National Sea Grant Offshore Wind Energy Liaison
Synthesized Research: Underwater Noise

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Main Takeaways:

- Offshore wind farms generate noise in the marine environment in all stages of their lifetimes
- There are four key phases of offshore wind development that each have different noise levels associated with them: survey, construction, operation, and decommissioning. The phases that generate the most noise are the construction and decommissioning phases.
- Underwater noise can impact marine species in many different ways, from behavioral changes to physiological injuries depending on sound levels, distance and other factors.
- The part of the offshore wind process that has the most potential to harm nearby marine life is impact pile driving.
- Mitigation strategies have been developed to help offset the noise generated by offshore wind farms, including time-of-year restrictions to protect vulnerable species.
- Mitigation technologies have also been developed to help offset underwater noise like bubble curtains that create a physical barrier between the construction and marine life.
- More scientific studies are needed to fully understand the effects of offshore wind sounds in the marine environment.

Learn more:

We all hear underwater sound when we are in the ocean. Underwater sound can be generated by biological, physical, and anthropogenic sources. However, when it comes to unwanted sound sources, such as those from offshore development, those are referred to as “noise.”

Underwater noise can impact a variety of marine life through sound pressure and vibration. Although underwater noise can decrease in volume with distance from the source, it can still travel far in the underwater environment. To measure sound, hydrophones can be used to gather data on sound amplitude, frequency, and directionality.

Offshore wind areas often share their space with ocean life and fisheries habitats, so there is an increasing need to understand, mitigate, and manage offshore wind farms and the acoustic impacts they leave on the environment. All phases of a wind farm’s lifetime produce underwater sound, which is “a concern because high noise levels and/or persistent anthropogenic noise can impact marine life in many ways.” (Source: TETHYS)

There are four key phases of offshore wind development that each have different noise associated with it.

