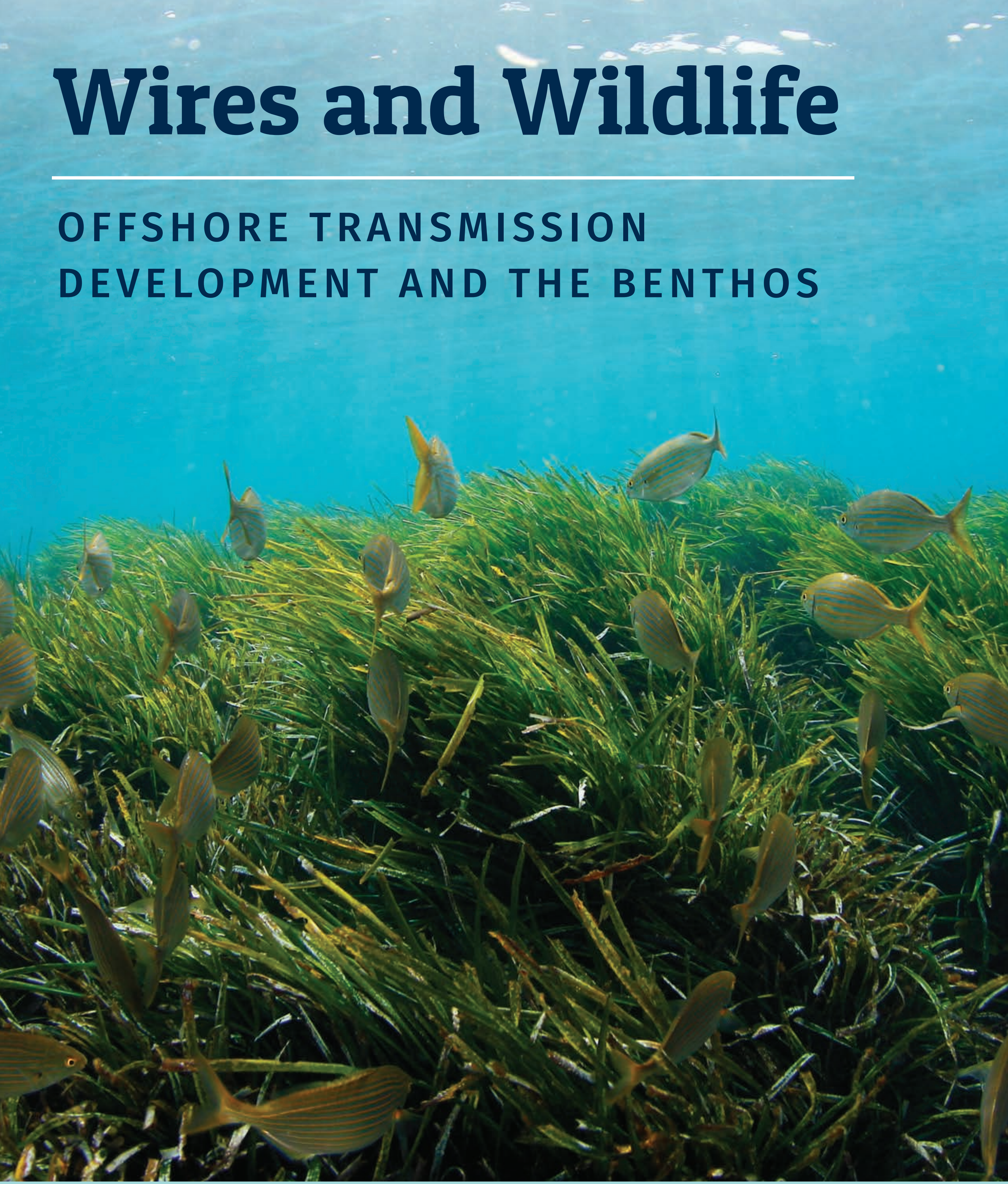
Wires and Wildlife

OFFSHORE TRANSMISSION DEVELOPMENT AND THE BENTHOS



NATIONAL WILDLIFE FEDERATION

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Northern sea star. Photo: Jennifer Idol

Executive Summary

Marine wildlife, particularly marine mammals and fish, depend on healthy benthic (seabed) habitats and resources to reproduce, rear offspring, and thrive. Natural seasonal variations, climate change, and offshore wind and the associated offshore transmission development change the condition of the marine environment. Seasonal variations, like spring tides and changes to biological communities' composition shift the conditions of the marine environment. Climate change creates additional risks for seabed disruption, with bigger and more frequent storms. Offshore wind and the associated transmission provide new challenges to understanding the seabed, as new hard surfaces are introduced to marine environments and construction and operations disturb the environment. While there have been significant steps towards integrated and ecosystem-led marine spatial planning, more research is needed.

Simultaneously, offshore wind and transmission together provide an urgently needed solution to address climate change and meet growing electrification demands. Some of the best places to generate clean, reliable, and renewable energy are along the coasts with offshore wind. To export this energy to the onshore grid, transmission lines must carry this energy over long distances to shore.

This report provides an overview of the threats facing benthic species and resources and underscores the need to better understand the potential implications of offshore transmission development on the Outer Continental Shelf. Regulatory and industry-informed opportunities exist to better understand potential solutions. We identify a number of regulatory mechanisms that have been used to protect these important species and resources and identify opportunities to more consistently and clearly define requirements to provide developers with more certainty and better inform regulators' decision-making.

Through an extensive literature review and interviews with international and domestic experts, we also identified significant research gaps that, if addressed, could inform the design of offshore transmission development now and in the future. The published research review was conducted by creating a search string that was put into the Web of Science academic search platform. All results were screened for possible inclusion by title first and then by abstract. All papers that had been flagged for inclusion after abstract review were fully analyzed for possible inclusion in the paper. Google Scholar was used as a secondary academic search engine to locate additional papers that the search string may not have captured on Web of Science. Gray literature was compiled through consulting subject experts and reviewing relevant government agency sites.

To prevent unintended impacts to marine ecosystems, the National Wildlife Federation recommends increased support for research, while development continues to occur, and data sharing where possible to help industry and regulators identify specific and practical solutions. Finally, we offer a range of recommendations to guide industry and regulators on the path to responsible transmission development. Responsible development of offshore transmission is not only possible, it is practical.

Photo: Charlie Chesvick/Getty Images

Key Findings

- Benthic resources and habitats are critical to marine ecosystem health and resiliency.
- Using the best available science and assessing climate and cumulative impacts of development makes it possible to conserve wildlife and build an interconnected offshore power grid that can benefit people and wildlife.
- Offshore transmission has varied impacts on benthic habitats and resources, including direct mortality and habitat loss. These impacts can be mitigated with techniques such as avoidance, micrositing, and proactive planning, which is critical for protecting benthic species specifically, as much scientific attention has historically focused on other areas like marine mammals and commercial fishing.
- There are two regulatory pathways to build transmission; neither allows for urgently needed proactive interregional planning and instead focuses on singular project-specific development.
- The Bureau of Ocean and Energy Management's (BOEM) requirements for benthic mitigation at the leasing stage vary tremendously and have evolved over time.
- Collaboration from decision-makers and industry to conduct and share research on environmental impacts of offshore transmission on benthic resources is necessary to resolve outstanding knowledge gaps.

Benthic organisms, including species such as crustaceans, mollusks, and certain types of fish that inhabit the ocean floor, are essential for nutrient cycling, habitat structure, and function as a food source within marine ecosystems.

American lobster. Photo: Jennifer Idol

Introduction

The United States needs a responsibly developed offshore power grid to meet increasing demand for electricity, address land limitations for onshore renewable generation, and achieve federal and state clean energy goals. An offshore grid can help reduce reliance on fossil fuels like coal, oil, and natural gas, whose emissions threaten public health and wildlife, and contribute to climate change. These impacts have disproportionately affected lower-wealth, frontline communities that have historically faced the highest levels of pollution in the U.S.[1] A well-planned offshore grid can help bring clean, equitable energy solutions to these communities and the nation as a whole. Modernizing our power grid and building generation offshore provides an alternative to polluting fossil fuels, delivering reliable and resilient electricity from both floating and fixed-bottom wind turbines. This grid could span from Maine to South Carolina, from Oregon to California, and the Gulf of Mexico, providing access to lower cost-offshore wind, unlocking jobs, and creating a new offshore economy.

Offshore wind provides an unmatched opportunity to help meet the challenge of climate change by reducing our reliance on polluting fossil fuels and creating a world where humans and wildlife can thrive.

Given significant gaps in understanding of the complex interactions between benthic organisms and environmental stressors like undersea cable infrastructure and electromagnetic fields (EMF), this report aims to address these challenges. Benthic organisms, including species such as crustaceans, mollusks, and certain types of fish that inhabit the ocean floor, are essential for nutrient cycling, habitat structure, and function as a food source within marine ecosystems. EMF are invisible fields produced by the transmission of electricity through cables, including those used in offshore wind energy. These fields have been shown to have some influence on certain marine species and have been an impact of interest for scientists, policymakers, and members of the public. As offshore transmission infrastructure introduces impacts to the benthic environment, understanding its potential effects is crucial for responsible development. This report therefore provides an overview of existing knowledge and highlights regulatory opportunities to support informed offshore wind and transmission planning.

This report aims to balance the priorities of building new offshore transmission with the protection of healthy benthic habitats, offering avoidance, monitoring, mitigation, and adaptive management practices that regulators can adopt immediately. It also highlights how existing science can guide future studies to ensure the responsible buildout of offshore transmission.

