to the size and health of their populations. Of this group, only Sperm Whales are endangered, but due to their low density in the Offshore Project Area and preference for deep water, the predicted impact to this species is negligible (i.e., 0% of population).

Low-frequency cetaceans are more likely to exceed the SEL exposure threshold. This occurs because the hearing frequency of this group overlaps with the highest energy frequency bands produced during pile driving. The sound attenuation mitigation proposed for the Project, will significantly reduce the number of predicted exposures as a percentage of abundance for all species, including mysticetes. For the critically endangered NARW, modeled sound attenuation by 12 dB reduces the number of predicted animals potentially exposed to injurious levels of sound to less than two animals in the Maximum Design scenario, and less than one animal in the Most Likely scenario, 0.03% and 0.02% of the species' population, respectively. For all other low-frequency cetaceans, a targeted sound reduction of approximately 12 dB reduced the number of modeled animals potentially exposed to injurious levels of sound to nearly zero in all scenarios for all species. Therefore, the impact risk rating for low-frequency cetaceans is very low to negligible.

These exposure predictions and ratings do not account for aversion, which is commonly seen in mysticetes exposed to anthropogenic sound, nor do they account for other proposed mitigation measures, including ramp-up, zone clearance and monitoring. Therefore, they are conservative estimates. An example model run was conducted for NARW that included aversion. Even without attenuation, the aversion model predicted that the number of NARW that could potentially receive injurious levels of sound was nearing zero.

Both received sound levels and the distance from the sound source are known to influence the probability of marine mammal behavioral response (Dunlop et al., 2017). The modeled propagation range for the behavioral level exposure criteria was calculated using both the unweighted NOAA (2005) criteria, and the Wood et al. (2012) step-function with M-weighting applied to all species (Table 13). Using these parameters and a 50% probability of response to sound levels above the exposure criteria, the ensonified area for most species is relatively small, except for the sensitive high-frequency Harbor Porpoise. Harbor Porpoise are a well-studied species, with many behavioral response studies associated with wind energy projects and pile driving demonstrate a highly aversive response (Tougaard, Carstensen, Teilmann, Skov, & Rasmussen, 2009). Viewed in the context of their population; however, the impact severity rating for Harbor Porpoise is very low.

Assuming 12 dB of attenuation, the largest percentage of a population potentially exposed to behavioral harassment thresholds is just over 2% of NARW (Table 20). As shown in the exposure estimates (Tables 14 and 17), other species have much larger absolute values of potential exposures, so this result is driven by the very low abundance of NARW. Nonetheless, the percentage calculated represents a small portion of the North Atlantic right whale population and very small portions for all other species. Potential exposures at injurious levels are even smaller portions of some populations and effectively zero for most. Assuming no attenuation, the percentage of the NARW population potentially exposed at behavioral harassment levels rises to just over 5%, while most other species remain below 2%. Once again, these values and the lower values associated with potential injurious exposures represent small portions of the species populations. Based on this approach to assessing potential exposures in the context of marine mammal population or stock sizes, impacts to the species present in the region are expected to be negligible.

Using the NMFS injury criteria (unweighted 180 dB L_p) with sound exposure estimates, < 1 Loggerhead sea turtle is predicted to be exposed to an injurious sound level threshold. When attenuation is considered, the number of modeled Loggerhead sea turtles estimated to receive injurious exposures decreased to ~0.1. For both Maximum Design and Most Likely scenarios, ~0.1 Leatherback and Kemp's Ridley sea turtles were predicted to receive injurious levels of sound without attenuation. With attenuation, the predicted number approaches zero. When using the Popper et al. (2014) criteria (210 dB L_E, or 207 dB L_{pk}) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014) (Popper et al., 2014), fewer than one, or approaching zero, animals were predicted to receive injurious levels of sound with or without attenuation. The modeled maximum radius within which sea turtles might experience above injury threshold sound levels with only 6 dB attenuation is small (maximum 487 m [1,597 ft]). While data suggest that visual mitigation measures are not 100% effective for sea turtles (McDiarmid, 2012), this radius is well within the range of typical PSO observation.

The behavioral criteria used by the NMFS for sea turtles is an unweighted 166 dB SPL (NSF, 2011). This level of sound is predicted to propagate to a range of approximately 4 km (2.5 miles) from the piling source. Exposure results predict ~ 3 Loggerhead Turtles would receive sound levels sufficient to result in a behavioral response for the modeled scenarios without attenuation. With attenuation, the predicted number of Loggerhead Turtles expected to experience a behavioral response is ~2 for 6 dB of attenuation and ~1 for 12 dB of attenuation. Models predict that fewer than one each of Leatherback and Kemp's Ridley Turtles may potentially receive sound levels above the behavioral threshold without attenuation, and even less with attenuation.

Modeling of sound producing activities during Project construction, including vessel traffic, but particularly pile driving installation activities, indicates that there is potential for marine mammals, sea turtles and fish to experience sound exposure at levels that may cause behavioral response, including aversion and avoidance. Research suggests that this displacement is temporally limited to the construction phase and re-occupation of habitat in the Offshore Project Area is expected at equivalent or higher levels relative to the region around the Project post-construction and during operation (Bergström et al., 2014). Monitoring and mitigation efforts, combined with the limited ensonified area around each pile, and the low predicted number of exposures, are likely to result in low impacts to marine mammals and sea turtles. The Most Likely impacts are short-term behavioral responses such as diving or avoidance.