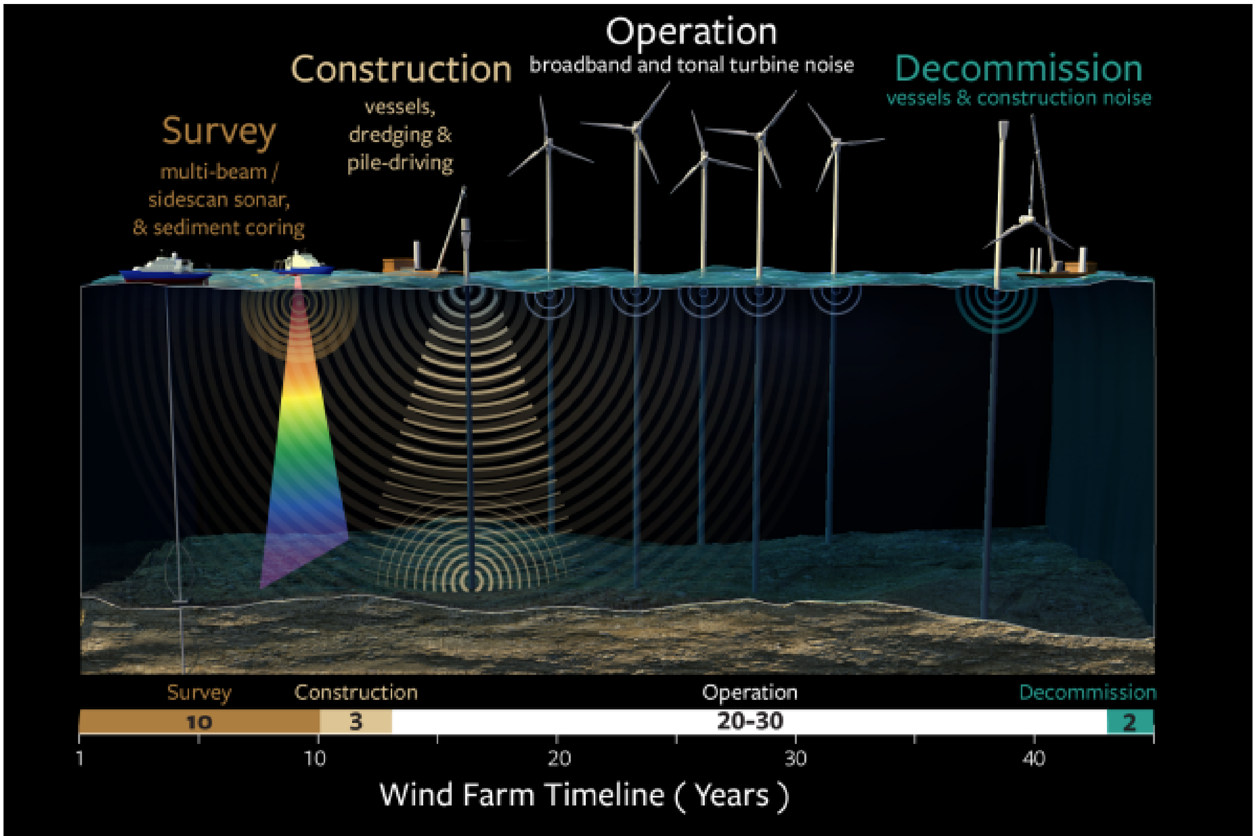

Figure 2. *Underwater noise associated with the life cycle of an OSW farm area, including during site surveys, construction, operations and maintenance, and decommissioning. Illustration from* ***Mooney et al. (2020).***

Four Key Phases of Offshore Wind Development:

1. Survey:

   Site surveys are the first phase of offshore wind development. During this phase, an area is examined to characterize site conditions and map out the marine floor. This is done with sensors, platforms, and vessels. The vessels use sonar and echo sounders as they conduct acoustic benthic surveys.*

   **Note: Lower energy and quieter systems are used during the survey phase for offshore wind compared to the high-intensity air guns used to locate oil and gas deposits in the seafloor.*

2. Construction:

   During the construction phase, the foundations of the turbines are placed in the marine environment, and there is a high potential that this activity will generate high-intensity noise. If pile driving is used to install monopiles, tripods, or jacket foundations, there will be high, potentially harmful amounts of sound pulses. There are other kinds of foundation technologies that require less noise, including suction bucket, gravity-based, and floating foundations.

Because impact pile driving can create so much noise, noise assessment and mitigation activities are now a standard part of the offshore wind farm permitting process.

3. Operation:

   This is the longest phase of an offshore wind farm's lifespan. The operation phase includes the noise generated by maintenance activities and by the turbines themselves while they are in the water. During this phase, underwater noise is "produced at a relatively low level (compared to natural sound levels) over the 20+ year project lifetime by the rotation of the wind turbine blades." (Source: SEER)

   Scientists indicate the operational noise emission from currently installed turbines is a relatively low level threat and does not significantly exceed natural noise levels.

4. Decommission:

   When an offshore wind farm reaches the end of its lifetime, the turbines need to be removed from the marine environment. During this decommissioning phase, noise is generated from support vessels and the dismantling process itself, which involves taking down the turbines, the foundations that have been embedded in the seafloor, the subsea cables, and the offshore substations. The dismantling process is the shortest phase but may generate enough noise to disturb marine life. This phase and the sound associated with it still need further scientific study.

How do we even measure sound?

When we talk about measuring sound in the ocean, we call it "passive acoustic monitoring, or PAM." The technology has advanced over the years, allowing researchers to record underwater sounds using hydrophones in a variety of configurations, including on buoys and towed behind vessels.

By examining this data, we can learn about marine mammal presence and underwater noise levels, including the frequency, amplitude, location, and seasonality of underwater sounds.

How does Europe handle the impacts on marine life?

According to SEER, in Europe, most knowledge around the effects of offshore wind pile driving originates from studies of porpoises, seals, and fish around smaller turbines than those now being considered for deployment off of U.S. shores. In the U.S., we need to consider the impacts on large whale and sea turtle species that do not live in areas where large-scale offshore wind development has previously occurred abroad, so more studies are needed.

What mitigation measures can we take?

According to SEER, in the U.S., sound thresholds have been identified to help assess noise impacts on marine life. We can also employ the use of quieting technologies, such as bubble curtains and noise abatement systems, to help reduce the spread of noise underwater by placing physical noise barriers around piles.