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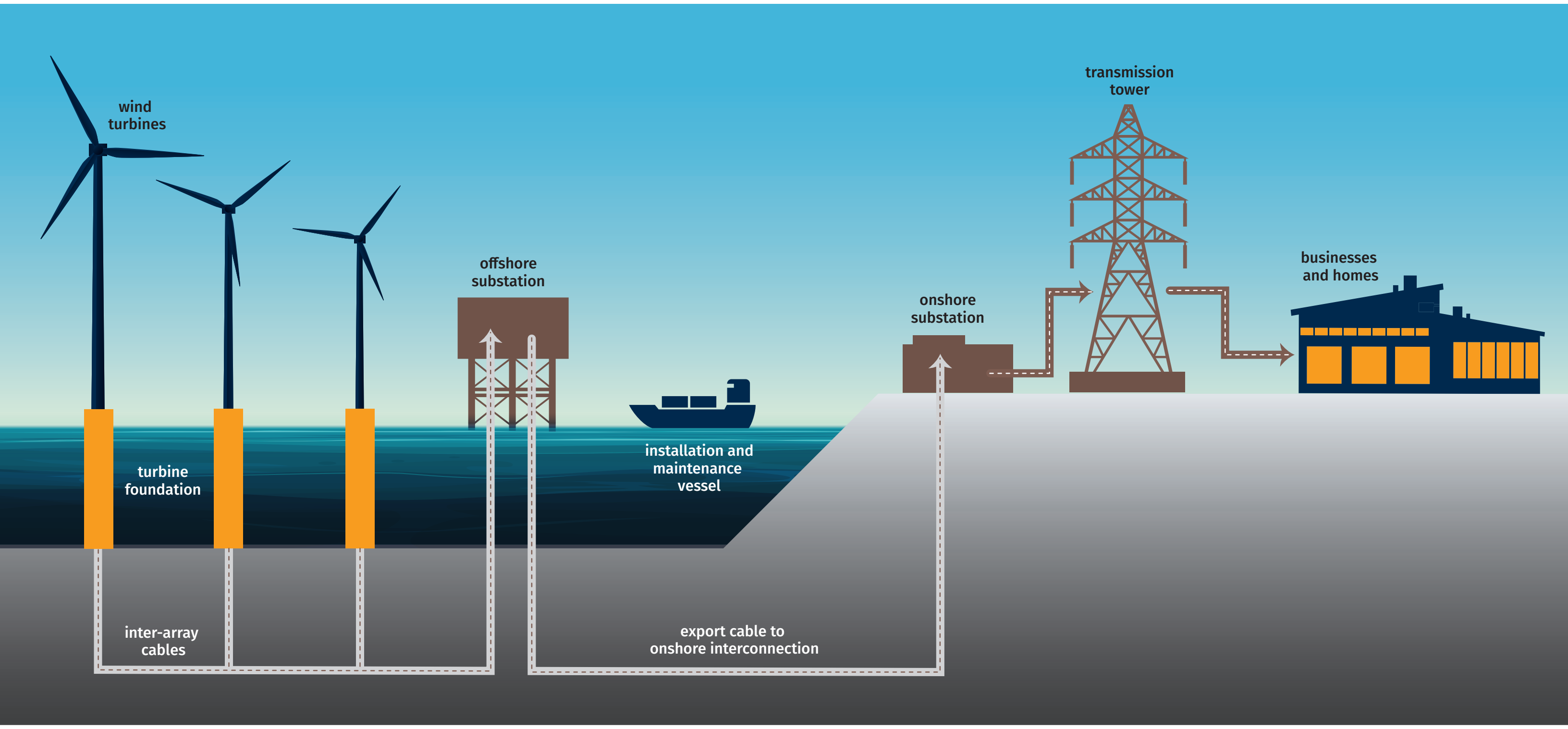
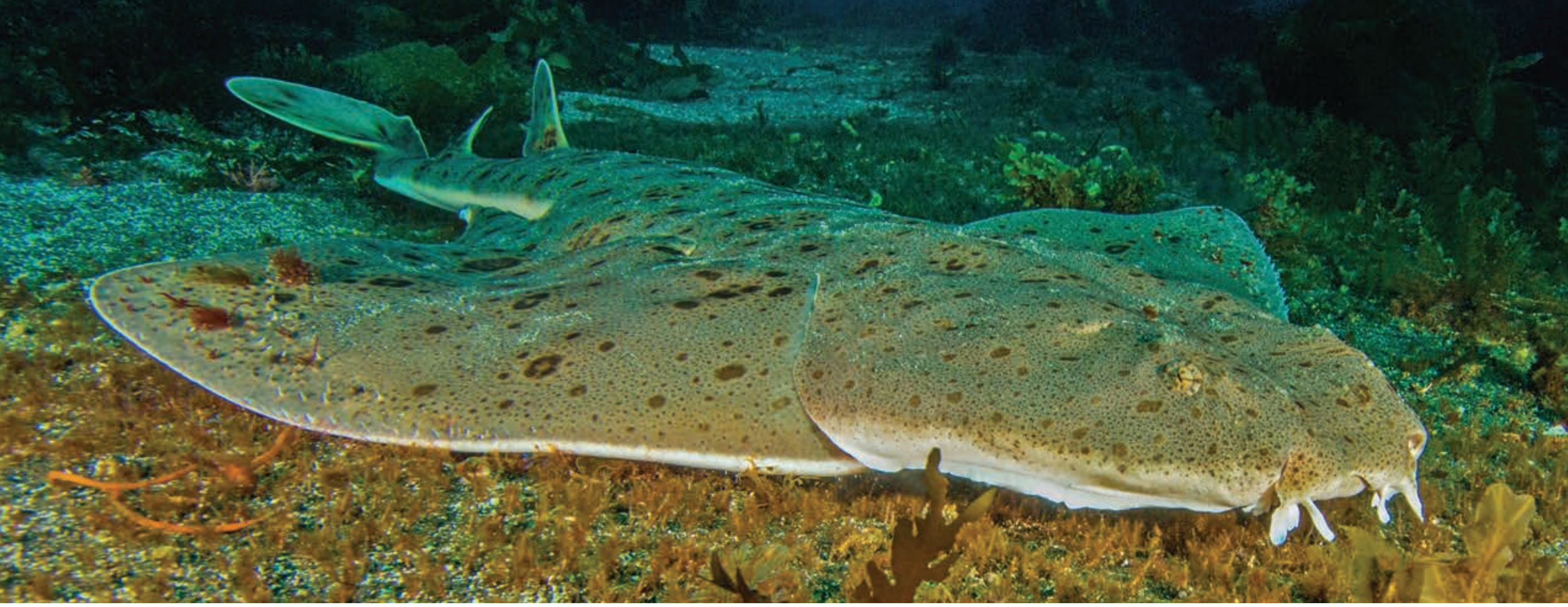


Figure 1. Major offshore wind facility and transmission elements. Not to scale.



Shark. Photo: Douglas Klug/Getty Images

II. The Importance of a Healthy Benthos

The benthic environment refers to the lowest level of the ocean, including the sediment surface and sub-surface layers of the ocean.

Benthic resources and habitats are critical to marine ecosystem health and resiliency.

The biodiverse and varied seabed environments—otherwise known as benthic habitat—serve as the foundation for healthy ocean ecosystems and fisheries.[2] The benthic environment refers to the lowest level of the ocean, including the sediment surface and sub-surface layers of the ocean. It is home to a wide variety of organisms—benthic species—that live on (**epifaunal**) or in (**infaunal**) the seabed, including worms, crustaceans, mollusks, corals, and various microorganisms. The benthic environment plays an important role in nutrient cycling, food webs, and ecosystem health. It can be sensitive to disturbances such as fishing, dredging, or offshore energy development.

Benthic habitats often—literally—shoulder the ecological burden of offshore transmission cable installation to ensure the energy generated by offshore wind turbines reaches the onshore power grid. Though the species of the benthos often do not receive the same attention as **charismatic megafauna**, the benthos plays an important role in ecosystems, including providing biomass to large predators and nursery areas for their young. Such species could not survive without the fish, invertebrates, and other marine life that depend on a healthy benthos to reproduce, grow, and thrive. Ocean resources also support human health and well-being in communities throughout the U.S., often forming the foundation of cultural and social identities.

The importance of benthic habitats remains understudied and many of the most important benthic habitats[3] are vanishing. There has been a 29 percent loss of global seagrass habitats,[4] an 85 percent loss of oyster reefs,[4] and widespread and increasing coral reef depletion.[5] Benthic habitats also support many economically important species. In 2022 alone the U.S. Atlantic lobster fishery harvested 120 million pounds of lobster, which represents $519 million in ex-vessel value.[6] The destruction and depletion of the benthos puts these vital ecosystem services and valuable industries at risk.

Some impacts to the benthos are temporary and mitigable. For instance, increased turbidity from cable laying and burial is typically short-term and highly localized. This can be mitigated through techniques like jet plowing, a cable laying method that reduces turbidity compared to other more invasive techniques. However, other impacts are considered unmitigable, particularly when species or habitats are unable to recover or require hundreds of years to rebound. Damage to **biogenic structures** such as corals and sponges is a key example, where avoidance is the only viable strategy to prevent unacceptable, lasting harm. Unlike the **pelagic zone** (area of ocean away from shore; open ocean), the benthic zone is home to many **sessile** (immobile) organisms, which cannot flee to avoid direct impacts from development.

Offshore wind development typically involves four phases: site assessment and characterization, construction, operations and maintenance, and decommissioning. Each has distinct benthic impacts. In addition to direct impacts such as habitat conversion, loss, and disturbance, offshore wind development also introduces indirect effects. For example, should construction activities displace prey species, there may be energetic costs to the predator species as it follows its prey to new areas. The short- and long-term effects of offshore transmission development on these habitats and species remain poorly understood. As the U.S. works towards developing an offshore transmission grid, we must also focus on what that means for sustaining a healthy benthos.[7]

Even with a limited understanding of these impacts, new technical solutions and current best practices may provide a clear pathway forward for minimizing environmental harm.[8] It is critical that we address the key ways to mitigate benthic disturbance and deliver necessary, renewable energy to our power grid.

Anemone. Photo: Yiming Chen/Getty Images

Currently, more than one-third of marine mammals and nearly one-third of sharks, rays, and reef-forming corals face the threat of extinction. Less than three percent of the global ocean is free from human pressure.