There are few studies that have measured the responses of marine species to habitat modification resulting from offshore wind farm construction and operation, and none have yet assessed longer term impacts at the population level (Bailey et al., 2014). Researchers have concluded, from the limited studies that do exist, that the most significant negative impacts of offshore wind farm construction are likely to occur as a result of avoidance of construction noise or structures rather than direct mortality (Bailey et al., 2014). During operations, studies have shown that there are benefits to the habitat gain that results from infrastructure installation. These include increased prey, including fish aggregation and production (Keenan et al., 2007; McConnell et al., 2010), and provision of important resting and foraging habitat, particularly during inter-nesting periods (Nuttall & Wood, 2012; Patterson III et al., 2009). Bergström et al. (2014) summarized probable impacts of wind energy project construction and operation on marine mammals, fish, and benthos, and concluded that there is a moderate level of certainty of significant positive habitat gain for fish arising from wind energy project habitat modification. Other studies suggest that there are little to no differences in species' presence inside and outside wind farms post-construction and during operation (Tougaard et al., 2009). Potential negative impacts, particularly during the relatively limited construction period, are likely outweighed by the long-term benefits of habitat gain over the operational lifetime. Negative impacts related to habitat gain and loss are not expected to be significant.

Vineyard Wind will implement several mitigation measures over the course of the Project. Limiting pile driving activities to months when critically endangered NARW are less likely to be present in the WDA will significantly reduce potential impact to this species, as well as other species in the area in this timeframe. In addition to a voluntary no pile driving period, Vineyard Wind will implement sound attenuating mitigation technology. Based on analysis and consultation with BOEM and the NMFS, it was determined that an average of up to approximately 12 dB is a reasonable target for sound reduction. Exposure analysis indicates that this level of attenuation may not be required to reduce injurious levels of sound for species of concern, including NARW. SFV will take place at the beginning of the Project to confirm modeled sound levels. Other mitigation measures are planned related to vessel transit and monitoring. After mitigation measures are implemented, the residual risk of impacts from the Project is expected to be significantly reduced.

Literature Cited

[BOEM] Bureau of Ocean Energy Management. (2012). *Outer Continental Shelf Oil and Gas Leasing Program: 2012-2017. Final Programmatic Environmental Impact Statement*. Retrieved from https://www.boem.gov/uploadedFiles/BOEM/Oil_and_Gas_Energy_Program/Leasing/Five_Year_Program/2012-2017_Five_Year_Program/2012-2017_Final_PEIS.pdf

[BOEM] Bureau of Ocean Energy Management. (2014). *Commercial Wind Lease Issuance and Site Assessment Activities on the Atlantic Outer Continental Shelf Offshore Massachusetts Revised Environmental Assessment*. Retrieved from https://www.boem.gov/uploadedFiles/BOEM/Renewable_Energy_Program/State_Activities/BOEM%20RI_MA_Revised%20EA_22May2013.pdf

[BOEM] Bureau of Ocean Energy Management. (2016). *Gulf of Mexico OCS Proposed Geological and Geophysical Activties. Western, Central, and Eastern Planning Areas. Draft Programmatic Environmental Impact tatement Volume 1: Chapters 1-8*. Retrieved from Stuart, Florida: https://www.boem.gov/BOEM-EIS-2016-049-v1/

[CRESLI] Coastal Research and Education Society of Long Island. (2018). CRESLI seal sightings. Retrieved from http://cresli.org/cresli/seals/seal_sightings.html#2012-2013-sightings

[DFO] Fisheries and Oceans Canada. (2017). *Stock Assessment of Canadian Northwest Atlantic Grey Seals (Halichoerus Grypus): Quebec and Maritimes Regions*.

[DoN] Department of the Navy. (2007). *Navy OPAREA Density Estimate (NODE) for the Gulf of Mexico*. Retrieved from http://seamap.env.duke.edu/seamap2/downloads/resources/serdp/Gulf%20of%20Mexico%20NODE%20Final%20Report.pdf

[DoN] Department of the Navy. (2012). *Commander Task Force 20, 4th, and 6th Fleet Navy marine species density database*.

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

[HESS] High Energy Seismic Survey. (1999). *High Energy Seismic Survey Review Process and Interim Operational Guidelines for Marine Surveys Offshore Southern California*.

[ISO] International Organization for Standardization. (2017). ISO 18405:2017. Underwater Acoustics – Terminology. In (pp. 51). Geneva.

[NEFSC] Northeast Fisheries Science Center, & [SEFSC] Southeast Fisheries Science Center. (2011a). *2010 Annual report to the inter-agency agreement M10PG00075/0001: A comprehensive assessment of marine mammal, marine turtle, and seabird abundance and spatial distribution in US waters of the western North Atlantic Ocean*. Retrieved from https://www.nefsc.noaa.gov/psb/AMAPPS/docs/Final_2010AnnualReportAMAPPS_19Apr2011.pdf

[NEFSC] Northeast Fisheries Science Center, & [SEFSC] Southeast Fisheries Science Center. (2011b). *2011 Annual report to the inter-agency agreement M10PG00075/0001: A comprehensive assessment of marine mammal, marine turtle, and seabird abundance and spatial distribution in US waters of the western North Atlantic Ocean*. Retrieved from https://www.nefsc.noaa.gov/psb/AMAPPS/docs/NMFS_AMAPPS_2011_annual_report_final_BOEM.pdf

[NEFSC] Northeast Fisheries Science Center, & [SEFSC] Southeast Fisheries Science Center. (2011c). *Preliminary summer 2010 regional abundance estimate of loggerhead turtles (Caretta caretta) in northwestern Atlantic Ocean continental shelf waters*. Retrieved from https://www.nefsc.noaa.gov/publications/crd/crd1103/1103.pdf

