OFFSHORE WIND FACTS

MARINE MAMMALS & SEA TURTLES

What you should know:

- Almost all marine animals rely on sound for their key biological needs, including communication, orientation and navigation, predator avoidance, and feeding.
- One of the offshore wind noise-producing activities that has a significant potential to impact marine animals is pile driving. Impact pile driving is a method used to install monopile and jacket wind turbine foundations. Regulatory agencies require that offshore wind developers minimize and mitigate effects that could lead to auditory injuries or behavioral disturbance via a range of monitoring and mitigation strategies.
- Public concern that noise from offshore wind pre-construction activities is contributing to whale deaths along U.S. beaches is not supported by any scientific evidence. While offshore wind activities during pre-construction do produce noise, most of these sounds are less impactful than those produced by other human activities and emit at far lower intensities than marine activities used in oil and gas or military applications.
- The most common sources of mortality and injury to marine animals are collisions with boats or becoming entangled with ropes that are used to secure and mark fishing gear. To reduce the risk of lethal collision, vessels that are used for offshore wind activities are required to observe various speed restrictions. Further, offshore wind survey vessels must have dedicated protected species observers (PSOs) or a trained lookout on board watching for marine mammals and sea turtles, a requirement that goes above and beyond most other marine activities.
- While not conclusively demonstrated in field studies, some marine animals and their prey may be sensitive to changes in electromagnetic fields (EMFs) from subsea cables. Other disturbances, such as dredging or effects on currents, may cause these animals to temporarily avoid the wind farm areas or have a negative effect on key food sources. This is discussed further below and in Coastal and Marine Habitats.
- Technology applications and installation methods used by offshore wind developers can significantly reduce the intensity of these impacts and help to mitigate negative effects. Restorative measures can also be taken to help reestablish habitats, while the artificial reefs that develop around turbine structures have the potential to improve localized biodiversity and ecosystem health.

Spotlight Question: Is noise from offshore wind farm pre-construction surveys harming or killing whales?

There has been public concern that offshore wind farm pre-construction survey activities may be linked to recent increases in whale strandings in the U.S and at this point, there is no scientific evidence that noise resulting from offshore wind site characterization surveys is causing whale deaths. These concerns were precipitated by the Unusual Mortality Event (UME) for humpback whales that started in 2016 (National Oceanic and Atmospheric Administration Fisheries [NOAA Fisheries], 2023a). With elevated strandings along the entire East Coast, concerns arose that these deaths could have been caused by the noise and acoustic pulses generated by offshore wind site characterization surveys. The thought was that these surveys could harm marine mammals' sense of hearing and, therefore impact their ability to navigate.

However, the National Oceanic and Atmospheric Administration Fisheries (NOAA Fisheries) reported that there is no scientific evidence that links noise from offshore wind site characterization surveys to these whale mortalities (NOAA Fisheries, 2023b: NOAA Fisheries, 2023c). Sounds generated by offshore wind site characterization surveys (further discussed below in the Underwater Noise section of this summary) are considerably different from seismic airguns used in oil and gas surveys or tactical military sonar. Offshore wind developers typically conduct high-resolution geophysical (HRG) surveys for site characterization. Unlike seismic airgun surveys, which produce intense broadband, low-frequency sounds that are within the frequency range of acoustically sensitive marine animals, only a few types of sounds from HRG survey equipment are detectable by marine mammals. Furthermore, HRG sound pulses are transmitted for brief, intermittent periods through a very narrow beamwidth that is focused directly towards the seafloor. Any high sound frequencies used in HRG surveys attenuate very quickly in the ocean. As such, the noise levels and the area of exposure for offshore wind related surveys are orders of magnitude smaller than those from seismic airguns or military sonar, which have been in use since the 1960's (NOAA Fisheries, 2023a; NOAA Fisheries, 2023b; Taddiken & Krock, 2021; Dellagiarino, 2001).

As of June 2023, 200 humpback whale mortalities were recorded during the UME. NOAA Fisheries conducted a full or partial necropsy examination on 40% of the whales (necropsies were not conducted on carcasses that were too decomposed, floating offshore, or stranded on protected lands with limited or no access) and found that many of these mortalities were caused by ship strikes or entanglement in fishing gear. This is especially true offshore of New York and New Jersey where more whales are occupying waters with some of the busiest shipping lanes on the East Coast. Notably, NOAA Fisheries (2023b; 2023c) concluded that, to date, none of the necropsies indicate that these whale deaths are attributable to noise from offshore wind activities. The causal link may be due to a combination of the rebounding whale population and changes in prey distribution as a response to climate change. As these whales follow their prey to more favorable near-shore habitats, and the whales themselves increase in number, interactions with ships increase as well.

Despite regulatory agencies affirming that there are no scientific links between these recent whale mortalities and offshore wind activities (Bureau of Ocean Energy Management [BOEM], 2023a; NOAA Fisheries, 2023b; NOAA Fisheries, 2023c), careful and robust consideration of associated impacts to marine life from offshore wind development is warranted. Monitoring will continue to be conducted as part of the standard project environmental review process, especially considering the ongoing UME. In addition, organizations of experts, like the Regional Wildlife Science Collaborative for Offshore Wind (RWSC) and the New York State Environmental Technical Working Group (E-TWG) are essential for pooling knowledge across disciplines. These efforts will help industry regulators, developers, and other stakeholders make informed decisions and deploy offshore wind energy projects in an environmentally responsible manner.