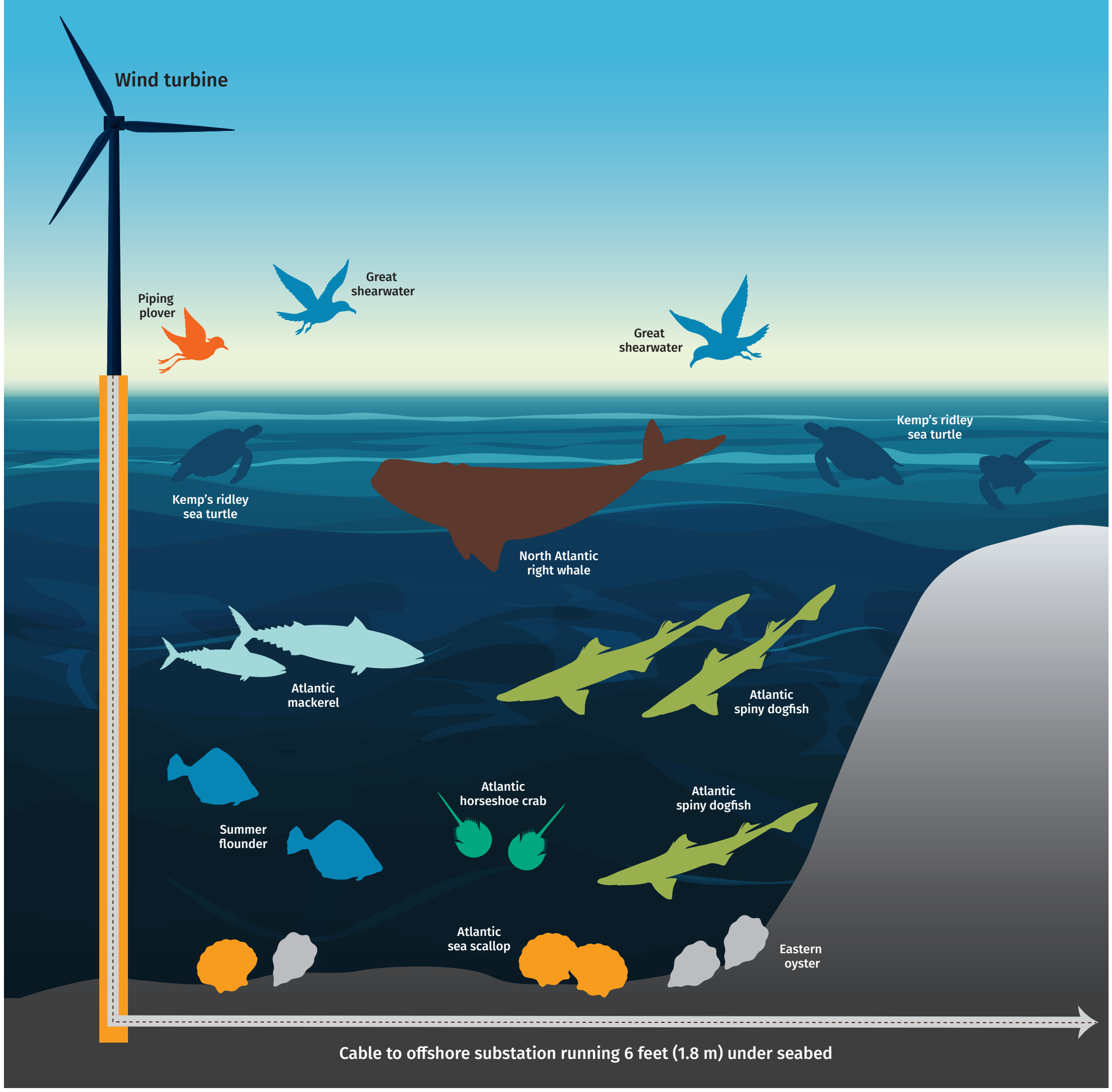


Figure 2. *Schematic showing sea life from the Mid-Atlantic with offshore wind and transmission. Not to scale.*

A. Balancing the Paradox: Offshore Wind's Role in Both Protecting and Impacting the Ocean

Using the best available science to understand both current climatic threats and potential impacts of development is critical to conserve wildlife and build an interconnected offshore power grid that can benefit people and wildlife.

The increasing intensity of climate change, biodiversity loss, and ocean acidification are a consequence of pushing environmental limits towards catastrophic tipping points. Experts are identifying emerging concerns, including ocean deoxygenation, as an additional global environmental threshold that threatens the stability of the planet's systems.[9]

These changes to the physical and chemical composition of the ocean affect species fitness, cause shifts in species distribution, alter predator-prey dynamics, and lead to changes in productivity and phenology. Currently, more than one-third of marine mammals and nearly one-third of sharks, rays, and reef-forming corals face the threat of extinction.[10] Less than three percent of the global ocean is free from human pressure.[11] Ocean-dwelling species are disappearing from their habitats at twice the rate of those on land.[12] If greenhouse gasses are not reduced, up to 90 percent of marine life could be at risk of extinction by 2100.[13] This heightened vulnerability is partly because marine species like fish, crabs, and lobster already live near life-threatening temperature thresholds with few places to escape from extreme heat in the ocean.[14] While climate-related declines have been well-documented in shallow-water habitats such as coral reefs, seagrass beds, and kelp forests,[15] there is limited evidence available to assess these impacts in the deep sea.[16] Similarly, Indigenous Knowledges continue to reveal the breadth of climate impacts on human health, ecosystems, and subsistence resources, as well as the effectiveness of adaptation measures.[17]

As climate change increasingly threatens marine ecosystems and biodiversity, the urgency to adopt renewable energy solutions that mitigate these impacts grows. Within this context, the ocean faces both challenges and opportunities in supporting a renewable energy transition. While fossil fuel emissions remain the main driver of climate change, the power grid still needs energy to electrify homes, businesses, and schools. And energy demand in the U.S. is increasing.[18] Offshore wind provides the unique opportunity to generate large volumes of clean energy—thus mitigating climate change—while avoiding the land-use conflicts associated with traditional terrestrial renewable sources.[19] Ultimately, there is no viable offshore wind solution to climate change without offshore transmission.

The Biden-Harris administration has recognized the critical need to leverage the wind potential across all three U.S. coasts, and has set a goal to achieve at least 30 GW of offshore wind energy generation capacity by 2030 and to work toward 110 GW of capacity by 2050.[20] To bring this volume of energy to the onshore power grid, proactive and interregional planning must inform decision-making.[21]

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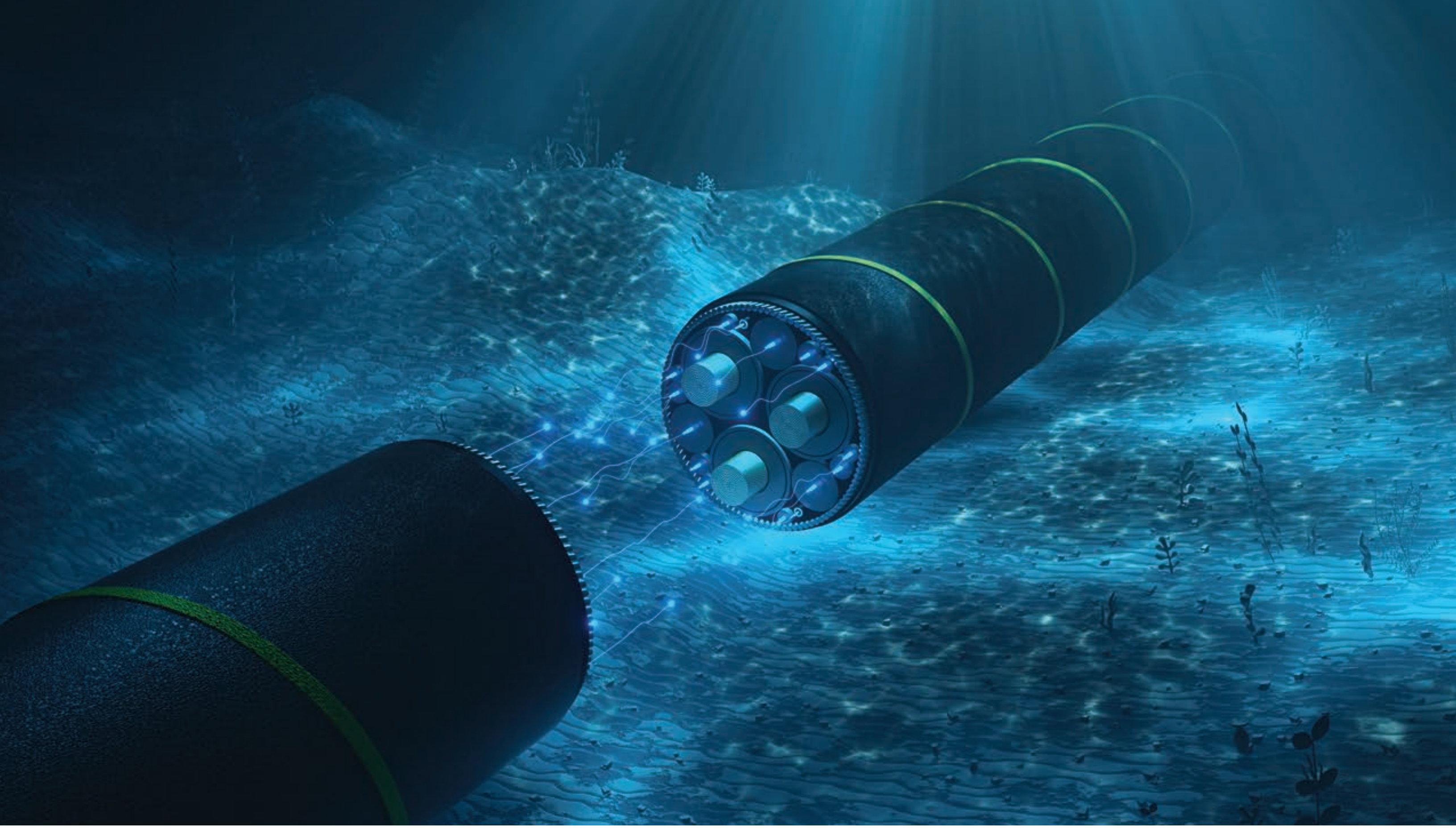
Photo: Huizeng Hu



Schematic showing electricity traveling through an underwater transmission cable in cross section. Photo: Serg Myshkovsky/Getty Images

There is great urgency to ensure that transmission infrastructure can match the pace of approved generation projects, as additional, offshore transmission capacity provides value to the onshore grid.