[NEFSC] Northeast Fisheries Science Center, & [SEFSC] Southeast Fisheries Science Center. (2012). *2012 Annual report to the inter-agency agreement M10PG00075/0001: A comprehensive assessment of marine mammal, marine turtle, and seabird abundance and spatial distribution in US waters of the western North Atlantic Ocean*. Retrieved from https://www.nefsc.noaa.gov/psb/AMAPPS/docs/NMFS_AMAPPS_2012_annual_report_FINAL.pdf

[NEFSC] Northeast Fisheries Science Center, & [SEFSC] Southeast Fisheries Science Center. (2013). *Annual report to the inter-agency agreement M10PG00075/0001: A comprehensive assessment of marine mammal, marine turtle, and seabird abundance and spatial distribution in US waters of the western North Atlantic Ocean*. Retrieved from https://www.nefsc.noaa.gov/psb/AMAPPS/docs/NMFS_AMAPPS_2013_annual_report_FINAL3.pdf

[NEFSC] Northeast Fisheries Science Center, & [SEFSC] Southeast Fisheries Science Center. (2014). *2014 Annual report to the inter-agency agreement M10PG00075/0001: A comprehensive assessment of marine mammal, marine turtle, and seabird abundance and spatial distribution in US waters of the western North Atlantic Ocean*. Retrieved from https://www.nefsc.noaa.gov/psb/AMAPPS/docs/NMFS_AMAPPS_2014_annual_report_Final.pdf

[NEFSC] Northeast Fisheries Science Center, & [SEFSC] Southeast Fisheries Science Center. (2015). *Annual report of a comprehensive assessment of marine mammal, marine turtle, and seabird abundance and spatial distribution in US waters of the western North Atlantic Ocean – AMAPPS II*. Retrieved from https://www.nefsc.noaa.gov/psb/AMAPPS/docs/NMFS_AMAPPS_2015_annual_report_Final.pdf

[NEFSC] Northeast Fisheries Science Center, & [SEFSC] Southeast Fisheries Science Center. (2016). *Annual report of a comprehensive assessment of marine mammal, marine turtle, and seabird abundance and spatial distribution in US waters of the western North Atlantic Ocean – AMAPPS II*. Retrieved from https://www.nefsc.noaa.gov/psb/AMAPPS/docs/Annual%20Report%20of%202016%20AMAPPS_final.pdf

[NMFS] National Marine Fisheries Service. (2016). *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts*. U.S. Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-55. Retrieved from http://www.nmfs.noaa.gov/pr/acoustics/Acoustic%20Guidance%20Files/opr-55_acoustic_guidance_tech_memo.pdf

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

[NSF] National Science Foundation (U.S.), U.S. Geological Survey, & [NOAA] National Oceanic and Atmospheric Administration (U.S.). (2011). *Final Programmatic Environmental Impact Statement/Overseas. Environmental Impact Statement for Marine Seismic Research Funded by the National Science Foundation or Conducted by the U.S. Geological Survey*. Arlington, VA: National Science Foundation.

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

Amano, M., & Yoshioka, M. (2003). Sperm whale diving behavior monitored using a suction-cup-attached TDR tag. *Marine Ecology Progress Series, 258*, 291-295.

Anderson, J. J. (1990, 10-12 October 1990). *Assessment of the risk of pile driving to juvenile fish.* Paper presented at the Proceedings of the 15th Annual Member's Conference, Deep Foundations Institute, Seattle, Washington.

ANSI S1.1-2013. (R2013). American National Standard Acoustical Terminology. In. New York: American National Standards Institute.

Aoki, K., Amano, M., Yoshioka, M., Mori, K., Tokuda, D., & Miyazaki, N. (2007). Diel diving behavior of sperm whales off Japan. *Marine Ecology Progress Series, 349*, 277-287.

Au, W. W. L., & Hastings, M. C. (2008). *Principles of Marine Bioacoustics*: Springer.

Austin, M. E., Hannay, D. E., & Bröker, K. C. (2018). Acoustic characterization of exploration drilling in the Chukchi and Beaufort seas. *Journal of the Acoustical Society of America, 144*(1), 115-123. doi:10.1121/1.5044417

Bailey, H., Brookes, K. L., & Thompson, P. M. (2014). Assessing environmental impacts of offshore wind farms: Lessons learned and recommendations for the future. *Aquatic Biosystems, 10*(1), 8. doi:10.1186/2046-9063-10-8

Barnette, M. C. (2017). Potential impacts of artificial reef development on sea turtle conservation in Florida.

Baumgartner, M. F., Van Parijs, S. M., Wenzel, F. W., Tremblay, C. J., Esch, H. C., & Warde, A. M. (2008). Low frequency vocalizations attributed to sei whales (*Balaenoptera borealis*). *Journal of the Acoustical Society of America, 124*(2), 1339-1349. doi:Doi 10.1121/1.2945155

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

Bentivegna, F. (2002). Intra-Mediterranean migrations of loggerhead sea turtles (*Caretta caretta*) monitored by satellite telemetry. *Marine Biology, 141*, 795-800.

Bergström, L., Kautsky, L., Malm, T., Rosenberg, R., Wahlberg, M., Capetillo, N. Å., & Wilhelmsson, D. (2014). Effects of offshore wind farms on marine wildlife—a generalized impact assessment. *Environmental Research Letters, 9*(3), 12.

Brandt, M. J., Diederichs, A., Betke, K., & Nehls, G. (2011). Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. *Marine Ecology Progress Series, 421*, 205-216.

Brasseur, S., van Polanen Petel, T., Aarts, G., Meesters, E., Dijkman, E., & Reijnders, P. (2010). *Grey seals (Halichoerus grypus) in the Dutch North sea: Population ecology and effects of wind farms*. Retrieved from http://edepot.wur.nl/260049

Brown, M. W., Marx, M. K., & Nichols, O. (2000). Assessing environmental impacts of offshore wind farms: Lessons learned and recommendations for the future Cape Cod Bay, Massachusetts: January to mid-May.