In January 2024, BOEM and NOAA Fisheries released a North Atlantic Right Whale (NARW) and Offshore Wind (OSW) Strategy to protect and promote the recovery of endangered NARWs, while continuing to responsibly develop offshore wind energy. The NARW population is currently in decline, mainly due to vessel strikes and entanglement in fishing gear (Pettis et al., 2023) and regulations to further mitigate those effects are underway. This strategy identifies a number of actions under three main goals: Mitigation and Decision-Support Tools; Research and Monitoring; and Collaboration, Communication, and Outreach. Coordinated efforts between BOEM, NOAA, the offshore wind industry, and partners will allow for the collection and application of the best available scientific data and insights to inform monitoring and mitigation. Immediate impact mitigation efforts include avoiding leasing in areas where major impacts to NARWs may occur, establishing noise limits during construction, and providing guidance to developers on conducting robust sound field verification (for certain activities) to ensure that expected impacts are not being exceeded. The strategy is being considered a "living" document that will be regularly evaluated and updated as progress is made and new information becomes available. The full report can be found on BOEM's website (BOEM-NOAA Fisheries, 2023).

Key Species

The Endangered Species Act (ESA) identifies plant and animal species that are endangered or at risk of extinction and provides enforceable tools designed to prevent extinction and foster recovery of these species and their habitats. Under the ESA, conservation is enforced and aided through:

- protection from take;
- assessment of projects for potential impacts to listed species and critical habitats (Section 7 consultation);
- funding;
- recovery plan development and implementation, and;
- critical habitat designation (Gibbs & Currie, 2012).

Marine mammals and sea turtles comprise 38% of the 163 ESA-listed marine species, which includes subspecies and distinct population segments (NOAA Fisheries, 2023d; Valdivia et al., 2019). Of these species, some marine mammals that occur near the larger wind energy areas off the East Coast include the blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), North Atlantic right whale (NARW) (*Eubalaena glacialis*), sei whale (*Balaenoptera borealis*), and sperm whale (*Physeter macrocephalus*). Endangered or threatened sea turtle species that occur relatively near offshore wind energy areas include the green turtle (*Chelonia mydas*), Kemp's ridley turtle (*Lepidochelys kempii*), leatherback turtle (*Dermochelys coriacea*), and loggerhead turtle (*Caretta caretta*).

North Atlantic right whales (NARWs) are one of the most endangered whales on the planet. With approximately 360 individuals remaining, including fewer than 70 reproductively active females, NARWs are approaching extinction. Facing serious mortality threats, primarily from fishing gear entanglement and vessel strikes, the species has experienced an ongoing UME since 2017. Further, climate change is altering their habitat, migratory patterns, and prey availability, creating additional risks to their survival (NOAA Fisheries, n.d.-a). Due to this extreme sensitivity, the regulations and policies set forth for offshore wind have a strong focus on protecting the remaining population.

While trends suggest some marine mammals and sea turtle populations may be recovering since being listed under the ESA (Valdivia et al., 2019), they may still be vulnerable to population declines as man-made stressors increase and tip the scales against their survival. With offshore wind energy development adding structures to the water and vessel traffic offshore, the cumulative effects of offshore wind development on ESA-listed species must be considered.

Congress passed the Marine Mammal Protection Act (MMPA) in 1972, which established a national policy to prevent marine mammal species and population stocks from "declining beyond the point where they ceased to be significant functioning elements of the ecosystems of which they are a part". The term "take" is used in the MMPA to describe any activities that "harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal" (16 U.S.C. 1362). Take of marine mammals is prohibited under the MMPA, with certain exceptions. Regulators are permitted to issue incidental take authorizations allowing the unintentional "take" of marine mammals, incidental to specified activities like fishing activity, military exercises, scientific research, and offshore wind (NOAA Fisheries, n.d.-b). Federal regulators maintain a list of offshore wind applications for such applications viewable on the NOAA Fisheries website.

A resource for further reading on this topic is the New York State Energy Research & Development (NYSERDA)'s Environmental Technical Working Group (E-TWG)'s FAQ on Offshore Wind and Whales.

Climate Change Effects

Climate change is known to increase temperatures, alter ocean acidity, raise sea levels, and increase the frequency and intensity of storms. Melting ice caps and changes in ocean temperature can alter the availability of suitable habitats and cause shifts in the distribution of animals or their prey. Increased carbon dioxide (CO_2)

levels in the atmosphere contribute to ocean acidification, which can change the abundance of essential marine mammal and sea turtle prey species. For example, between 1982 and 2018 the average center of biomass for 140 marine fish and invertebrate species along U.S. coasts shifted approximately 20 miles north, which can affect marine mammal and sea turtle foraging. These 140 fish and invertebrate species also migrated an average of 21 feet deeper, presumably to avoid ocean warming (U.S. Environmental Protection Agency [EPA], 2023). More frequent and intense extreme weather events, such as hurricanes and storms, can also disrupt migratory patterns, damage habitats, and cause displacement from feeding grounds for marine mammals and sea turtles. Climate-related shifts in prey abundance and distribution mean that the distance between breeding grounds and feeding areas could grow. Migratory species that travel over increasingly large distances to feed could see a decline in overall health and reproductive success, especially for species with narrow thermal or prey niches (Hawkes et al., 2009; Leaper et al., 2006). The extent of these impacts is currently unknown; however, it is likely that within the current offshore wind energy areas, marine mammals, sea turtles, and their prey are already stressed and would be among those significantly affected by climate change (Gulland et al., 2022; Patrício et al., 2021; Hawkes et al., 2009). To read more on the effects of climate change visit Climate Change.