One of the greatest challenges to offshore wind is building and interconnecting an offshore power grid to an onshore power grid. Globally, the number of offshore wind turbines doubled from 2017 to 2020, surpassing offshore oil structures.[22] Approximately 10,000 offshore wind turbines have been globally deployed, and thousands more are projected to be built.[23] In the U.S., as of October of 2024, 10 offshore wind projects have been approved in the last four years, and 13 federal lease auctions have occurred. There is great urgency to ensure that transmission infrastructure can match the pace of approved generation projects, as additional, offshore transmission capacity provides value to the onshore grid.[24] Indeed, the Atlantic grid operator regions are highly **congested**; offshore transmission with interlinking platforms may ensure consistently flowing power from lower- to higher-price regions benefits electricity consumers with reduced electricity generation costs.

Decision-making must balance the demand for offshore transmission with the protection of marine ecosystems. The National Wildlife Federation and many others in the nonprofit community, advocate for a comprehensive approach to offshore transmission development to ensure the needs of people and wildlife are addressed, in particular following the mitigation hierarchy, which first avoids, then minimizes and mitigates impacts from development.

With improved federal, regional, and state coordination and planning, we can create an offshore power grid that can accommodate the long-term needs of the power grid and coastal communities—especially Tribes and environmental justice communities—while protecting marine ecosystems.

Climate Impacts on Benthic Habitats and the Intersection of Offshore Transmission Development

In addition to assessing the direct and indirect impacts of transmission development on benthic habitats, including the impacts detailed in Section II of this report, it is critical to consider how climate change may affect future offshore transmission development in this crucial ecosystem. Recent regulatory framework changes from the Council on Environmental Quality specifically direct federal agencies to consider the effects of climate change in environmental reviews, and encourage finding reasonable alternatives that mitigate climate impacts whenever possible.[25]

Climate change creates new risks for seabed disruption, with shifts from calm to storm conditions driving greater seabed stress than individual storms. However, **natural seasonal variations, such as large spring tides,** at this time may have a more significant impact than those driven by climate change.[26] Given evolving climate science—and expanding climate impacts—it can be difficult to understand how climate change may compound the impacts of offshore transmission development. Developers and wildlife managers may struggle to address the cumulative adverse effects of multiple offshore wind farms.[27] It may, for example, prove difficult to definitively attribute environmental impacts to climate change compared to offshore wind development or natural sources of variability.

Atlantic spotted dolphins. Photo: Brandon Cole

Many benthic organisms are particularly vulnerable to the impacts of transmission development and climate change, in part, due to their low mobility rates. While mobile species such as fish and marine mammals can move in accordance with changing temperatures and weather patterns, many benthic species lack the ability to move large distances, and some are immobile.

These climate impacts are part of a wider array of cumulative impacts that are applying stress to the benthos. Alongside the installation of offshore wind and climate change, these habitats face stress from boat traffic, pollution, fishing pressures, and other anthropogenic developments and disturbances. While none of these stressors individually may destabilize the ecosystem, when combined, some additional stressors, particularly significant or synergistic ones, could potentially push the ecosystem closer to a tipping point. Future areas of study assessing the cumulative impacts on the seabed should include: future ocean temperature, natural variability in storm wave height including the impact of future waves on bed stresses, and storm clustering's effect on increasing mobility of loosening seabed.[28]

Leopard shark. Photo: Stuart Westmoreland/Getty Images

III. Impacts of Offshore Wind Transmission on the Benthos

Offshore transmission has varied impacts on benthic habitats and resources, including direct mortality and habitat loss. These impacts can be mitigated with techniques such as avoidance, micrositing, and proactive planning, which is critical for protecting benthic species specifically, as much scientific attention has historically focused on other areas like marine mammals and commercial fishing.

A. Direct Mortality and Habitat Loss

Introducing hard bottom structures onto the seabed can lead to a variety of impacts. In addition to the footprint of turbine foundations, offshore transmission such as substation foundations and subsea cables occupy space on the ocean floor, permanently removing or altering natural habitats. Most directly, construction can result in mortality of sessile organisms immediately underneath the towers by compaction or burial (the footprint of such an effect would be relatively small). The burial of cables can also lead to direct mortality through entrainment, in which sediment disturbed by construction activities covers and buries sessile organisms and eggs.

The type of foundation matters greatly in determining the size of the direct impact. Fixed bottom foundations, as compared to floating foundations, have a larger footprint on the seabed, but even variation among fixed bottom foundations presents tradeoffs. **Gravity-based foundations**, which are held in place by the force of gravity rather than piling, for example, have the largest footprint (though they reap benefits in reduced noise impacts during construction as compared to piled foundations).[29] Assuming best practices are adopted concerning siting away from hard substrate, biogenic structures, and important habitat, these impacts are considered minimal, generally covering less than one percent of the offshore wind project site.[30]

B. Habitat Change

The introduction of artificial structures, such as foundations, anchors, and scour protection, converts soft sediment habitats into hard substrate environments. This increased habitat heterogeneity in areas that were predominantly composed of soft substrate may alter the composition of the benthos, and potentially result in broader ecosystem-level effects, as these new habitats are colonized by species like mussels, crabs, and barnacles. These changes may benefit certain species while displacing others, particularly those adapted to soft-bottom environments.

Habitat change caused by the introduction of hard substrates can have cascading effects on the broader ecosystem. For example, the colonization of hard substrates by filter feeders like mussels and barnacles may increase local biodiversity in the short term, providing shelter and food for other species, such as fish and invertebrates. However, the presence of these new habitats may alter local food webs, potentially creating competition for space and resources with native benthic species. Opportunistic species may dominate, leading to shifts in community structure and reducing the abundance of species that rely on undisturbed soft sediments, such as burrowing organisms or benthic infauna.

Recent research from Europe, which analyzed fourteen case studies, has indicated that wind farms had more **polychaetes, echinoderms,** and **demersal fish** compared to control areas, suggesting an **artificial reef-effect**.[31]

The artificial reef effect is the phenomenon where structures such as shipwrecks, oil rigs, offshore infrastructure, and other human-made structures attract species. These structures alter the local ecosystem by providing hard substrate for colonization, which in turn affects the type of prey available for benthic fish.[32] If a hard substrate

Habitat change caused by the introduction of hard substrates can have cascading effects on the broader ecosystem.

Blue crab in eelgrass. Photo: Jay Fleming

In a meta-analysis of 109 articles to assess the impacts of artificial structures in the marine environment, researchers found that operational offshore wind farms can support higher fish biomass, but not invertebrate biomass, and also found that biodiversity did not increased.

provides easier prey accessibility and the composition is of the same or even better quality, secondary production (the creation of biomass from the consumption of other organisms) of fish species might be enhanced,[33] though questions remain about this potential benefit. In a meta-analysis of 109 articles to assess the impacts of artificial structures in the marine environment, researchers found that operational offshore wind farms can support higher fish biomass, but not invertebrate biomass, and also found that biodiversity did not increase.[34] Comparatively, research conducted on a Dutch offshore wind farm found higher biodiversity rates occurred when nature-inclusive design components (such as having a variety of rock sizes and stone types make up the scour protection substrate) were used.[35] One study indicates that scour protections around turbines in offshore wind farms may support Atlantic cod, as the scour protections provide habitat for prey in the summer and desirable conditions for spawning during the winter.[36]

Another study of offshore wind impacts on **epibenthic** biodiversity in the North Sea found that scour protection supported greater species diversity and higher abundances of some species, compared to the surrounding area.[37]

A case study in France combining sampling and modeling of likely ecosystem impacts found that filter-feeding detritivores may dominate the offshore wind farms ecosystem and create a “dead end” in the trophic web, because species benefiting from the new habitat may not be large enough or accessible enough to support many of the fish species present.[38] This can relate to biofouling, which refers to the settlement and growth of organisms on human-made structures in marine environments such as offshore wind turbines and cables.[39] A long-term study following the development of a **fouling** community near two Belgian offshore wind farms found that the composition of species present continued to change and diverge

Artificial Reefs and Refuge Areas: Opportunities and Concerns

Offshore wind farms could benefit some benthic species via reducing anthropogenic pressures in benthic habitats and via the creation of new habitat (the artificial reef effect, mentioned above). Offshore wind infrastructure may damage fishing gear and fishing activities may be prohibited or impractical.[45] In reducing the ability to conduct bottom-trawling activity and increasing the amount of hard substrate (e.g., through the installation of scour protection), offshore wind farms may benefit some epibenthic organisms, particularly in areas where rocky habitat has been degraded or eliminated due to industrial activity.[46] In European wind farms where fishing is limited, infrastructure areas can act as “refuge areas” for commercial fish.[47]

Whether these refuge areas will occur at U.S. facilities, however, remains to be seen. It is currently unclear whether commercial or recreational fishing will be prohibited at U.S. facilities, and important to note that many in the fishing community are concerned about displacement from fishing areas due to offshore wind development. Our understanding of exactly how artificial reefs may benefit benthic organisms—and the greater ecosystem—is also still evolving. And, potential benthic benefits from artificial reefs, which can include offshore oil and gas structures, should not be an excuse for that industry to not responsibly decommission their infrastructure.

Seal. Photo: Douglas Klug/Getty Images

over time. The study's authors emphasized the importance of continuous, long-term ecological monitoring to understand the impacts of offshore wind and the transmission cables on ecosystems.[40]

It has been theorized that an increase of human-made structure in the sea would also increase population connectivity between species that form on hard substrates. However, a study of *Jassa herdmani,* a biofouling amphipod, found that an increase in offshore installations did not lead to an overall increase in genetic connectivity for this species, when human-made structures in the region were tested.[41]

Researchers have found that mussels may attach to dynamic cables in floating offshore wind installations.[42] Still, the researchers stressed that more study is needed to understand thermal impacts of high mussel densities on cables.[43] Researchers also looked at the Hywind Scotland Floating Offshore Wind Pilot Park to see how the benthic species communities would shift with the addition of new hard structures. They found a total of 11 phyla with 121 different taxa on the structures, with differences depending on depth. For example, plumose anemones *(Metridium senile)* and tube-building fan worms *(Spirobranchus sp.)* dominated the bottom and mid-sections (80–20 meters) of the turbines, while kelp and other *Phaeophyceae* with blue mussels *(Mytilus spp.)* dominated top sections of the turbines (20–0 meters).[44]

C. Habitat Disturbance

Site assessment and characterization, construction, and decommissioning activities may all disturb the seabed, particularly through activities like geotechnical and biological sub-bottom sampling, foundation installation, anchoring, and cable laying. These activities can lead to temporary habitat disruption, sediment suspension, and reduced water quality. For example, the ships that lay the underwater transmission lines use a

Spiny dogfish shark. Photo: Gerard Soury

considerable number of anchoring stabilizers, which create plumes of resuspended sediments along the sealine track and may have near-term impacts on benthic species.[48] Array cable installation has been shown to disturb phytoplankton populations, which are primary producers and rely upon light and low-turbidity conditions for growth.[49] Suspended sediment reduces the amount of light penetration necessary for these species to photosynthesize. When measured up to 80 days after installation, the entire time period showed a significant decrease in phytoplankton communities near cable installation sites.[50] This study took place over a very limited window of time, highlighting the need for further long-term studies into the impacts of cable installation on phytoplankton populations.