Buehler, D., Oestman, R., Reyff, J., Pommerenck, K., & Mitchell, B. (2015). *Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish* (CTHWANP-RT-15-306.01.01). Retrieved from http://www.dot.ca.gov/hq/env/bio/files/bio_tech_guidance_hydroacoustic_effects_110215.pdf

Carstensen, J., Henriksen, O. D., & Teilmann, J. (2006). Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). *Marine Ecology Progress Series, 321*, 295-308. doi:10.3354/meps321295

Christopherson, A., & Lundberg, J. (2013). *Underwater Sound Attenuation in Construction Projects: Applying Science to Pile Driving Permits*.

Conn, P. B., & Silber, G. K. (2013). Vessel speed restrictions reduce risk of collision-related mortality for North Atlantic right whales. *Ecosphere, 4*(4), 1-16.

Cranford, T. W., & Krysl, P. (2015). Fin whale sound reception mechanisms: Skull vibration enables low-frequency hearing. *PLoS ONE, 10*(1), e0116222.

Croll, D. A., Acevedo-Gutiérrez, A., Tershy, B. R., & Urbán-Ramírez, J. (2001). The diving behavior of blue and fin whales: Is dive duration shorter than expected based on oxygen stores? *Comparative Biochemistry and Physiology Part A, 129*(4), 797-809.

Dahlheim, M. E., & Ljungblad, D. K. (1990). Preliminary hearing study on gray whales (*Eschrichtius robustus*) in the field. In J. Thomas & R. Kastelein (Eds.), *Sensory abilities of cetaceans* (Vol. 196, pp. 335-346): Springer US.

Dähne, M., Tougaard, J., Carstensen, J., Rose, A., Nabe-Nielsen, J. (2017). Bubble curtains attenuate noise from offshore wind farm construction and reduce temporary habitat loss for harbour porpoises. *Marine Ecology Progress Series, 580*(221-237).

Dähne, M., Gilles, A., Lucke, K., Peschko, V., Adler, S., Krügel, K., . . . Siebert, U. (2013). Effects of pile-driving on harbour porpoises (*Phocoena phocoena*) at the first offshore wind farm in Germany. *Environmental Research Letters, 8*(2).

DeRuiter, S. L., & Larbi Doukara, K. (2012). Loggerhead turtles dive in response to airgun sound exposure. *Endangered Species Research, 16*(1), 55-63.

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

Dolphin, W. F. (1987). Dive behavior and estimated energy expenditure of foraging humpback whales in southeast Alaska. *Canadian Journal of Zoology, 65*(2), 354-362.

Dunlop, R. A., Noad, M. J., McCauley, R. D., Scott-Hayward, L., Kniest, E., Slade, R., . . . Cato, D. H. (2017). Determining the behavioural dose–response relationship of marine mammals to air gun noise and source proximity. *Journal of Experimental Biology, 220*(16), 2878-2886. doi:10.1242/jeb.160192

Eckert, S. A. (2006). High-use oceanic areas for Atlantic leatherback sea turtles (*Dermochelys coriacea*) as identified using satellite telemetered location and dive information. *Marine Biology, 149*, 1257-1267.

Ellison, W. T., Clark, C. W., & Bishop, G. C. (1987). *Potential use of surface reverberation by bowhead whales, Balaena mysticetus, in under-ice navigation: Preliminary considerations*.

Ellison, W. T., & Frankel, A. S. (2012). A common sense approach to source metrics. In A. N. Popper & A. Hawkins (Eds.), *The Effects of Noise on Aquatic Life* (pp. 433-438): Springer.

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

Erbe, C., McCauley, R., & Gavrilov, A. (2016). Characterizing marine soundscapes. In N. A. Popper & A. Hawkins (Eds.), *The Effects of Noise on Aquatic Life II* (pp. 265-271). New York, NY: Springer New York.

Feist, B. E. (1992). *Potential impacts of pile driving on juvenile pink (Oncorhyncus gorbuscha) and chub (O. keta) salmon behavior and distribution.* (MS), University of Washington, Retrieved from http://www.cbr.washington.edu/sites/default/files/papers/Feist1991UWMSThesis.pdf

Finneran, J. J. (2016). *Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise*. Retrieved from San Diego, U.S.: http://www.dtic.mil/dtic/tr/fulltext/u2/1026445.pdf

Fossette, S., Ferraroli, S., Tanaka, H., Y., R.-C., Arai, N., Sato, K., . . . Georges, J.-Y. (2007). Dispersal and dive patterns in gravid leatherback turtles during the nesting season in French Guinea. *Marine Ecology Progress Series, 338*, 233-247.

Frankel, A. S., Ellison, W. T., & Buchanan, J. (2002). *Application of the acoustic integration model (AIM) to predict and minimize environmental impacts*. Paper presented at the OCEANS'02 MTS/IEEE.

Fujii, T. (2015). Temporal variation in environmental conditions and the structure of fish assemblages around an offshore oil platform in the North Sea. *Marine Environmental Research, 108*, 69-82.

Fujii, T. (2016). Potential influence of offshore oil and gas platforms on the feeding ecology of fish assemblages in the North Sea. *Marine Ecology Progress Series, 542*, 167-186.

Garrison, L. P. (2016). *Abundance of marine mammals in waters of the U.S. East Coast during summer 2011*.

Gjertz, I., Lydersen, C., & Wiig, Ø. (2001). Distribution and diving of harbour seals (*Phoca vitulina*) in Svalbard. *Polar Biology, 24*(3), 209-214.