Specific examples of noise reduction technology and mitigation measures:

- Bubble curtains – Bubble curtains work by creating a physical bubble barrier around the pile driving platform, thus reducing noise outside the curtain and helping protect marine life. These curtains have been shown to decrease noise levels by 10 dB.
- Isolation casings – A simple isolation casing consists of a steel pipe around the pile reflecting a part of the noise back inside. Similar to a bubble curtain, the basic principle of an isolation casing is the shielding effect of a complete casing around the noise generating structure (Federal Agency for Nature Conservation).
- Cofferdams – Similar to isolation casings, cofferdams are rigid steel tubes surrounding the pile from seabed to surface (Federal Agency for Nature Conservation).
- Hydro sound dampers – Small, gas-filled elastic balloons and robust PE-foam elements that are fixed to nets or frames and placed around the pile. The underlying principle is identical to that of a bubble curtain with the exception that the frequencies at which the maximum noise reduction are provided are adjustable by variations in the balloon size (Federal Agency for Nature Conservation).
- Time-of-Year Restrictions – Pile driving activities may be excluded during certain times of the year due to the presence of sensitive marine life during these periods. Time-of-year restrictions have been implemented for the North Atlantic right whale.
- Protected Species Observers – Trained observers maintain an exclusion area for certain protected species around pile driving activities. For example, if a marine mammal or sea turtle is observed entering or within the relevant exclusion zones, pile-driving activity must be shut down and delayed.
- Soft Start for Pile Driving – Gradual ramp- up of hammer energy for impact pile driving that includes an initial set of strikes from the impact hammer at reduced energy, followed by a waiting period, with repetition of this process several times prior to initiation of pile driving.

What about marine mammals?
Can Offshore Wind Energy and Marine Mammals Coexist?

First of all, according to TETHYS, we are data deficient for most species' populations, life stages, and other phases as they relate to wind farm development, making it difficult to evaluate impacts with any certainty. More scientific studies are needed to "adequately address impacts of offshore wind farms on vulnerable and ecologically and economically important taxa." (Source: Acoustic Impacts of Offshore Wind Energy on Fishery Resources: An Evolving Source and Varied Effects Across a Wind Farm's Lifetime)

However, here is what we do know:

Hearing is one of the main ways marine life gathers information and communicates underwater. In addition, underwater sound travels more quickly and over larger distances than it does on land. Noise in the marine environment can lead to behavioral changes, physiological effects like hearing loss or non-auditory injury, or it could interfere with a species' ability to communicate and hear important sounds (which is called auditory masking). Some species rely on sound for protection, some use it to gather together, and some rely on sound to mate (like shrimp and lobster).

Fish and invertebrate species can be impacted by noise on many different levels, including by:

- particle motion (which occurs when particles in the water move back and forth and is the primary acoustic stimulus for all fish and invertebrates),
- sound pressure,
- and substrate vibration (when the seafloor vibrates).

Scientists can measure species' impact by employing a host of monitoring methods used to estimate the distribution, abundance, and behaviors of different species. Researchers can gather this data in many different ways, including visual surveys from vessels, the use of animal tagging, and aerial surveys to understand the distributions and behaviors of different species. This data is then taken into account when it comes to the offshore wind farm permitting process.

Scientists have developed a framework to describe potential noise impacts on marine species at wind farms that includes the following four zones of auditory impact (listed from largest to smallest): (1) zone of audibility; (2) zone of responsiveness; (3) zone of masking; and (4) zone of hearing loss, discomfort, and injury.