Soft-bottom habitats tend to be more dynamic ... and therefore are more adapted to constant sediment movement.

Changes in water movement due to construction—the wake effect, where anthropogenic structures alter the flow of water—can also have broader ecological impacts. One study of a tidal energy turbine in Northern Ireland, for example, found that the wake effect created a predictable foraging hotspot for some seabirds.[51] More research is needed on how hydrodynamic forces around turbines and associated structures may affect benthic ecosystems.

Trenching and cable burial also disturb benthic habitats (or can lead to direct habitat loss), though the techniques used for both greatly influence the degree of impact. For example, the use of horizontal directional drilling to bring cables onshore, as well as jetting and jet plow cable laying methods are considered to be less impactful compared to dredging.[52] And using a narrow blade conventional plough to backfill trenches, instead of mechanical cutter or jetting systems, helps limit disturbance to sediment, and quickens recovery.[53]

Soft-bottom habitats tend to be more dynamic—experiencing more regular natural disturbances from waves, tides, and currents—and therefore are more adapted to constant sediment movement with a higher tolerance for some degree of disruption. Post-construction studies at Block Island Wind Farm found that while soft-bottom habitats may recover relatively quickly after construction, certain areas experienced shifts in sediment composition and species recolonization.[54] Opportunistic species, which are well-suited to dynamic environments, often repopulated disturbed areas. However, long-term impacts were observed in less dynamic and more stable habitats where recovery was slower and changes to benthic community composition persisted.

Though floating offshore wind avoids many aspects of benthic disturbance caused by foundations, anchors used to affix turbines to the seafloor can disturb the benthos if the **mooring lines** drag along the seafloor due to slack in the line. The tautness of a floating offshore wind mooring system corresponds to how much flexibility the system can tolerate when responding to wave action. The more slack a mooring system has, the more likely that the mooring chains may rest on and disturb the seafloor.[55] Catenary mooring lines in particular, which have more slack, can cause greater seabed disruption compared to other systems. Additionally, there is an increased risk for sedimentation with a mooring system compared to a standing system. This increased risk comes from the movements of the mooring system.[56]

Photo: Amber Hewett

D. Noise

Noise will be produced from all phases of the offshore wind development process, but the noise produced during construction, particularly from the use of pile driving for foundation installation, poses the greatest risks. Underwater noise impacts benthic species through both pressure (the expansion and compression of water from sound waves) and particle motion (the displacement of the water molecules). Noise from pile driving, as well as vessel traffic, seismic surveys, and other construction activities can disrupt benthic habitats, causing stress, behavioral changes, or even injury to organisms. While most impacts are expected to be local, temporary, and negligible, knowledge gaps exist regarding noise thresholds and recovery time for most marine invertebrates.[57] Current research suggests that invertebrates may be less susceptible to loud noise compared to mammals and fish, but noise levels can still trigger short-term behavioral responses.

E. Entanglement

Unlike transmission cables for fixed foundations, which primarily pose risks to the benthos as the cables are run along and buried under the seafloor, floating offshore wind transmission cables and mooring lines pose risk throughout the water column. Floating cables and lines may create a risk of secondary entanglement, where the cables could become entangled with fishing gear or other materials, which in turn could ensnare wildlife.[58] The risk of entanglement is dependent upon the characteristics of the mooring lines (such as their tautness and diameter), the behavior of animals near the lines, the ability of animals to detect the lines, the amount of lost fishing gear near the array, and the proximity to fishing areas.[59] Entanglement monitoring and deterrent technologies may be critical to mitigate this risk. The use of underwater cameras, motion and load detection on lines, and the use of remote vehicles for removal of marine debris are all possible solutions.[60] Pingers (acoustic alarms) may help to reduce entanglement on moorings and other lines, though this technique needs additional research.[61] Notably, acoustic deterrents could also contribute to noise pollution.

Current research has shown that the effects of heat on most sediment and seafloor-dwelling species are low overall.

F. Heat

Heat is produced by offshore wind interarray and export cables ranging from between 0.15-2.5 degrees Celsius when cables are buried.[62] The effect of heat from buried transmission cables is influenced by a wide range of factors, including submarine terrain, sediment type, water depth, water temperature, and species composition. Despite this high variability, current research has shown that the effects of heat on most sediment and seafloor-dwelling species are low overall.[63]

Heat is also a byproduct from converting the alternating current (AC) generated by wind farms, to direct current (DC). This conversion is necessary when wind farms are located more than 30 miles offshore, as AC incurs greater losses with increasing distance. DC is able to transport energy longer distances without such losses. Open-loop cooling systems are the most effective means of conducting this conversion. In these systems an intake pipe brings sea water into the heat exchanger where it absorbs heat from the converter system and then the heated water is subsequently released back into the ocean. Depending on the location of the intake pipe, some species may be at risk of **impingement**, where species are sucked into the inflow and trapped on intake screens where they ultimately die. Species are also at risk of **entrainment**, in which they are brought into the system when filtering/screening is ineffective. Ultimately, the warmed water discharged by these systems is expected to have minimal impacts on species as the warmed water would quickly match the ambient temperature.[64] To minimize impacts from discharging heated water, some projects, such as Sunrise Wind, use hydrothermal modeling to determine the optimal location to discharge the water and contain the thermal plume.[65]

Other systems, such as air cooling or closed-loop systems, have been deemed either infeasible due to ambient air temperatures, not market ready, or require much larger support structures.[66]

G. Electromagnetic Fields

1. Introduction to EMF Impacts

Electromagnetic fields (EMF) are composed of electric fields (generated by stationary electric charges) and magnetic fields (produced when electric currents flow). EMF can occur naturally, such as through the Earth's geomagnetic field and thunderstorms, or EMF can be created by human-made (anthropogenic) sources such as through subsea power cables. Subsea power cables, such as those used by offshore wind to transport the energy to shore, emit low frequency electromagnetic radiation, which unlike high frequency radiation, is not known to cause cellular damage. Anthropogenic EMF from subsea power cables have been part of the marine environment for at least the last 150 years, as power and telecommunication cables have helped connect regions across oceans and bodies of water.[67]

EMF impact marine species primarily through the magnetic fields emitted by these cables, as electric fields are eliminated through shielding. These magnetic fields induce electric fields in the surrounding water, potentially affecting marine life, particularly species that are sensitive to electromagnetic changes such as **elasmobranchs** (a group of animals including sharks, skates, and rays). Some species, such as salmonids, some sea turtles, invertebrates, and possibly some cetaceans, are sensitive to magnetic fields, while some fish species, such as sturgeon, lamprey, and eel are electrosensitive.[68] The strength of the electric field depends on the amount of current flowing through the cable.[69] As current flow changes, so too does the strength of the EMF and its potential impacts on benthic species.

Research on the effects of EMF on marine wildlife remains inconclusive. Many electroreceptive species rely on natural EMF for navigation and predator-prey interactions.[70] There is concern that

Subsea power cables, such as those used by offshore wind to transport the energy to shore, emit low frequency electromagnetic radiation, which unlike high frequency radiation, is not known to cause cellular damage.

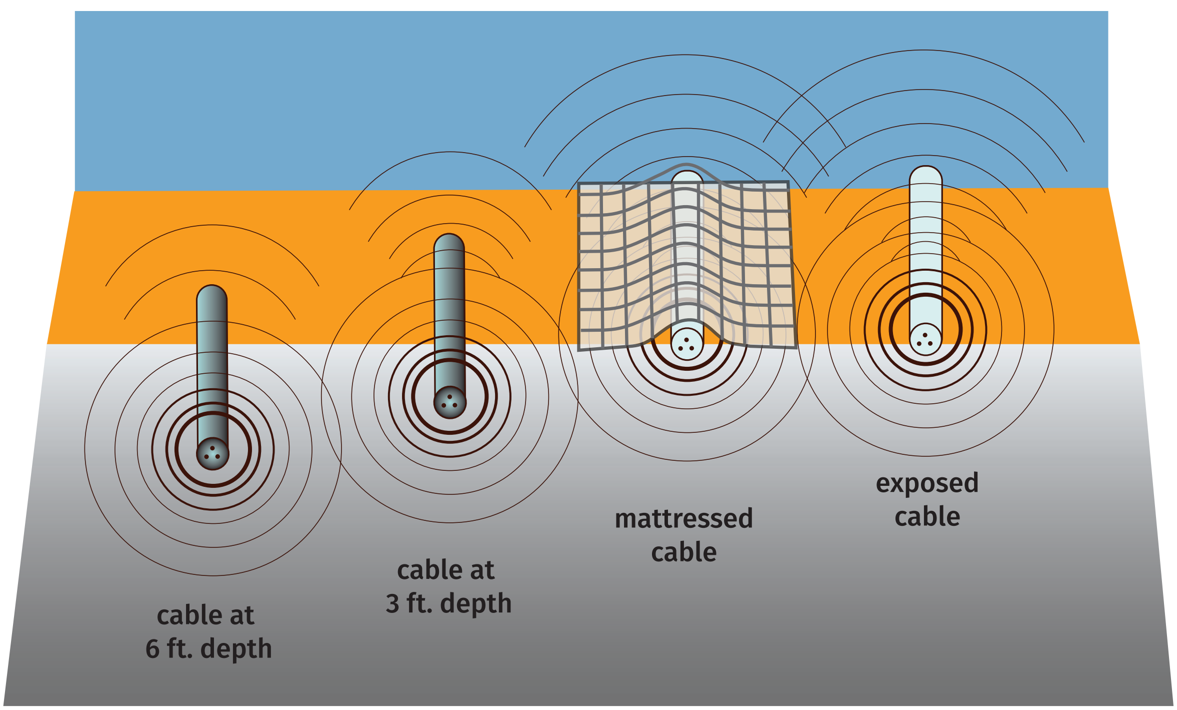


Figure 3. *Burying cables reduces EMF.*

Photo: Labsas/Getty Images

anthropogenic EMF from power cables may mask natural EMF signals or interfere with these critical cues. Research has found that anthropogenically generated EMF may alter the behavior of magneto-receptive and electrosensitive seafloor species,[71] potentially causing avoidance behaviors or stress, and affecting reproduction and trophic dynamics.[72] There are also concerns about the impact of EMF on marine mammals and their migration patterns, though this area requires further research.[73] Most studies to date have focused on specific species' interactions with transmission cables, leading to varied findings depending on the species and effects studied.