Underwater Sound Overview

Increased use of the sea for commercial shipping and fishing, geophysical exploration, advanced warfare, research activities, and recreational activities, has resulted in higher levels of noise pollution over the past few decades. Informed estimates suggest that noise levels are at least ten times higher today than they were a few decades ago. This noise pollution can range from high intensity and acute, such as underwater explosions, to low-level and chronic, such as engine noise from ships (Hildebrand, 2004). As some anthropogenic (i.e., from human activity) noise overlaps with the frequency band used by animals, their biological processes can be disrupted.

To understand the implications of noise on marine animals, it is important to first gain an understanding of the underwater acoustic environment which are detailed on NOAA's website.

Offshore Wind Effects

The development of offshore wind has an important role in transitioning the global energy supply from fossil fuels to clean, sustainable energy. If done carefully, offshore wind development provides an opportunity to mitigate climate change, reduce local and regional air and water pollution, and boost employment in the energy sector. However, the benefits of offshore wind energy can be offset by harms if the development is not conducted responsibly. Many of the habitats and species that may be affected by offshore wind development are already in a dynamic relationship with existing ocean uses, natural processes, and shifts due to climate change (Kershaw et al., 2023).

Underwater Noise

In the context of offshore wind energy projects, sound is generated both in-air and underwater through various activities and mechanisms and at varying levels during each phase of the project (Amaral et al., 2020). The offshore wind farm life cycle, which includes prospecting and site surveys, construction and installation, operation and maintenance, and decommissioning (Mooney et al., 2020; Musial & Ram, 2010), generates noise that could be detectable kilometers away from the wind farm. The sources of noise and vibrations come from pile driving, vessel noise, survey noise, dredging, and operational turbine noise (Nedwell et al., 2003).

The rapid, global expansion of offshore wind development and significant push for increased energy output indicates a proportional increase in the number, size, and magnitude of offshore wind turbines in the coming decades (Musial et al., 2021). This means that the cumulative contribution of noise, generated from multiple larger turbines and from a potentially larger fleet of vessels servicing offshore wind operations, could exert significant pressures and noise impacts on sensitive species. When coupled with existing anthropogenic noise, especially in highly urbanized areas (e.g., New York Bight where the ambient soundscape and ship traffic is much higher), the effects may be significant enough to raise concerns. While there is limited information on the cumulative effects of noise generated from offshore wind activities, these effects could have varying long-term physiological and behavioral impacts at the individual or population level.

Pile Driving

One of the noise-producing activities that has a significant potential to impact marine animals is pile driving. Impact pile driving is a method used to install monopile and jacket wind turbine foundations. The installation of a monopile requires one large pile driven into the seabed, whereas jacket foundation requires multiple smaller piles (Norro et al., 2013). Impact pile driving creates considerable levels of low-frequency impulsive noise which radiates into the environment. This has the potential to affect sensitive marine animals.

Vibratory pile driving is another method used to drive piles into the seafloor and may be used prior to impact pile driving to ensure that the pile is stable in the seabed (JASCO & LGL, 2019). Vibratory pile driving may also be used in the installation of a retaining wall made of steel sheet piles to construct temporary cofferdams, which are water-tight enclosures built around offshore structures to remove water from the work area during assembly (Tetra Tech, 2012). During vibratory pile driving, a pile is vibrated at a certain frequency (typically between 20 and 40 Hz) to drive it into the sediment rather than hammering the top of the pile (Matuschek & Betke, 2009). Although the vibratory process produces lower-level, continuous sounds compared to the high-amplitude impulsive noise produced during impact pile driving, it is still considered a potential impact, and regulated as such.

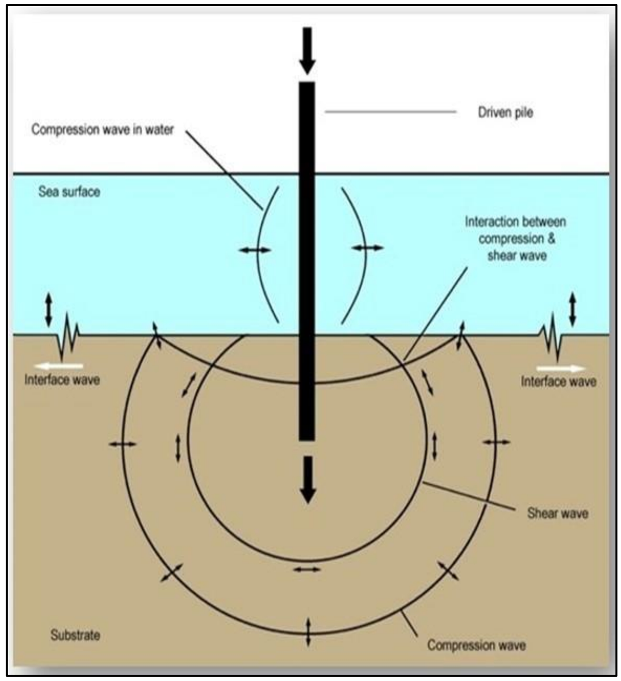

Figure 1. Diagram of sound waves generated by pile driving (Hawkins, 2022).