Goldbogen, J. A., Calambokidis, J., Oleson, E., Potvin, J., Pyenson, N. D., Schorr, G., & Shadwick, R. E. (2011). Mechanics, hydrodynamics and energetics of blue whale lunge feeding: efficiency dependence on krill density. *Journal of Experimental Biology, 214*, 131-146.

Grace, M. A., Watson, J., & Foster, D. (2010). Time, temperature, and depth profiles for a loggerhead sea turtle (*Caretta caretta*) captured with a pelagic longline. *Southeastern Naturalist, 9*(2), 191-200.

Halpin, P. N., Read, A. J., Fujioka, E., Best, B. D., Donnelly, B., Hazen, L. J., . . . Hyrenbach, K. D. (2009). OBIS-SEAMAP: The world data center for marine mammal, sea bird, and sea turtle distributions. *Oceanography, 22*(2), 104-115.

Hammill, M. O., Stenson, G. B., Doniol-Valcroze, T., & Mosnier, A. (2015). Conservation of northwest Atlantic harp seals: Past success, future uncertainty? *Biological Conservation, 192*, 181-191.

Harris, D. E., Lelli, B., & Jakush, G. (2002). Harp seal records from the Southern Gulf of Maine: 1997–2001. *Northeastern Naturalist, 9*(3), 331-340. doi:10.1656/1092-6194(2002)009[0331:HSRFTS]2.0.CO;2

Hassel, A., Knutsen, T., Dalen, J., Skaar, K., Løkkeborg, S., Misund, O. A., . . . Haugland, E. K. (2004). Influence of seismic shooting on the lesser sandeel (*Ammodytes marinus*). *ICES Journal of Marine Science, 61*(7), 1165-1173. doi:10.1016/j.icesjms.2004.07.008

Hastie, G. D., Wilson, B., & Thompson, P. M. (2006). Diving deep in a foraging hotspot: Acoustic insights into bottlenose dolphin dive depths and feeding behaviour. *Marine Biology, 148*, 1181-1188.

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

Hawkins, A. D., Pembroke, A. E., & Popper, A. N. (2014). Information gaps in understanding the effects of noise on fishes and invertebrates. *Reviews in Fish Biology and Fisheries*, 1-26. doi:10.1007/s11160-014-9369-3

Hayes, S. A., Josephson, E., Maze-Foley, K., & Rosel, P. E. (2017). *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments− 2016*. Retrieved from Woods Hole, Massachusetts: https://repository.library.noaa.gov/view/noaa/14864

Herzing, D. L., & Elliser, C. R. (2016). Opportunistic sightings of cetaceans in nearshore and offshore waters of Southeast Florida. *Journal of Northwest Atlantic Fisheries and Science, 48*, 21-31.

Hooker, S. K., Whitehead, H., & Gowans, S. (1999). Marine protected area design and the spatial and temporal distribution of cetaceans in a submarine canyon. *Conservation Biology, 13*(3), 592-602.

Houghton, J. D. R., Broderick, A. C., Godley, B. J., Metcalfe, J. D., & Hays, G. C. (2002). Diving behaviour during the internesting interval for loggerhead turtles *Caretta caretta* nesting in Cyprus. *Marine Ecology Progress Series, 227*, 63-70.

Houser, D. S. (2006). A method for modeling marine mammal movement and behavior for environmental impact assessment. *IEEE Journal of Oceanic Engineering, 31*(1), 76-81.

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

Houser, D. S., Dankiewicz -Talmadge, L. A., Stockard, T. K., & Ponganis, P. J. (2010). Investigation of the potential for vascular bubble formation in a repetitively diving dolphin. *Journal of Experimental Biology, 213*, 52-62.

Houser, D. S., Helweg, D. A., & Moore, P. W. B. (2001). A bandpass filter-bank model of auditory sensitivity in the humpback whale. *Aquatic Mammals, 27*(2), 82-91.

Kastelein, R. A., Bunskoek, P., Hagedoorn, M., Au, W. L. W., & de Haan, D. (2002). Audiogram of a harbor porpoise (*Phocoena phocoena*) measured with narrow-band frequency-modulated signals. *Journal of the Acoustical Society of America, 112*, 334-344.

Kastelein, R. A., Hoek, L., & Gransier, R. (2013). Hearing thresholds of two harbor seals (*Phoca vitulina*) for playbacks of multiple pile driving strike sounds. *Journal of the Acoustical Society of America, 134*(3), 2307-2312. doi:10.1121/1.4817889

Kastelein, R. A., Wensveen, P. J., Hoek, L., Verboom, W. C., & Terhune, J. M. (2009). Underwater detection of tonal signals between 0.125 and 100kHz by harbor seals (*Phoca vitulina*). *Journal of the Acoustical Society of America, 125*(2), 1222-1229. doi:10.1121/1.3050283

Koschinski, S., & Lüdemann, K. (2013). *Development of noise mitigation measures in offshore windfarm construction*. Retrieved from https://www.bfn.de/fileadmin/MDB/documents/themen/meeresundkuestenschutz/downloads/Berichte-und-Positionspapiere/Mitigation-Measures-Underwater-Noise_2013-08-27_final.pdf

Kraus, S. D., Leiter, S., Stone, K., Wikgren, B., Mayo, C., Hughes, P., . . . Tielens, J. (2016). *Northeast Large Pelagic Survey Collaborative Aerial and Acoustic Surveys for Large Whales and Sea Turtles*.

Laist, D. W., Knowlton, A. R., & Pendleton, D. (2014). Effectiveness of mandatory vessel speed limits for protecting North Atlantic right whales. *Endangered Species Research, 23*(2), 133-147.