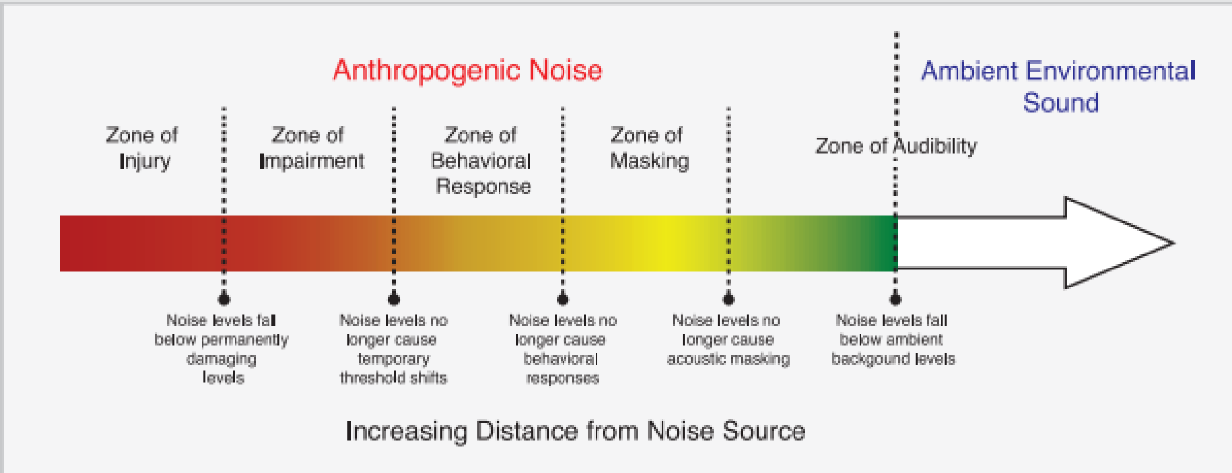

Figure 4. *Framework for potential noise impacts on marine mammals based on zones of auditory impact, with distance from the sound source. Illustration from* ***Mooney et al. (2020).***

The most potentially harmful phase of offshore wind development for marine species is construction, especially if impact pile driving is used to install the turbine foundations.

University of Washington researchers explain there are two basic pile driving methods: impact pile driving where the pile is driven by strikes from a high-energy hammer, and vibratory pile driving where the pile is effectively vibrated into the sediment. Often both methods are used on the same pile.

At ranges on the order of 10 meters, and considering steel piles of diameter 0.75-1 meter, vibratory pile driving produces underwater sound pressures of order 100-1000 Pa, which is often sustained for minutes. In contrast, each impact pile strike produces peak sound pressures on the order of 100 kPa, with an effective duration of the sound from the strike being of order tens of milliseconds. To install one monopile, a 1000 or more pile strikes or blows may be needed over the course of an hour or more.

We use decibels (dB) to describe sound levels, which provides a convenient measure of relative intensity. Underwater, 100 kPa peak pressure corresponds to 220 dB relative to 1 micropascal (one micropascal is the standard underwater pressure reference). To give one an idea of the intensity of such as signal, one can compute the levels using airborne decibels by subtracting 60 dB. **Thus, the pile driving intensity is equivalent to 140 dB relative to 20 micropascal in air. This level is about what is measured 1 meter from a rifle being shot.**