Underwater sound levels from pile driving, and the distance the sound travels, depend on factors such as substrate characteristics, depth, water temperature, salinity, pile diameter, and size of the impact hammer (Figure 1). Field measurements report sound pressure levels at 220 dB re 1 μPa at a range of approximately ten meters and 200 dB re 1 μPa at a range of 300 meters depending on the pile size (Reinhall & Dahl, 2011). These sound pressure levels have the potential to cause auditory injuries and behavioral disturbance, as the reported levels exceed marine mammal and sea turtle injury and behavioral disturbance thresholds (Table 1).

Table 1. Acoustic criteria for impulsive sources

Faunal Group	PTS/Injury Thresholds[1]	TTS Threshold[2]	Behavioral Threshold
Low-frequency cetaceans	219 dB	213 dB	160 dB
Mid-frequency cetaceans	230 dB	224 dB	160 dB
High-frequency cetaceans	202 dB	196 dB	160 dB
Phocid pinnipeds (in water)	218 dB	212 dB	160 dB
Sea Turtles	232 dB	226 dB	175 dB

dB = decibel
Cetaceans = a subgroup of marine mammals consisting of dolphins, porpoises, and whales

Phocid pinnipeds = a subgroup of marine mammals consisting of the earless or “true seals” from the Family Phocidae
PTS = permanent threshold shift referenced to 1 μPa^2 s and equivalent to Lpk = zero-to-peak sound pressure level; TTS = temporary threshold shift; SPL = root-mean-square sound pressure level referenced to 1 μPa
[1]PTS/injury thresholds are defined here as onset of PTS in marine mammals (National Marine Fisheries Service [NMFS], 2018) and sea turtles (Finneran et al., 2017)
[2]TTS thresholds are defined here as onset of TTS in marine mammals (NMFS, 2018) and sea turtles (Finneran et al., 2017)

Potential behavioral effects of pile driving noise include avoidance and displacement (Dähne et al., 2013; Lindeboom et al., 2011; Russell et al., 2016; Scheidat et al., 2011; National Science Foundation [NSF] & U.S. Geological Survey [USGS], 2011; Samuel et al., 2005). Potential physiological effects include a temporary threshold shift (TTS) or permanent threshold shift (PTS) in an animal’s hearing ability when exposed to pile driving noise at close range. Behavioral effects and most physiological effects (e.g., stress responses and TTS) are expected to be short term and limited to the duration of pile driving activity. However, chronic exposure to pile driving noise could displace an animal from an important feeding, breeding, or migratory area and therefore have significant long-term effects on an individual or population (New et al., 2013; Nowacek et al., 2015; Forney et al., 2017).

Regulatory agencies require that offshore wind developers mitigate any effects that could lead to auditory injuries or behavioral disturbance via a range of monitoring and mitigation strategies. Some of these strategies include establishing site-specific exclusion and harassment zones, PSO monitoring, and reducing or delaying pile driving activities if marine mammals or sea turtles approach within a potential injury range. Effective mitigation strategies also include seasonal and time-of-year restrictions for survey and construction activities, especially when densities are high for certain at-risk species (Marine Mammal Commission [MMC], 2023). The application of noise abatement systems (NAS) is particularly effective in reducing the overall acoustic energy, meaning the potential noise exposure does not exceed injury and behavioral disturbance thresholds for animals that may be within range of the pile (Buehler et al., 2015; Bellmann et al., 2020). While a combination of NAS (e.g., big bubble curtain, hydrosound dampers, noise mitigation screens, etc.) and noise-optimized pile driving procedures (e.g., time-limited pile driving duration and reduced hammer energy) has an additive effect in overall noise reduction (Bellmann et al., 2020), further technological advancements in noise mitigation are needed to significantly reduce impacts to marine mammals and sea turtles from offshore wind construction. Examples of other mitigation measures typically implemented by offshore wind developers, as well as innovative technologies that may be adopted in the future, are discussed in detail under the Mitigation and Monitoring Measures section below.

Vessel Noise

Another significant source of underwater noise in offshore wind development is vessel noise. Global maritime traffic has steadily increased over the last few decades with a world fleet consisting of 105,493 vessels of 100 gross tons and above (United Nations Conference on Trade and Development [UNCTAD], 2023). Vessels servicing offshore wind operations during various phases of the project will, albeit marginally, contribute to the overall increase in vessel traffic. Offshore wind farms typically required dozens of different types of vessels across all phases of the project. Vessels range from construction barges, support tugs, jack-up rigs, supply/crew vessels, to cable-laying vessels (Miller et al., 2018). Offshore wind farms require periodic maintenance during the operational phase, likely on an annual basis, resulting in increased noise from vessels servicing turbines and transformer stations. Decommissioning vessel noise levels would be expected to be similar to those during the construction phases. These vessel activities have been shown to elevate ambient sound pressure levels by 20–30 dB within one kilometer of the turbine site (Bailey et al., 2010). While vessel noise emits lower frequencies than those produced by other high-intensity noise sources, the continuous characteristic of this lower frequency noise, and its ability to propagate farther, could cause behavioral, stress, and masking responses (Erbe et al., 2018, 2019; Nowacek et al., 2007; Southall et al., 2007) as it overlaps in frequency to that of marine mammals’ auditory and vocalization ranges (Piniak et al., 2012). The sources of vessel noise in the overall ocean are considerably broader than those involved with offshore wind activities, and this impact should not be viewed as one isolated to offshore wind.