Lander, M. E., Harvey, J. T., Hanni, K. D., & Morgan, L. E. (2002). Behavior, movements, and apparent survival of rehabilitated and free-ranging harbor seal pups. *Journal of Wildlife Management, 66*(1), 19-28. doi:10.2307/3802867

Lawson, J. W., & Gosselin, J. F. (2011). *Fully-corrected cetacean abundance estimates from the Canadian TNASS survey*.

Lesage, V., Hammill, M. O., & Kovacs, K. M. (1999). Functional classification of harbor seal (*Phoca vitulina*) dives using depth profiles, swimming velocity, and an index of foraging success. *Canadian Journal of Zoology, 77*(1), 74-87.

Lopez, B. D. (2009). The bottlenose dolphin *Tursiops truncatus* foraging around a fish farm: Effects of prey abundance on dolphin's behavior. *Current Zoology, 55*(4), 243-248.

Lowry, L. F., Frost, K. J., Hoep, J. M., & Delong, R. A. (2001). Movements of satellite-tagged subadult and adult harbor seals in Prince William Sound, Alaska. *Marine Mammal Science, 17*(4), 835-861.

Madsen, P. T., Wahlberg, M., Tougaard, J., Lucke, K., & Tyack, P. L. (2006). Wind turbine underwater noise and marine mammals: Implications of current knowledge and data needs. *Marine Ecology Progress Series, 309*, 279-295.

Malme, C. I., Miles, P. R., Clark, C. W., Tyack, P., & Bird, J. E. (1984). *Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior. Phase II: January 1984 migration* (5586).

Malme, C. I., Miles, P. R., Clark, C. W., Tyak, P., & Bird, J. E. (1983). *Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior* (5366). Retrieved from http://www.boem.gov/BOEM-Newsroom/Library/Publications/1983/rpt5366.aspx

McCauley, R. D., Fewtrell, J., Duncan, A. J., Jenner, C., Jenner, M.-N., Penrose, J. D., . . . Mccabe, K. (2000). Marine seismic surveys: A study of environmental implications. *Australian Petroleum Production Exploration Association (APPEA) Journal, 40*(1), 692-708.

McDonald, M. A., Hildebrand, J. A., Wiggins, S. M., Thiele, D., Glasgow, D., & Moore, S. E. (2005). Sei whale sounds recorded in the Antarctic. *Journal of the Acoustical Society of America, 118*(6), 3941-3945. doi: 10.1121/1.2130944

Meynecke, J. O., Vindenes, S., & Teixeira, D. (2013). Monitoring humpback whale (*Megaptera novaeangliae*) behaviour in a highly urbanised coastline: Gold Coast, Australia. In E. Moksness, E. Dahl, & J. Støttru (Eds.), *Global Challenges in Integrated Coastal Zone Management* (pp. 101-113).

Miller, J. H., & Potty, G. R. (2017). Overview of underwater acoustic and seismic measurements of the construction and operation of the Block Island Wind Farm. *Journal of the Acoustical Society of America, 141*(5), 3993-3993. doi:10.1121/1.4989144

Miller, P. J. O., Aoki, K., Rendell, L. E., & Amano, M. (2008). Stereotypical resting behavior of the sperm whale. *Current Biology, 18*(1), R21-R23.

Miller, P. J. O., Johnson, M. P., Tyack, P. L., & Terray, E. A. (2004). Swimming gaits, passive drag and buoynacy of diving sperm whales *Physeter macrocephalus*. *Journal of Experimental Biology, 207*, 1953-1967.

Moein, S. E., Musick, J. A., Keinath, J. A., Barnard, D. E., Lenhardt, M., & George, R. (1994). *Evaluation of Seismic Sources for Repelling Sea Turtles from Hopper Dredges* (NTIS ADA332588).

Nachtigall, P. E., Au, W. W. L., Pawloski, J. L., & Moore, P. W. B. (1995). *Risso's dolphin (Grampus griseus) hearing thresholds in Kaneohe Bay, Hawaii*. Woerden, Netherlands.: De Spil Publ.

Nachtigall, P. E., Yuen, M. M. L., Mooney, T. A., & Taylor, K. A. (2005). Hearing measurements from a stranded infant Risso's dolphin, *Grampus griseus*. *Journal of Experimental Biology, 208*(21), 4181-4188. doi:10.1242/jeb.01876

Nedwell, J. R., & Turnpenny, A. W. (1998). *The use of a generic frequency weighting scale in estimating environmental effect*. Paper presented at the Workshop on Seismics and Marine Mammals, London, U.K.

Nedwell, J. R., Turnpenny, A. W. H., Lovell, J., Parvin, S. J., Workman, R., & Spinks, J. A. L. (2007). *A validation of the dB$_{ht}$ as a measure of the behavioural and auditory effects of underwater noise*. Retrieved from www.subacoustech.com/information/downloads/reports/534R1231.pdf

Normandeau and Associates Inc. (2012). *Effects of Noise on Fish, Fisheries, and Invertebrates in the U.S. Atlantic and Arctic from Energy Industry Sound-Generating Activities*. Retrieved from https://www.cbd.int/doc/meetings/mar/mcbem-2014-01/other/mcbem-2014-01-submission-boem-04-en.pdf

Normandeau Associates Inc., & APEM Inc. (2016). *Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy: Summer 2016 Taxonomic Analysis Summary Report*. Retrieved from https://remote.normandeau.com/docs/NYSERDA%20Summer%202016_Taxonomic%20Analysis%20Summary%20Report_final%20Updated.pdf

Normandeau Associates Inc., & APEM Inc. (2018). *Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy: Summer 2017 Taxonomic Analysis Summary Report*. Retrieved from https://remote.normandeau.com/docs/NYSERDA_SUMMER%202017_Taxonomic_Analysis_Summary_Report.pdf

Nuttall, S. M., & Wood, L. D. (2012). A comparison of hawksbill sea turtle site occupancy between natural and artificial reefs in Palm Beach County, FL, USA. In T. T. Jones & B. P. Wallace (Eds.), *Proceedings of the thirty-first annual symposium on sea turtle biology and conservation, NOAA Technical Memorandum NMFS-SEFSC-631* (pp. 152-153).