> **In the broader context of offshore wind farms, EMF impacts have been found to be relatively minor compared to other environmental pressures.**

2. Relative Impact of EMF Compared to Other Environmental Pressures

In the broader context of offshore wind farms, EMF impacts have been found to be relatively minor compared to other environmental pressures. A cumulative effects assessment conducted across nine vertebrate species at operational North Sea wind farms ranked "significant changes" in EMF twelfth out of 18 pressures, contributing less than one percent to the overall cumulative effects of the wind farm. Other pressures, such as construction-induced underwater noise, marine litter, and contact with fuel and chemicals, were found to have more substantial impacts on marine species.[74] Indeed, through the 10 NEPA assessments by BOEM at the time of publishing this report, all have concluded EMF impacts will be negligible with specific project requirements.

3. Species-Specific Sensitivity to EMF

While overall impacts of EMF may be subtle, some species are particularly sensitive. For example, elasmobranchs can detect EMF generated power cables at distances up to 250 meters away for DC cables and 120 meters for AC cables. However, how these species respond to EMF is not fully understood, and behavioral responses could vary by life stage.

One study of eight migratory fish species, including the European eel *(Anguilla anguilla)*, the Atlantic salmon *(Salmo salar)* and the yellowfin tuna *(Thunnus albacares)*, found evidence to suggest that these species are electrosensitive.[75] Importantly, the researchers noted that there is still a large gap in field data regarding this phenomenon. This study only examined eight species, and it can be difficult to extrapolate if or how other marine organisms might respond.

Though there have been few *in situ* studies, a study on red rock crabs *(Cancer productus)* off the coast of California showed no preference for crossing or not crossing a transmission line that was emitting EMF. In this instance, the emitted EMF decayed to background levels at a distance of less than a meter away, and no difference was detected in the crabs' preferred crossing direction.[76]

In studies focusing on movement, researchers have found that EMF may affect certain species' swimming speeds. In one study of European eel *(Anguilla anguilla)*, researchers found swimming speed slowed near marine power cables.[77] Other researchers have found that the larvae of Atlantic haddock *(Melanogrammus aeglefinus)*[78] and Atlantic cod *(Gadus morhua)* reduced their swimming activity when exposed to static magnetic fields that are generated in a way that is similar to those emitted by marine transmission cables.[79] Other researchers have found juvenile Atlantic lumpfish *(Cyclopterus lumpus)* tested in a laboratory setting showed a 16 percent decrease in swimming speed when directly exposed to EMF. However, researchers concluded that this would have a negligible impact on their migration even if their migratory path transits cable routes.[80]

Another study examining HVDC lines found impacts of EMF on the lagoon cockle *(Cerastoderma glaucum)*, a species of saltwater clam. EMF exposure was associated with a detrimental effect on cockle swimming speed and leading to oxidation and neurotoxicity.[81] This study only examined HVDC lines.

Researchers have also expressed concerns about the potential for EMF to alter species' biological processes, including physiological and behavioral responses, though in one study of four coastal invertebrates they found no significant differences in these responses when exposed to EMF.[82] Continued research in this area will be critical to establish a baseline of how EMF can impact species from the cellular to behavioral level.

Researchers have also found species-specific effects of EMF exposure on marine invertebrates during early development. Researchers studying commercially important

Sea turtle. Photo: Tyler MacDonald

species of European lobster *(Homarus gammarus)* and edible crab *(Cancer pagurus)* exposed these species to EMF during the egg-bearing stage; there was no impact detected

Pacific octopus. Photo: Brook Peters/Getty Images

on embryonic development time, larval release time, or vertical swimming speed for either species. Long-term exposure led to an increase in larval deformities, which may have wider impacts on juvenile survival rates.[83]

Depending on the species and the timing of exposure in its life cycle, the effects of EMF exposure may be neutral.[84] In the first study to measure the impacts of EMF on marine invertebrates, polychaetes *(Hediste diversicolor)* were found to show no avoidance or attraction behaviors to EMF. Researchers also found that their consumption and respiration rates were not affected, but their ammonia excretion rate decreased significantly for reasons that are not yet clear.[85]

4. EMF from Floating Offshore Transmission

More information is needed on the ecological impacts of suspended cables versus buried cables beyond the known ecological disruptions that occur during the construction phase.[86] Compared to transmission from fixed foundation arrays, floating offshore wind poses different risks from the production of EMF, as the interarry cables and transmission cables will be suspended in the water column rather than buried—the typical measure to mitigate the proliferation of EMF in fixed arrays. For example, while concerns have been raised about EMF on the seafloor attracting EMF-sensitive predators, concerns have also been raised about large amounts of EMF in the water column acting as a barrier to movement for electro-sensitive species.[87] Without burial, and given their location throughout the water column, such cables may increase EMF exposure for a variety of species. Further, the use of DC current to transport energy from floating arrays farther from shore would likely require high voltage current, which *may* emit higher intensity magnetic fields.[88]

Limited research exists on the emission of EMF from floating offshore wind and the impacts it could have on species. Potential mitigation options to reduce emission of EMF could include standard cable insulation or sheathing to eliminate electric fields, though magnetic fields, and therefore induced electric fields, are still problematic. The use of both higher voltage cables and AC can produce lower magnetic fields, as can potentially placing cables together to allow magnetic fields to cancel one another out.[89] Ultimately, the most effective approach may be to avoid routing cables through areas likely to contain EMF-sensitive species.

IV. Regulatory Structure Governing Offshore Grid Buildout

There are two regulatory pathways to build transmission; neither allows for urgently needed proactive interregional planning and instead focuses on singular project-specific development.

Two U.S. regulatory pathways exist to build offshore transmission. Each of these pathways offer opportunities to regulate benthic resources and habitats and apply the existing science above. However, scientific gaps regarding impacts to the benthos also illustrate the need for more in-depth analysis from regulators to inform protections applied by regulators and developers during the offshore wind development process. The first path to develop offshore transmission is embedded within the process that regulates offshore energy generation, like offshore wind. Under the Outer Continental Shelf Lands Act (OCSLA) Section 585.200(b), a developer may apply or compete for an offshore wind lease, which will confer the right to one or more project easements upon the applying developer. These easements are subsequently used for the development of transmission cables from the lease area to shore. Under the second path, a developer may apply directly for an easement from BOEM. In this section, we examine the opportunities industry and decision-makers have leveraged to safeguard benthic habitats through these pathways.

> **The first path to develop offshore transmission is embedded within the process that regulates offshore energy generation, like offshore wind.**

A. Path One: Planning and Analysis

BOEM first assesses how offshore wind and transmission development may affect benthic resources and sensitive habitat during the

Figure 4. *Two regulatory pathways exist for building offshore transmission under the Outer Continental Shelf Lands Act.*

Seal. Photo: Douglas Klug/Getty Images

Request for Information (RFI) (which is an optional comment period) and/or the Call for Information and Nominations (Call), which is required under OCSLA. These comment periods are used to gauge interest in leasing and gather information about important resources in the area under consideration. Using the information gathered, BOEM refines the area under consideration for leasing. This ultimately creates the Call Area, a geographic region or discrete areas that may be suitable for offshore wind development. For example, BOEM refined the Call Area for the Gulf of Maine by eliminating almost 800,000 acres of Habitat Management Areas and Coral Protection Areas among thousands of other acres of important resource areas.[90]

Since 2022, BOEM has offered an additional comment period on Draft Wind Energy Areas, the next refined area under consideration, after conducting a suitability analysis in partnership with the National Centers for Coastal Ocean Sciences (NCCOS). Through the NCCOS suitability analysis and subsequent comment period, BOEM continues to consider a multitude of potential resource constraints that further refine the lease area. For example, the suitability analysis for the Gulf of Maine constrained the model by ranking habitat such as known coral and hard bottom habitat with the lowest possible suitability score.[91]

Finally, BOEM evaluates public comments and publishes Final Wind Energy Areas (WEAs). Though not attributable only to benthic concerns, the Gulf of Maine Final WEA represents an 80 percent reduction in size from the Call Area due to resource constraints such as low suitability of sensitive benthic habitats.[92]

B. Path One: Leasing

Through the leasing process there are three federal comment periods as well as several state and agency consultations.

During leasing, BOEM initiates a sale by publishing a Proposed Sale Notice (PSN).[93] The PSN details the proposed lease areas, the competitive leasing process, as well as potential environmental protections that may be required as a condition of the lease. BOEM invites public comments, evaluates those comments, and then publishes the Final Sale Notice (FSN). The FSN finalizes the areas available for leasing, auction procedures, lease provisions/stipulations, and bidding credits, and schedules the lease auction. The lease provisions outlined at this stage offer one of the first opportunities to require mitigation to protect benthic habitat and species.

Leasing also triggers BOEM's responsibilities under the Coastal Zone Management Act (CZMA),[94] which offers the first opportunity for state regulators to provide benthic mitigation requirements consistent with the states enforceable policies. States may: concur that BOEM's action to lease areas off the OCS and authorize site assessment and site characterization activities are consistent, reject that the actions are consistent, or concur with conditions. Those conditions may become lease stipulations and have sometimes included measures to protect benthic habitats.

Under the National Environmental Policy Act (NEPA), BOEM also conducts an Environmental Assessment (EA) and Consultation with the National Marine Fisheries Service and U.S. Fish and Wildlife Service to evaluate potential impacts of leasing and mitigation measures, called Standard Operating Conditions and Best Management Practices (BMPs), that will be required to address impacts. At this stage, the construction and operations of transmission infrastructure is not considered; only site assessment and site characterization activities are evaluated. Given that transmission is *not* considered at this stage, BOEM does not evaluate EMF in the EA and leaves such analysis for the NEPA review during the subsequent Construction and Operations phase.[95]

All three of these reviews, the Sale Notice and subsequent lease stipulations, the CZMA Consistency Review and conditions of concurrence, as well as the EA and Consultation with the Services, may lead to protections for benthic habitat and species as a requirement of leasing.