Site Characterization Surveys

Prior to the construction of an offshore wind farm, planning requires scanning of the seabed to understand the geology of the locations where wind turbines may be installed. High-resolution geographic (HRG) surveys produce sounds that are reflected off subsea structures to obtain images of the seafloor and shallow geophysical features, and identify marine-protected species, habitats, shipwrecks, and/or archeological sites (Figure 2). HRG equipment, such as sparkers and boomers, use lower frequencies that are in the hearing range of whales. However, these sound sources are very different from the seismic air guns used by the oil and gas industry, which are designed to penetrate deep into the seafloor and are therefore very high-energy and very loud (260 dB) (Hildebrand, 2004). The sound sources used in HRG surveys are much lower in energy (approximately 220 dB) (Ruppel et al., 2022; Crocker & Fratantonio, 2016).

Figure 2. Conceptual illustration of typical High Resolution Geophysical (HRG) Surveys for O&G Exploration, Renewable Energy Siting, and Sand and Gravel Resource Identification. (BOEM, 2023b)

Unlike seismic airguns that create sound in all directions, HRG sound sources have a very narrow cone of sound. This means that to experience disturbance, an animal would have to be directly underneath the sound source for very long time periods to cross thresholds of exposure duration. Furthermore, the high sound frequencies used for the HRG surveys attenuate very quickly in sea water, so they do not travel nearly as far as the low frequency sounds produced at the same amplitude. Finally, some of the HRG surveys are conducted with the sources being towed or operating autonomously just above the sea floor, making the ensonified area considerably smaller (Ruppel et al., 2022). As marine mammals and sea turtles are highly mobile, they would likely avoid these ensonified areas and therefore avoid major impacts. Displacement as they change their swimming speed or direction, or behavioral disturbances such as changes in vocalization patterns, would likely be the maximum impact that these animals would experience should they encounter an HRG sound source. NOAA Fisheries asserts that, at this point there is no scientific evidence that noise resulting from offshore wind site characterization surveys could potentially cause whale deaths. The equipment being operated for HRG surveys can produce noise that may disturb marine mammals, but not cause auditory injury. Further, the area within which these sounds might disturb a marine mammal, is orders of magnitude smaller than the impact areas associated with seismic airguns or military sonar (NOAA Fisheries, 2023b).

Site Preparation

Other noise sources associated with site preparation include cable laying and dredging (Nedwell & Howell, 2004). Cable laying involves noise-producing activities such as trenching, jet plowing, backfilling, and installation of cable protection. Dredging may be used in site preparation for sand wave clearance and involves the use of a hydraulic suction dredger to remove or relocate sediment from the seabed. The sound produced by hydraulic dredging results from the combination of impact and abrasion of the sediment passing through the dredger's internal components and motors. The frequency of the sounds produced by hydraulic suction dredging ranges from approximately 1 to 2 kilohertz, with reported source levels of 172 to 190 dB re 1 μPa at 3.3 feet (1 meter) (Robinson et al., 2011; Todd et al., 2015; McQueen et al., 2020). Long-term exposure to dredging noise could cause avoidance behaviors or communication masking effects in marine mammals (Todd et al., 2015; NOAA Fisheries, 2018; Pirotta et al., 2013) and sea turtles (Popper et al., 2014). Such effects can negatively impact these organisms by causing them to expend energy inefficiently. However, this potential noise disturbance would dissipate once site preparation has been completed and the transitory nature of these animals would reduce the risk of long-term disturbance effects. Indeed, studies of cetaceans in and around the construction of European offshore wind farms show that animals can and do leave the area during construction but return after the activities have concluded (Lindeboom et al., 2011).

Operational Noise

While offshore wind operational noise levels are considered relatively low compared to noise generated during construction, operational noise does persist over the life of the wind farm and can extend 1-2 kilometers from the turbine before ambient noise masks the sound (Stöber & Thomsen, 2021). Wind turbines projected for deployment in U.S. waters will be larger (15 MW) than the average 7.4 MW installed turbines in 2021 (Musial et al., 2021). As the size of the turbines increase, so would the noise generated from each turbine; thus, impacts from larger wind turbines require additional research. Some wind farms consist of 100 or more turbines, and with the spatial expansion of future developments, understanding the effects of the compounded operational noise of multiple turbines over a relatively large area is needed.