O'Hara, J., & Wilcox, J. R. (1990). Avoidance responses of loggerhead turtles, *Caretta caretta*, to low frequency sound. *Copeia, 2*, 564-567.

Osmek, S., Calambokidis, J., Laake, J., Gearin, P., DeLong, R., Scordino, J., . . . Brown, R. (1996). Assessment of the status of harbor porpoise (*Phocoena phocoena*) in Oregon and Washington waters. In *(NOAA Technical Memorandum)*.

Otani, S., Naito, Y., Kato, A., & Kawamura, A. (2000). Diving behavior and swimming speed of a free-ranging harbor porpoise, *Phocoena phocoena*. *Marine Mammal Science, 16*(4), 811-814. doi:10.1111/j.1748-7692.2000.tb00973.x

Otani, S., Naito, Y., Kawamura, A., Kawasaki, M., Nishiwaki, S., & Kato, A. (1998). Diving behavior and performance of harbor porpoises, *Phocoena phocoena*, in Funka Bay, Hokkaido, Japan. *Marine Mammal Science, 14*(2), 209-220. doi:10.1111/j.1748-7692.1998.tb00711.x

Pacini, A. F., Nachtigall, P. E., Quintos, C. T., Schofield, T. D., Look, D. A., Levine, G. A., & Turner, J. P. (2011). Audiogram of a stranded Blainville's beaked whale (*Mesoplodon densirostris*) measured using auditory evoked potentials. *Journal of Experimental Biology, 214*(14), 2409-2415. doi:10.1242/jeb.054338

Palka, D. L. (2012). *Cetacean abundance estimates in U.S. northwestern Atlantic Ocean waters from summer 2011 line transect survey*. Retrieved from https://www.nefsc.noaa.gov/publications/crd/crd1229/crd1229.pdf.

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

Parks, S. E., Ketten, D. R., O'Malley, J. T., & Arruda, J. (2007). Anatomical predictions of hearing in the North Atlantic right whale. *The Anatomical Record, 290*(6), 734-744. doi:doi:10.1002/ar.20527

Patterson III, W. F., Addis, D. T., & Dance, M. A. (2009). The Refuge Effect of Unpublished Artificial Reefs Deployed on the Northwest Florida Shelf (FWC-06120): 2005-08 Modeling Report.

Pearson, W. H., Skalski, J. R., & Malme, C. I. (1992). Effects of sounds from a geophysical survey device on behavior of captive rockfish (*Sebastes* spp.). *Canadian Journal of Fisheries and Aquatic Sciences, 49*(7), 1343-1356. doi:10.1139/f92-150

Pettis, H. M., Pace III, R. M., & Hamilton, P. K. (2017). *North Atlantic Right Whale Consortium Annual Report Card*. Retrieved from https://www.narwc.org/uploads/1/1/6/6/116623219/2017_report_cardfinal.pdf

Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D. A., Bartol, S., Carlson, T. J., . . . Tavolga, W. N. (2014). *Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI* (J. Cottingham, D. Deutsch, M. Hamilton, W. Hartmann, P. Marston, A. Pierce, A. N. Popper, E. Ryherd, M. Andrea, M. Siderius, N. Xiang, & W. Yost Eds. Vol. ASA S3/SC1.4 TR-2014): ASA Press.

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

Reinhall, P. G., Dardis, T., & Dahl, P. H. (2015). *Underwater Noise Reduction of Marine Pile Driving Using a Double Pile*.

Renaud, M. L., & Carpenter, J. A. (1994). Movements and submergence patterns of loggerhead turtles (*Caretta caretta*) in the Gulf of Mexico determined through satellite telemetry. *Bulletin of Marine Science, 55*(1), 1-15.

Richardson, W. J., Greene, C. R., Jr., Malme, C. I., & Thomson, D. H. (1995). *Marine Mammals and Noise*. San Diego, California: Academic Press.

Roberts, J. J., Best, B. D., Mannocci, L., Fujioka, E., Halpin, P. N., Palka, D. L., . . . Khan, C. B. (2016). Habitat-based cetacean density models for the US Atlantic and Gulf of Mexico. *Scientific Reports, 6*.

Roberts, J. J., Best, B. D., Mannocci, L., Fujioka, E., Halpin, P. N., Palka, D. L., . . . Lockhart, G. G. (2016). Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. *Scientific Reports, 6*. doi:10.1038/srep22615

Roberts, J. J., Best, B. D., Mannocci, L., Halpin, P. N., Palka, D. L., Garrison, L. P., . . . McLellan, W. M. (2015). *Density Model for Seals (Phocidae) Along the U.S. East Coast, Preliminary Results, Version 3.2, 2015-05-14*.

Roberts, J. J., Mannocci, L., & Halpin, P. N. (2017). *Final project report: Marine species density data gap assessments and update for the AFTT study area, 2016-2017 (Opt. Year 1)*.

Samuel, Y., Morreale, S. J., Clark, C. W., Greene, C. H., & Richmond, M. E. (2005). Underwater, low-frequency noise in a coastal sea turtle habitat. *Journal of the Acoustical Society of America, 117*(3), 1465-1472.