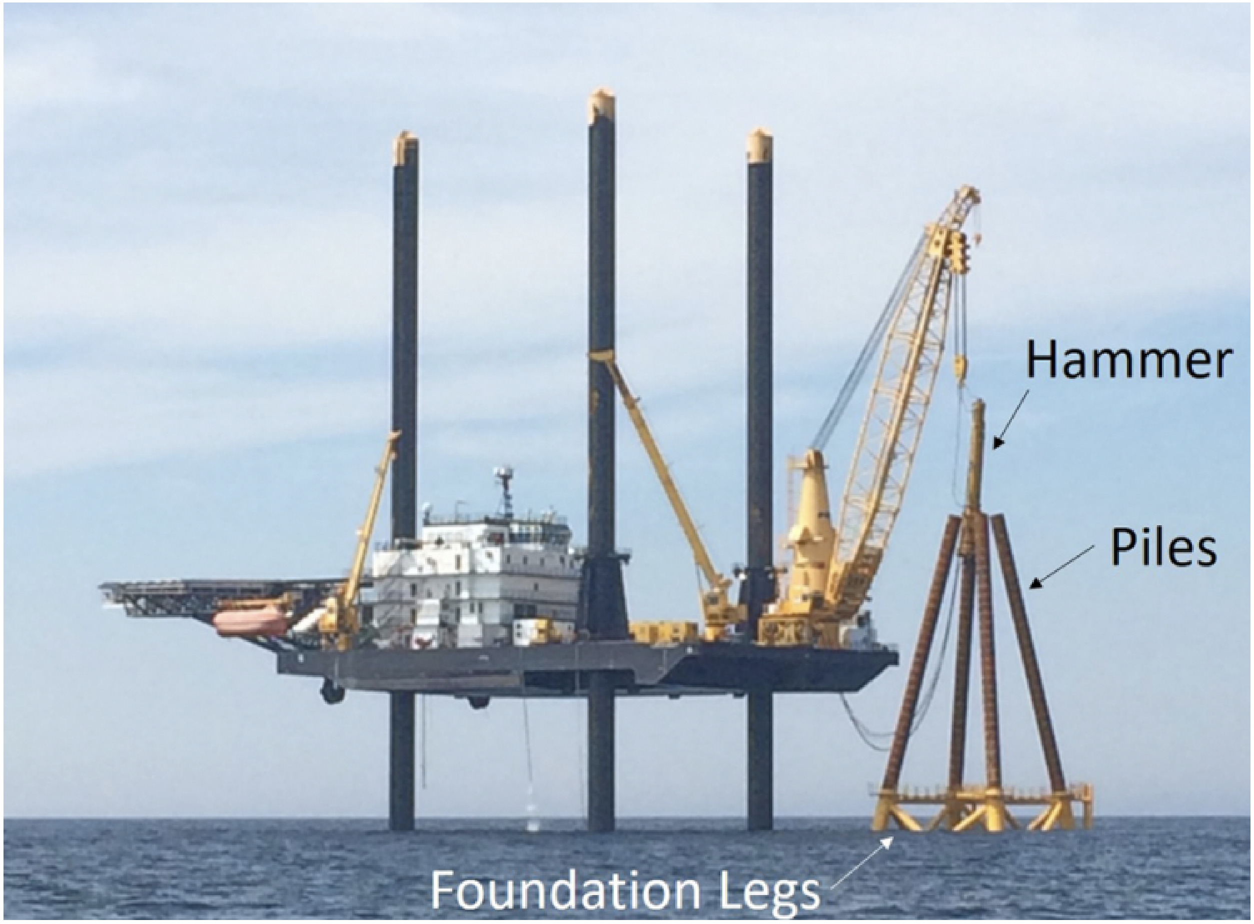

Figure source: Characterization of impact pile driving signals during installation of offshore wind turbine foundations

Marine life, when exposed to the sounds from impact pile driving, may experience behavioral changes, including a loss of direction, moving from a breeding or feeding site, habitat loss, or a diminished ability to hear biologically important sounds from their own species and from other sources in their environment. They also may experience physiological injuries that may include damage to their internal organs or their ears.

One study exposed groups of seabass to playbacks of pile-driving and found the pile-driving sounds affected the structure and dynamics of the fish shoals significantly. Groups of seabass experiencing the pile-driving playback became “less cohesive, less directionally ordered, and were less correlated in speed and directional changes. In effect, the additional-noise treatment disrupted the abilities of individuals to coordinate their movements with one another.” (Read et al., 2017)

There are several ongoing studies going on around the effects of noise on marine life, so we can expect more research on this topic in the near future.

During the operations phase, noise levels are not high enough to cause direct physical injury to marine life, but behavioral impacts may be observed in marine species in close proximity to the turbines. However, studies have also shown that fish might adapt to noises created by offshore wind farms.

When it comes to the decommissioning phase of offshore wind farms, there is not a lot of information available quite yet, as offshore wind farms are just being developed in the United States (U.S.), let alone being decommissioned yet. There is the potential for masking, displacement, physiological stress, and other impacts—especially if marine life is aggregated in habitats around wind farm foundations—so that is something we will need to be aware of and study further in the future.

Learn Even More:

- Acoustic Impacts of Offshore Wind Energy on Fishery Resources: An Evolving Source and Varied Effects Across a Wind Farm's Lifetime (Oceanography)
- Underwater Noise Effects on Marine Life Associated with Offshore Wind Farms (SEER)
- Development of Noise Mitigation Measures in Offshore Wind Farm Construction 2013 (Federal Agency for Nature Conservation)
- Anthropogenic noise pollution from pile-driving disrupts the structure and dynamics of fish shoals (The Royal Society Publishing)
- Turning Scientific Knowledge into Regulation: Effective Measures for Noise Mitigation of Pile Driving (Journal of Marine Science and Engineering)
- Underwater sound from pile driving, what is it and why does it matter (The Journal of the Acoustical Society of America)
- Characterization of impact pile driving signals during installation of offshore wind turbine foundations (The Journal of the Acoustical Society of America)
- Underwater Acoustic Monitoring Data Analyses for the Block Island Wind Farm, Rhode Island (TETHYS)
- Acoustic Noise and Electromagnetic Study in Support of the Rhode Island Ocean SAMP (Rhode Island Coastal Resources Management Council)