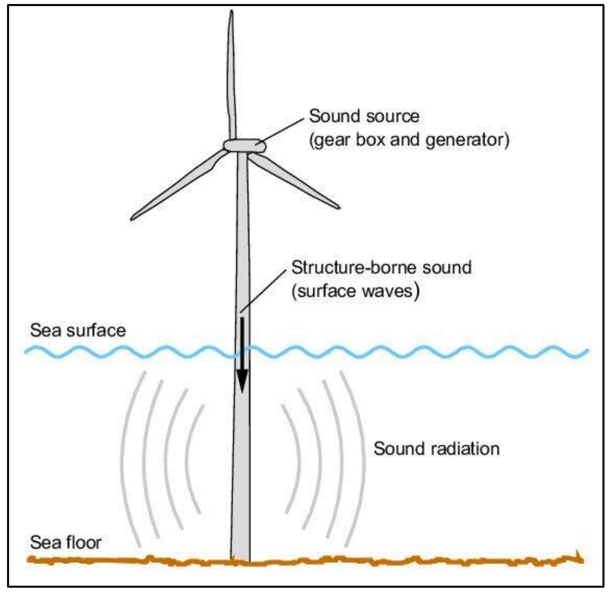

Figure 3. Mechanism of underwater noise generation by an offshore wind turbine (Betke et al., 2004).

Operational noise of wind turbines is not expected to lead to any injury or hearing impairment, but it could change habitat suitability by altering the ambient sound environment within and surrounding a wind farm (Figure 3). Depending on an animal's hearing sensitivity and the ability to adapt to low-intensity changes in the noise environment, operational noise could also affect an animal's behavior, interfere with communication, and reduce feeding efficiency in areas within a few hundred feet of the foundations under some conditions (Koschinski et al., 2003; Madsen et al., 2006; Betke et al., 2004).

Additional noise reduction technologies are being studied, including those that can potentially reduce mechanical noise from wind turbines by properly shielding the nacelle (drivetrain housing component), using sound-dampening buffer pads, suppressing vibration, and/or employing direct drive technology (Betke & Bellmann, 2023; Jianu et al., 2012; Stöber & Thomsen, 2021). Recent advancements in offshore wind turbine technology have also led to a significant reduction of overall wind turbine noise by using streamlined and aerodynamic design features (rounding any protruding features of the towers and nacelle) (Deshmukh et al., 2019).

Risk of Vessel Strikes

Vessel strikes to marine mammals and sea turtles are linked to vessels of all types and sizes, including commercial shipping. In most areas, offshore wind development will only increase vessel traffic by a small fraction. Vessel trips to offshore wind farms are estimated at 1-15 per day during construction and 1-3 per day during periodic maintenance cycles within the operations phase of the wind farm. With more than 60,000 similar commercial vessels transiting the sea each year (Equasis, 2015), each wind farm will be contributing a negligible amount of additional vessel traffic. Off the U.S. East Coast, NOAA Fisheries proposed a vessel speed rule (73 Fed. Reg. 60173) for all vessels greater than or equal to 65 feet in length to mitigate the risk of vessel strikes to the NARW (NOAA Fisheries, 2008). The rule went into effect in 2009. In September 2022, NOAA Fisheries proposed amendments to the existing rule to include smaller vessels, create larger speed zones, and make voluntary dynamic speed areas a requirement (87 Fed. Reg. 46921). Offshore wind survey and construction vessels, regardless of size, are required to adhere to the rule and transit at a speed of 10 knots (kt) or less throughout the ten designated seasonal management areas (SMAs) between Massachusetts and Florida. This speed restriction also applies to voluntary dynamic management areas (DMAs), which become active when groups of foraging NARWs are observed gathered in groups of three or more individuals outside the boundary of an active SMA.

Risk of Entanglement

There are two commonly identified types of entanglement: primary and secondary. Primary entanglement is when marine life is entangled with an offshore wind farm cable or mooring line. Secondary entanglement is when marine life interacts with marine debris associated with the wind farm (U.S. Offshore Wind Synthesis of Environmental Effects Research [SEER], 2022a). To read more about primary and secondary entanglement, check out this SEER research brief.

Floating offshore wind (a newer technology for offshore wind, where the turbine foundations are not fixed to the sea floor) introduces a potential for a greater level of entanglement of marine life due to the extensive underwater mooring and cable system. While floating offshore wind technology is still in its earlier stages of development, several environmental organizations developed *Recommendations to Reduce the Potential Risk of Entanglement of Marine Life During Floating Offshore Wind Energy Development*, which was released in October 2022 and can be accessed via the National Renewable Defense Council (NRDC) website.

Offshore wind developers are required to develop mitigation measures to reduce the risk of entanglement in equipment during site characterization and monitoring surveys. Entanglement risk is typically minimized by keeping all mooring lines at the shortest practicable length and using rubber sleeves and other devices to prevent lines from looping or having the ability to wrap around large marine animals. Monitoring survey vessels deploying fixed fishing gear (i.e., trap or pot sampling gear deployed on the seabed) will have disentanglement equipment available and follow protocols for safe release of any marine mammal or sea turtle. Offshore wind developers will sample fish populations with short trawl surveys at slow towing speeds, where risks of entanglement will be extremely low, and any protected species that are entrapped must be reported to the National Marine Fisheries Service (NMFS) within 48 hours.