Schlundt, C. E., Dear, R. L., Bowles, A. E., Reidarson, T., & Finneran, J. J. (2011). Auditory evoked potentials in two short-finned pilot whales (*Globicephala macrorhynchus*). *Journal of the Acoustical Society of America, 129*(2), 1111-1116. doi:10.1121/1.3531875

Sills, J. M., Southall, B. L., & Reichmuth, C. (2014). Amphibious hearing in spotted seals (*Phoca largha*): Underwater audiograms, aerial audiograms and critical ratio measurements. *Journal of Experimental Biology, 217*, 726-734.

Smith, J. N., Grantham, H. S., Gales, N., Double, M. C., Noad, M. J., & Paton, D. (2012). Identification of humpback whale breeding and calving habitat in the Great Barrier Reef. *Marine Ecology Progress Series, 447*, 259-272.

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

Stevick, P., T., Judith, A., Clapham, P., J., Friday, N., Katona, S., K., Larsen, F., . . . Hammond, P., S. (2003). North Atlantic humpback whale abundance and rate of increase four decades after protection from whaling. *Marine Ecology Progress Series, 258*, 263-273.

Stockin, K. A., Fairbairns, R. S., Parsons, E. C. M., & Sims, D. W. (2001). Effects of diel and seasonal cycles on the dive duration of the minke whale (*Balaenoptera acutorostrata*). *Journal of the Marine Biological Association of the United Kingdom, 81*(1), 189-190.

Terhune, J. M., & Ronald, K. (1972). The harp seal, Pagophilus groenlandicus (Erxleben, 1777). III. The underwater audiogram. *Canadian Journal of Zoology, 50*(5), 565-569. doi:10.1139/z72-077

Thomsen, F., Gill, A., Kosecka, M., Andersson, M., Andre, M., Degraer, S., . . . Neumann, T. (2015). *MaRVEN-Environmental impacts of noise, vibrations and electromagnetic emissions from marine renewable energy. Final study report*.

Todd, V. L. G., Lepper, P. A., & Todd, I. B. (2007). *Do porpoises target offshore installations as feeding stations?* Paper presented at the Improving Environmental Performance: A Challenge for the Oil Industry, Amsterdam, the Netherlands.

Todd, V. L. G., Pearse, W. D., Tregenza, N. C., Lepper, P. A., & Todd, I. B. (2009). Diel echolocation activity of harbour porpoises (*Phocoena phocoena*) around North Sea offshore gas installations. *ICES Journal of Marine Science, 66*(4), 734-745.

Tougaard, J., Carstensen, J., Teilmann, J., Skov, H., & Rasmussen, P. (2009). Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)). *Journal of the Acoustical Society of America, 126*(1), 11-14.

Tougaard, J., & Henrikson, O. D. (2009). Underwater noise from three types of offshore wind turbines: Estimation of impact zones for harbor porpoises and harbor seals. *Journal of the Acoustical Society of America, 125*(6), 3766-3773. doi:10.1121/1.3117444

Tubelli, A., Zosuls, A., Ketten, D., & Mountain, D. C. (2012). *Prediction of a mysticete audiogram via finite element analysis of the middle ear.* Paper presented at the The effects of noise on aquatic life.

Ward, B. G. (1999). *Movement patterns and feeding ecology of the Pacific coast bottlenose dolphin (Tursiops truncatus).* (Master), San Diego State University,

Wardle, C., Carter, T., Urquhart, G., Johnstone, A., Ziolkowski, A., Hampson, G., & Mackie, D. (2001). Effects of seismic air guns on marine fish. *Continental Shelf Research, 21*(8-10), 1005-1027.

Waring, G. T., DiGiovanni Jr, R. A., Josephson, E., Wood, S., & Gilbert, J. R. (2015). *2012 Population estimate for the harbor seal (Phoca vitulina concolor) in New England waters*. Retrieved from https://www.nefsc.noaa.gov/publications/tm/tm235/tm235.pdf

Waring, G. T., Josephson, E., Maze-Foley, K., & Rosel, P. E. (Eds.). (2010). *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2009* (Vol. 201): NOAA Technical Memo-NMFS-NE 213.

Waring, G. T., Josephson, E., Maze-Foley, K., & Rosel, P. E. (Eds.). (2011). *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2010*: NOAA Technical Memorandum NMFS NE 219.

Waring, G. T., Josephson, E., Maze-Foley, K., & Rosel, P. E. (Eds.). (2013). *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2012*.

Wartzok, D., & Ketten, D. E. (1999). Marine Mammal Sensory Systems. In J. Reynolds & S. Rommel (Eds.), *Biology of Marine Mammals* (pp. 117-175). Washington DC: Smithsonian Institution Press.

Watwood, S. L., Miller, P. J. O., Johnson, M. P., Madsen, P. T., & Tyack, P. L. (2006). Deep-diving foraging behaviour of sperm whales (*Physeter macrocephalus*). *Journal of Animal Ecology, 75*(3), 814-825.

Westgate, A. J., Head, A. J., Berggren, P., Koopman, H. N., & Gaskin, D. E. (1995). Diving behaviour of harbour porpoises, *Phocoena phocoena*. *Canadian Journal of Fisheries and Aquatic Sciences, 52*(5), 1064-1073. doi:10.1139/f95-104

Wood, J., Southall, B. L., & Tollit, D. J. (2012). *PG&E offshore 3 D Seismic Survey Project EIR-Marine Mammal Technical Draft Report*.

Würsig, B., & Würsig, M. (1979). Behavior an ecology of the bottlenose dolphin, *Tursiops truncatus* in the South Atlantic. *Fishery Bulletin, 77*(2), 399-412.

Appendix A. Underwater Acoustic Modeling of Construction Noise

Appendix A is redacted in its entirety.

Appendix B. Animal Movement and Exposure Modeling

Appendix B is redacted in its entirety.