1. Lease Stipulations, Requirements from Consultation with the Services, and Coastal Zone Management Act Consistency Review

Generally, BOEM's requirements for benthic mitigation at the leasing stage vary tremendously and have evolved over time.

The very first offshore wind leases, Deepwater Wind, Fishermen's Energy of New Jersey LLC, Bluewater Wind Delaware LLC, and Bluewater Wind New Jersey LLC, which were issued in 2009—and only one of which proceeded all the way to construction—contained minimal benthic-specific mitigation requirements, but had very prescriptive requirements for habitat field surveys and reports for biologically sensitive habitats. This included requirements to survey any sites within 100 meters of an area of proposed seafloor disturbance, or within 1,000 meters of proposed sites for

The very first offshore wind leases...were issued in 2009—and only one of which proceeded all the way to construction—contained minimal benthic-specific mitigation requirements, but had very prescriptive requirements for habitat field surveys and reports for biologically sensitive habitats.

Blue banded goby. Photo: Jeff Foott

excavation, where turbidity plumes are likely to occur.[96] This measure does not appear to be carried forth in future leases, though buffers for benthic habitat are being incorporated more recently (2022 and 2024) in West Coast leases.

Some of the oldest leases contain stipulations focused on latter phases of the offshore wind development process. Notably, the lease for Cape Wind (2010), included requirements for the configuration of cables to reduce EMF.[97] This is not common practice now. Generally, BOEM has little to no requirements for EMF mitigation at the leasing stage.[98] At minimum, BOEM requires the lessee in a designated defense area to enter into an agreement with the appropriate command headquarters to coordinate electromagnetic emissions associated with survey activities.[99]

In 2012, BOEM required specific physical and biological survey data be collected by Garden State Offshore Energy regarding benthic habitat in areas known as “Old Grounds”, “Mussel Bed”, “Inside Mud Hole”, “Middle Mud Hole”, and “Outer Mud Hole.”[100] This type of location-specific stipulation appears to be less common now.

From 2013 to 2022, leases became increasingly standardized, but lacked lease stipulations regarding protection of benthic habitat.

On the Atlantic Coast beginning in 2022 with the six New York Bight Leases, BOEM began incorporating by reference the 2021 Biological Assessment and Letter of Concurrence for Project Design Criteria (PDC) and BMPs.[101] This programmatic consultation has since been applied to all subsequent lease sales on the Atlantic Coast and requires lease holders to avoid live bottom features during any seafloor-sampling activities, which can only be conducted at least 150 meters from known locations of threatened or endangered coral species. The BMPs also require that sensitive live bottom habitats should be avoided.[102]

On the West Coast in 2023 with the five California leases, BOEM incorporated requirements into the leases for an anchoring plan intended to avoid placing anchors on sensitive seafloor habitats. The leases also required the lessee to avoid bottom contact with “hard substrate, rock outcroppings, seamounts, or deep-sea coral/sponge habitat, and include a buffer of at least 40 feet [12m]” from hard substrates.[103] These requirements were a direct result of CZMA Consistency Review, where the California Coastal Commission concurred with conditions to BOEM’s Consistency Determination. Through Consultation with the National Marine Fisheries Service, BOEM also prohibited

From 2013 to 2022, leases became increasingly standardized, but lacked lease stipulations regarding protection of benthic habitat.

trawling methodology for site assessment and site characterization as a means to protect benthic habitat.[104]

Subsequently in 2024, the leases for the two areas off the coast of Oregon also included similar requirements for benthic habitat protection based on the enforceable policies of the state. This includes the requirement for an anchoring plan to avoid sensitive seafloor habitat,[105] as well as a required 250 foot (76 meter) buffer for all bottom-disturbing activities from hard substrate, rock outcroppings, seamounts, or deep-sea coral/sponge habitat.[106] These measures were the result of Consistency Review by the Oregon Department of Land Conservation and Development. Though BOEM also incorporates by reference the National Marine Fisheries Service Consultation dated July 12, 2024, regarding PDC and BMPs, this document does not appear to be available online at this time to determine the benthic-related measures included.

In the Gulf of Mexico in 2023, while BOEM did not directly require any benthic-specific lease stipulations, nor are any required through consultation, the agency did direct lessees to its Gulf of Mexico BMPs Guidance Document, which is optional. This document, created in consultation with the National Marine Fisheries Service, recommended that all bottom-disturbing activities be at least 1,000 feet (304 meters) from any National Marine Sanctuary Boundary, and 500 feet (152 meters) from any other sensitive benthic features including chemosynthetic communities, topographic banks, pinnacles, live bottoms (e.g., submerged aquatic vegetation [SAV] and oyster beds), or any other hard bottom benthic feature(s). It also recommended that vessels maintain a clearance distance for mooring and anchoring of 15 feet (4.5 meters) from sensitive benthic features.[107] For the recent 2024 lease sale in the Central Atlantic, though the leases did not contain benthic-specific measures, the EA requires developers to engage with Tribes and other parties related to transmission planning before proposing an export cable route.[108] BOEM requires geotechnical/benthic sampling using methods like bottom-sampling devices, vibracores, deep borings, and cone penetration tests.[109] BOEM also requires biological surveys of benthic habitats as they relate to marine mammals.[110] As mentioned above, this lease continues to defer to the BMPs and PDC outlined in the 2021 Biological Assessment and Letter of Concurrence for PDC and BMPs,[111] and therefore only includes the single measure to avoid live bottom features.

For the 2024 lease sale for eight leases in the Gulf of Maine, BOEM again indicated within the lease that it defers to the 2021 Biological Assessment and Letter of Concurrence for PDC and BMPs. Nevertheless, the leases do include a new stipulation called the Habitat Impact Minimization Measure, which requires the lessee to use the best available data

Snowy egret. Photo: Joseph Giiter

Year	Lease/Region	Key Benthic-Specific Stipulations, Mitigation Measures, and Conditions of Concurrence
2009	Deepwater Wind, Fishermen's Energy of New Jersey LLC, Bluewater Wind Delaware LLC, Bluewater Wind New Jersey LLC (Atlantic)	Minimal benthic-specific mitigation; required habitat field surveys within 100m of proposed disturbance and 1,000m of excavation sites. Measure not continued in future leases.
2010	Cape Wind (Atlantic)	Cable configuration requirements to reduce EMF; currently uncommon. BOEM typically lacks EMF mitigation requirements at leasing stage but may require coordination for electromagnetic emissions in defense areas.
2012	Garden State Offshore Energy (Atlantic)	Location-specific survey data for benthic habitats (e.g., "Old Grounds," "Mussel Bed"). Less common in recent leases.
2013-2022	Various Leases (Atlantic)	Standardization increased; benthic habitat protection stipulations generally absent.
2022	New York Bight (Atlantic)	Stipulations require avoidance of live bottom features at least 150m from coral locations per 2021 Biological Assessment and Letter of Concurrence (BA & LoC) for PDC and BMPs.
2023	California Leases (Pacific)	Required anchoring plans to avoid sensitive seafloor habitats, buffer of 12m from hard substrates; CZMA Consistency Review incorporated additional protections against bottom contact. National Marine Fisheries Service (NMFS) prohibited trawling for site assessments.
2023	Gulf of Mexico	BOEM recommended (optional) guidance on avoiding sensitive features and National Marine Sanctuary Boundaries; mooring/anchoring clearance of 4.5m from sensitive features.
2024	Oregon Leases (Pacific)	Required anchoring plans, 76m buffer from hard substrate, and seafloor habitat protection from Oregon Department of Land Conservation and Development Consistency Review. NMFS consultation referenced but not publicly available.
2024	Central Atlantic Leases (Atlantic)	BOEM requires engagement with Tribes for transmission planning; benthic sampling includes bottom devices, vibracores, and biological surveys for marine mammals. BMP and PDC from 2021 BA & LoC applied with live bottom feature avoidance.
2024	Gulf of Maine Leases (Atlantic)	Habitat Impact Minimization Measure introduced to avoid/minimize harmful bottom-disturbing activities. Encourages use of shared cable corridors, regional transmission, and meshed systems.
2024	Oregon (Pacific)	BOEM requires high-resolution seafloor habitat data in Construction and Operations Plan (COP), including maps and navigation/equipment handling descriptions to minimize disturbance.

Horseshoe crab. Photo: Jennifer Idol/Getty Images

to identify sensitive biological resources or habitats and avoid or minimize bottom-disturbing activities likely to be harmful to identified sensitive resources.[112] The lease also requires that the lessee consider the use of shared cable corridors, regional transmission systems, or meshed systems.[113]

C. Path One: Site Assessment and Site Characterization

After the auction, BOEM awards commercial leases to winning bidder(s) granting the right to conduct site assessment and site characterization activities and submit an eventual Construction and Operations Plan (COP) to BOEM. Site assessment and site characterization activities are the first instances where the developer must abide by any mitigation measures outlined as conditions of the lease. Before site assessment and site characterization can begin, the lessee must develop and submit for approval a Site Assessment Plan (SAP). This document is not reviewed by the public for public comment.[114] Site assessment and characterization can take up to five years. Once BOEM receives the COP, BOEM assesses the COP under NEPA.[115] This presents another opportunity for BOEM to assess project impacts to benthic resources and habitats.

When the lessee submits their COP, they are required to also submit a Subseacable Risk Assessment.[116] The core assessments that developers use to outline cable pathways are the Preliminary Route and Landing Site Assessment (Critical Issues Analysis), the Submarine Cable Feasibility Assessment, and the Cable Burial Risk Assessment (CBRA).[117] A CBRA uses a risk-based methodology to determine the minimum recommended depth of lowering (DOL).[118] The factors considered include but are not limited to: maximum likely vessel traffic, anchor strikes, geotechnical data, geophysical data, and publicly available marine wildlife data. Developers then assess this data to find the most economically suitable depth for the cable to be buried.[119]

Site assessment and site characterization activities are the first instances where the developer must abide by any mitigation measures outlined as conditions of the lease.