Electromagnetic Fields

Electromagnetic radiation, including low-frequency electromagnetic fields (EMFs), is generated from natural and anthropogenic sources such as the Earth's geomagnetic field, thunderstorms, power cables, and common household electronics. Offshore wind farms use a variety of subsea power cables for intra-turbine, array-to-transformer, and transformer-to-shore transmissions (Ohman et al., 2007). These subsea power cables induce EMFs that may add to and interact with other sources of electric and magnetic radiation already present in the environment.

Marine mammals and sea turtles are capable of detecting magnetic field gradients under 0.1 percent of the Earth's magnetic field (Kirschvink, 1990; Normandeau et al., 2011). Since the expected magnetic fields from existing and proposed undersea power cables are well above the Earth's magnetic field, marine mammals and sea turtles are likely able to detect minor changes in, and may react to local variation of, geomagnetic fields associated with cable EMFs (Normandeau et al., 2011; Walker et al., 2003). Laboratory and field studies have shown that sensitive marine species may exhibit altered behavior in the presence of EMFs, but the level of disturbance appears to be too limited to affect migration patterns or to keep animals from their preferred habitats. In other words, the ability to detect or respond to the presence of EMFs does not necessarily mean there will be impacts to a species or life stage (Copping & Hemery, 2020). Currently, conclusive evidence of impacts is insufficient and additional research is needed.

In the interim, offshore wind developers are required to implement mitigation measures to reduce any potential effects from EMF and heat from subsea cables. For example, siting strategies include avoiding areas of special ecological interest when planning cable routes. Permit conditions require that cables be buried to an appropriate burial depth, between three to six feet, which reduces the magnetic field at the seafloor approximately four-fold (BOEM, 2020). In areas where sufficient cable burial is not feasible, power cables will be covered with 6- to 12-inch-thick concrete mattresses, rock berms, or other measures to protect the cable and reduce emission of EMF. Other potential measures include helically twisting AC cables in order to have parts of the EMF cancel each other out, resulting in an overall lower EMF emission, or grouping DC power cables, which can also reduce the effect of EMF as it remains more localized and limited (Hermans & Schilt, 2022).

Presence of Structures

The presence of foundation structures can have variable impacts. They could displace marine mammals and sea turtles from preferred habitats, alter movement patterns, or impact prey availability. Offshore structures could also create an artificial reef effect, providing hard substrates for biofouling communities and aggregating fish and invertebrate resources around these structures (Degraer et al., 2020; Krone et al., 2017; Langhamer & Wilhelmsson, 2009). This reef effect will concentrate recreational fishing around foundations, potentially increasing the risk of entanglement in both lines and nets (Moore & van der Hoop, 2012). As the presence of offshore structures could pose a navigational hazard, offshore wind farms could, conversely, discourage fishing activity within the project footprint, resulting in reduced fishing pressure. Thus, these offshore structures could also benefit marine mammals and sea turtles from locally increased food and shelter where natural habitat may be scarce. Tagged pinnipeds along the British and Dutch coasts of the North Sea, for example, are found to systematically utilize the areas around turbine structures to forage (Russell et al., 2014). Loggerhead and leatherback sea turtles may likely benefit from increased prey concentration (e.g., molluscs and crabs) around offshore structures, raising the possibility of offshore structures as potential foraging areas. For more on the reef effect from added foundation substructures, refer to Fish and Invertebrates.

There has been extensive research into characterizing and modeling atmospheric wakes created by the presence of wind turbines offshore. This research is used to design the layout of wind facilities and predict seabed scour zones. However, relatively few studies have analyzed how hydrodynamic wakes, coupled with the changes in atmospheric wakes, could interact with the water and the water column. While it is an active area of research, only a few studies have analyzed wakes and their impact on regional scale oceanographic processes and potential secondary changes to primary production and ecosystem dynamics. The National Academies of Science Engineering and Medicine (NASEM) recently evaluated the potential for offshore wind farms in the Nantucket Shoals region, a biologically important area for the NARW, to alter the hydrodynamic processes in the area and impact prey abundance and availability (NASEM, 2023). The study concluded that impacts of offshore wind projects on the NAWR and the availability of their prey will likely be difficult to distinguish from the significant impacts of climate change and other influences on the ecosystem. Further monitoring will be needed to have the spatial and temporal coverage to adequately understand the impact of future wind farms. For more on hydrodynamic impacts, refer to Coastal and Marine Habitats. Other potential impacts to biological resources are also discussed in the Coastal and Marine Habitats section, as well as Fish and Invertebrates, and Recreational and Commercial Fishing sections.

Mitigation and Monitoring Measures

While some effects may be unavoidable, all potential impacts from an offshore wind project are evaluated within a mitigation framework. The aim is to avoid, minimize, or mitigate adverse effects as much as is feasible. Offshore wind development is governed by Federal, state, and local regulations. This means that as part of the permitting process, offshore wind developers are required to implement a range of agency-approved mitigation measures designed to reduce or avoid potential impacts from project activities.

Examples of conventional and innovative mitigation measures for the most impactful offshore wind activities (e.g., construction noise, vessel transits, etc.) are summarized below.

Construction, Operation, and Decommissioning Noise

To minimize the effects of noise generated by offshore wind development, offshore wind developers use several mitigation and monitoring techniques developed and agreed to during the permitting process. These strategies include:

- Shutdown and clearance zones, which are maximum safe distances customized to each animal hearing group and activity type, are implemented and monitored by visual and acoustic (i.e., Passive Acoustic Monitoring) detection. In addition, Protected Species Observers (PSOs) are deployed on offshore wind vessels. The role of the PSOs is to monitor for the presence of protected species and implement mitigation measures where needed to ensure the animals are not impacted by marine activities. The PSOs work closely with the vessel crew to implement these mitigation measures. Animals detected in these zones prompt the cessation of project activities until the animals are outside of the zone of impact.

- Noise abatement systems (NAS), or quieting technologies such as bubble curtains and hydrosound dampeners, are used during noise-generating activities and are considered to be particularly effective in reducing the overall acoustic energy introduced in the environment.

- Soft-start or ramp-up procedures (i.e., the gradual increase of hammer energy) are implemented to deter marine mammals and sea turtles from the active area. The gradual increase of sound levels may reduce the chance of animals startled by the sharp change in the noise field (Discovery of Sound in the Sea [DOSITS], 2023).

- Dynamic restrictions based on time of year, time of day, or spatial-temporal analyses, such as restricting pile driving activities based on marine mammal or sea turtle foraging times/migratory seasons, are used to minimize impact, especially for critically endangered species such as NARWs.

- Other measures that may be adopted by future offshore wind projects include alternative foundations such as gravity bases and suction caissons. These bases would reduce noise installation output, however, their larger seabed footprint, and the impacts it may have on benthic habitats, would need to be balanced against noise reduction benefits (Merchant, 2019). Advancements in monopile installation techniques (e.g., “Blue piling technology”) use gas combustion-generated pressure to accelerate a large column of water into the pile head, resulting in a longer blow duration. This can potentially reduce noise levels to 20 dB, lower than that of conventional hammers (IQIP, 2023).

Vessel Interaction

- There is a significant, positive relationship between vessel speed and the probability that a vessel strike is lethal. Vessel speed restrictions can lower the risk of strikes and the severity of injuries, especially when reduced to 10 kt (Redfern et al. 2024).

- Vessel speed restrictions can also reduce noise levels. However, the trade-off in slower vessels is prolonged noise exposure and an increase in vessel transit time.

- Ship-quieting technologies that may be adopted by future offshore wind development include modifications of the propeller and/or hull, and injections of air through the propeller blades to reduce noise from propeller operations. Noise from onboard vessel machinery can also be reduced with appropriate vibration control measures, proper location of equipment in the hull, and optimization of foundation structures (International Maritime Organization [IMO], 2014). Retro-fitted design modifications to improve energy efficiency may also lead to lower noise levels (Gassmann et al., 2017).

- Maintenance of appropriate vessel distances through the aids of visual detection and real-time passive acoustic monitoring of marine mammals and sea turtles reduces the risk of strikes by helping vessels avoid critical habitats and dynamic feeding/foraging areas (i.e. jellyfish aggregations and floating vegetation).

- Visual detection and real-time passive acoustic monitoring can also help set vessel regulations in exclusion zones (e.g. Dynamic or Seasonal Management Areas).
- Vessels associated with offshore wind projects are required to follow BOEM best practices and guidelines to minimize protected species interactions when conducting fisheries surveys (BOEM, 2023c). These best practices include utilizing the best available mooring systems and following protocols for the recovery of lost or derelict survey gear; thus, reducing the accumulation of marine debris that may pose an entanglement risk. Other measures include having adequate disentanglement equipment onboard and personnel trained in regional protocols for disentanglement, resuscitation, handling, and reporting of animals that are incidentally caught.
- PSOs are deployed on all offshore wind vessels and keep watch for protected species during vessel transit to avoid potential strikes (RPS, 2023).

Future Directions

With the significant momentum that offshore wind development has had in recent years, continuous advancements in mitigation and adaptive management strategies play a key role in reducing future environmental impacts. As outlined in the previous section, mitigation strategies currently employed by offshore wind projects have the potential to minimize environmental stressors. Other innovations including noise-reducing turbine designs, protective measures during construction, and improved foundation technologies can further reduce such impacts. The integration of multiple mitigation and monitoring strategies such as the use of real-time passive acoustic monitoring systems, underwater drones, and satellite technologies, along with current mitigation standards, can enhance and optimize the offshore wind industry's ability to assess and mitigate impacts effectively and support the use of adaptive management practices.

Climate change can lead to displacement as some species may need to migrate to suitable habitats. Thus, continuous research, coupled with strategic site selection, is crucial in minimizing and addressing any compounding displacement effects from offshore wind development. Robust assessments and monitoring across multiple taxa allow for a comprehensive understanding of the potential interactions and cumulative stressors on marine life, identify any data gaps, and lend to the development of a more targeted conservation measures.

Another important aspect to consider is standardizing data collection/data sharing protocols from dedicated monitoring activities in offshore wind areas and aligning those to regional standards (RWSC, 2024). Data that can be integrated in future regional scale meta-analyses, species and habitat modeling, and other relevant studies, would be vital to policy makers and managers in developing informed and adaptive management strategies.

Collaborative stakeholder engagement, incorporating best practices and lessons from previous projects, and integrating new technologies for adaptive decision-making will contribute to more resilient and sustainable offshore wind development.

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