Atlantic croaker. Photo: Jay Fleming

D. Path One: Construction and Operations

The submission of the Construction and Operations Plan (COP) to BOEM initiates the second round of environmental review under the NEPA. It is during this second NEPA review, in which BOEM conducts an Environmental Impact Statement (EIS), that transmission impacts are considered and mitigation measures are enumerated. Under NEPA, BOEM considers many impacts, including EMF (from construction and operations) and benthic impacts to the marine environment. During this process, BOEM solicits public comment and conducts a second Consultation with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service. The agency also conducts a second Consistency Review under the Coastal Zone Management Act. Again, BOEM outlines specific conditions or BMPs to mitigate potential impacts to benthic resources and habitats.

BOEM's existing requirements for benthic mitigation and monitoring at the construction phase through the Final Environmental Impact Statement (FEIS) vary by project, pursuant to NEPA. BOEM has generally found that the following impacts are unavoidable:[120]

- Increase in suspended sediments and resulting effects due to seafloor disturbance,
- Habitat quality impacts including reduction in habitat as a result of seafloor surface alterations,
- Displacement, disturbance, and avoidance behavior due to habitat loss and alteration, equipment noise, vessel traffic, increased turbidity, sediment deposition, and electromagnetic fields,
- Individual mortality due to construction and installation, operation and maintenance, and conceptual decommissioning, and
- Conversion of soft-bottom habitat to new hard-bottom habitat.

To date, BOEM has concluded the NEPA process for 10 projects,[121] while several others are at various stages of the second NEPA review. The required and voluntary mitigation and monitoring measures across all ten projects focused on benthic impacts totaled nearly 350 measures.[122] A comparison across projects reveals some key similarities and differences:

1. Monitoring and Reporting

All 10 projects prioritize environmental monitoring through comprehensive surveys conducted before, during, and after construction. This includes benthic habitat assessments, plankton[123] and fish population studies, as well as evaluations of the ecological impacts related to construction activities. For example, New England Wind,[124] Ocean Wind,[125] Atlantic Shores South,[126] Sunrise Wind,[127] CVOW-C,[128] Revolution Wind,[129] and Empire Wind[130] all make specific commitments to create a Benthic Habitat Monitoring Plan.

2. Habitat Avoidance Strategies

Each project incorporates clear requirements for identifying and mapping sensitive habitats (through techniques such as multibeam sonar), such as hard-bottom areas and submerged aquatic vegetation (SAV), and implementing measures to avoid disturbance during construction. For example, micrositing, in which exact locations for project components are adjusted based on the avoidance of sensitive habitats and species, is a primary strategy identified by seven projects.[131]

3. Implementation of BMPs

Projects routinely cite BOEM's Best Management Practices (updated in 2023)[132] and opt for less invasive installation techniques (e.g., jetting, horizontal directional drilling) over traditional dredging methods to protect marine environments.

4. Anchoring Plans

Most of the projects outline a requirement for developing anchoring plans[133] aimed at reducing impacts to sensitive habitats. This includes using mid-line anchor buoys to minimize disturbance from anchor chains.

5. Time of Year Restrictions

The projects include temporal restrictions on construction activities to protect vulnerable species during critical life stages, particularly species like Atlantic cod[134] and horseshoe crab *(Limulus polyphemus)*.[135]

6. Use of Innovative Technologies

Many projects are implementing advanced technologies to reduce environmental impact, such as dynamic positioning vessels[136] in cable laying, which can minimize anchor usage.

7. Noise Mitigation Strategies

Though all the projects are required to mitigate noise from pile driving to protect marine mammals, several projects specifically identify benthic impacts as a reason to employ measures such as soft starts/ramp ups, attenuation technology like double bubble curtains, and sound field verification.[137]

8. Electromagnetic Field (EMF) Considerations

Though several of the projects consider EMF and specify measures for shielding and burial

The required and voluntary mitigation and monitoring measures across all ten projects focused on benthic impacts totaled nearly 350 measures.

Sperm whales. Photo: Brandon Cole

Overall, the conditions outlined during NEPA across the 10 completed projects reflect a shared commitment to protection of benthic habitat and species, with many similarities and overarching strategies.

of cables, only Ocean Wind,[138] CVOW-C,[139] Atlantic Shores South,[140] and Empire Wind[141] specifically note mitigation measures related to EMF impacts on the benthos. Many of the projects, however, require monitoring for EMF impacts to benthic species. Several projects specify cable burial depth (e.g., 4 to 6.6 feet) due to protection of benthic species and habitat,[142] though frequently the rationale is to protect against navigational hazards.

Overall, the conditions outlined during NEPA across the 10 completed projects reflect a shared commitment to protection of benthic habitat and species, with many similarities and overarching strategies. However, distinct differences are apparent, including the number of benthic-specific measures per project, the level of detail surrounding the measures, and the voluntary or mandatory nature of the measures. It appears that since the first of these NEPA reviews was completed for Vineyard in 2021, mitigation measures have increased in specificity and detail, with a shift towards stricter measures and environmental compliance, as well as an increase in community engagement through public reporting.

Accompanying the lease is an easement to shore. BOEM publishes easement details in the approved COP, sometimes as options under the Project Design Envelope to allow for the project proponent to have more than one option to consider in the next steps of the process.

E. Path One: Procurement

A state may establish—legislatively or administratively—a target amount of offshore wind energy to procure and a schedule for achieving the target. Sometimes, these laws or executive actions provide qualitative direction to state agencies guiding the solicitation, to include things like requirements for bidders to demonstrate initial plans to protect the marine environment.

Once a state establishes a target and schedule, the process generally continues with a solicitation phase of the procurement. During the solicitation phase, the state issues a request for proposals (RFP), containing eligibility criteria based on state law and state-granted discretion. The eligibility criteria set the rules for submitting a proposal, what information a proposal proponent must provide, and how state agencies will evaluate the proposals. New York[143] and New Jersey[144] have used the procurement process to include requirements for contributions to wildlife and fisheries research and mitigation funds (between $5,000-$10,000/megawatt from the selected project) within their RFPs, resulting in net-neutral gains for wildlife. Notably, the 2023 Connecticut[145] RFP requires contributions towards net-positive gains. Ultimately, this money could be used to address benthic impacts or benthic research as a requirement of procurement.

Project proponents must show proof of a granted BOEM lease during this process. The state then selects which proposals to pursue, and the proposal proponent signs a contract and a Power Purchase Agreement (PPA) or an Offshore Renewable Energy Credit (OREC) with the state, whereby the state agrees to buy the power from the project.

The state public utility commission leads the next step of the process, authorizing the electricity rates for regulated utilities in the state and allowing for cost recovery through rates charged to the utilities' customers. The state public utility commission evaluates the procurement contracts to ensure the contract complies with state law and policies and the commission's mandate, since offshore wind procurements can be used by electric distribution utilities to meet state renewable energy mandates or goals.

Usually in parallel to these processes, the lessee negotiates with state entities and utilities to determine the appropriate onshore point of interconnection. Simultaneously, the developer works with the ISO/RTO to conduct a grid connection study and determine what upgrades the developer must pay for to interconnect the proposed project.

F. Path Two

Under the second path (OCSLA Section 585.300), a developer may apply for a right-of-way (ROW) that authorizes the ROW holder to install only the transmission cables from a renewable energy project. This is a competitive process. Only one project—the Sea2shore: The Renewable Link, which connects the Block Island wind farm to the mainland of Rhode Island—has used this process.[146] In that instance, BOEM determined there was no competitive interest.[147]

Under the second path, BOEM must still apply a NEPA assessment to the proposed project and adhere to its responsibilities under the CZMA. These assessment opportunities allow regulators to assess impacts to benthic resources and habitats and require mitigation measures. Further mitigation measures are codified in the General Activities Plan (GAP) and affirmed in the final right of way grant.

The 2023 Connecticut RFP requires contributions towards net-positive gains. Ultimately, this money could be used to address benthic impacts or benthic research as a requirement of procurement.

Tiger shark. Photo: Alex Wright

V. Knowledge Gaps and Recommendations

The environmental risks of leaving oil and gas infrastructure in place are different than those posed by offshore wind infrastructure (particularly, the latter does not pose any risk of leaks).

Collaboration from decision-makers and industry to conduct and share research on environmental impacts of offshore transmission on benthic resources is necessary to resolve outstanding knowledge gaps.

A. Decommissioning

While the decommissioning of offshore wind projects generally includes cable removal in most cases, countries such as the Netherlands have moved to leaving concrete foundations, scour protection, and possible cable protection intact to provide reef habitat.[148] The Dutch government is also investing in a Joint Industry Project (JIP HaSPro) to investigate the possibilities for nature-inclusive design in cable protections.

In the U.S., significant amounts of oil and gas infrastructure has been left in place and abandoned rather than decommissioning for a multitude of reasons, and proponents of a program called Rigs-to-Reefs[149] argue that these structures can enhance marine biodiversity by providing new habitats for a range of marine organisms. This program is controversial, as critics argue that the ecological benefits may be overstated, and that the risks of leaving oil and gas infrastructure pose more environmental risks than benefits, including potential for leaks, restricted access to fishing grounds, and limitations to new development such as offshore wind. Opponents further argue that the creation of artificial reefs is another means for companies to escape responsibility for decommissioning in perpetuity, and according to the Government Accountability Office, 2,700 wells and 500 platforms are overdue for decommissioning in the Gulf of Mexico alone.[150] The environmental risks of leaving oil and gas infrastructure in place are different than those posed by offshore wind infrastructure (particularly, the latter does not pose any risk of leaks). It is still critical to determine if such a Rigs-to-Reefs program is appropriate for the offshore wind industry.

Recently the Bureau of Safety and Environmental Enforcement (BSEE), BOEM's sister agency in the management of offshore energy production, completed a Programmatic Environmental Impact Statement on Decommissioning for oil and gas on the Pacific Outer Continental Shelf.[151] The PEIS includes a suite of mitigation measures to reduce impacts from decommissioning activities,[152] including two measures related to turbidity and sedimentation, seven measures on seafloor disturbance, and four measures on loss of platform-based habitat. It is anticipated that a similar PEIS effort will be conducted by BSEE for decommissioning for offshore wind as well and will also enumerate programmatic avoidance, minimization, and mitigation measures. As of now, however, there do not appear to be decommissioning mitigation measures articulated for projects.

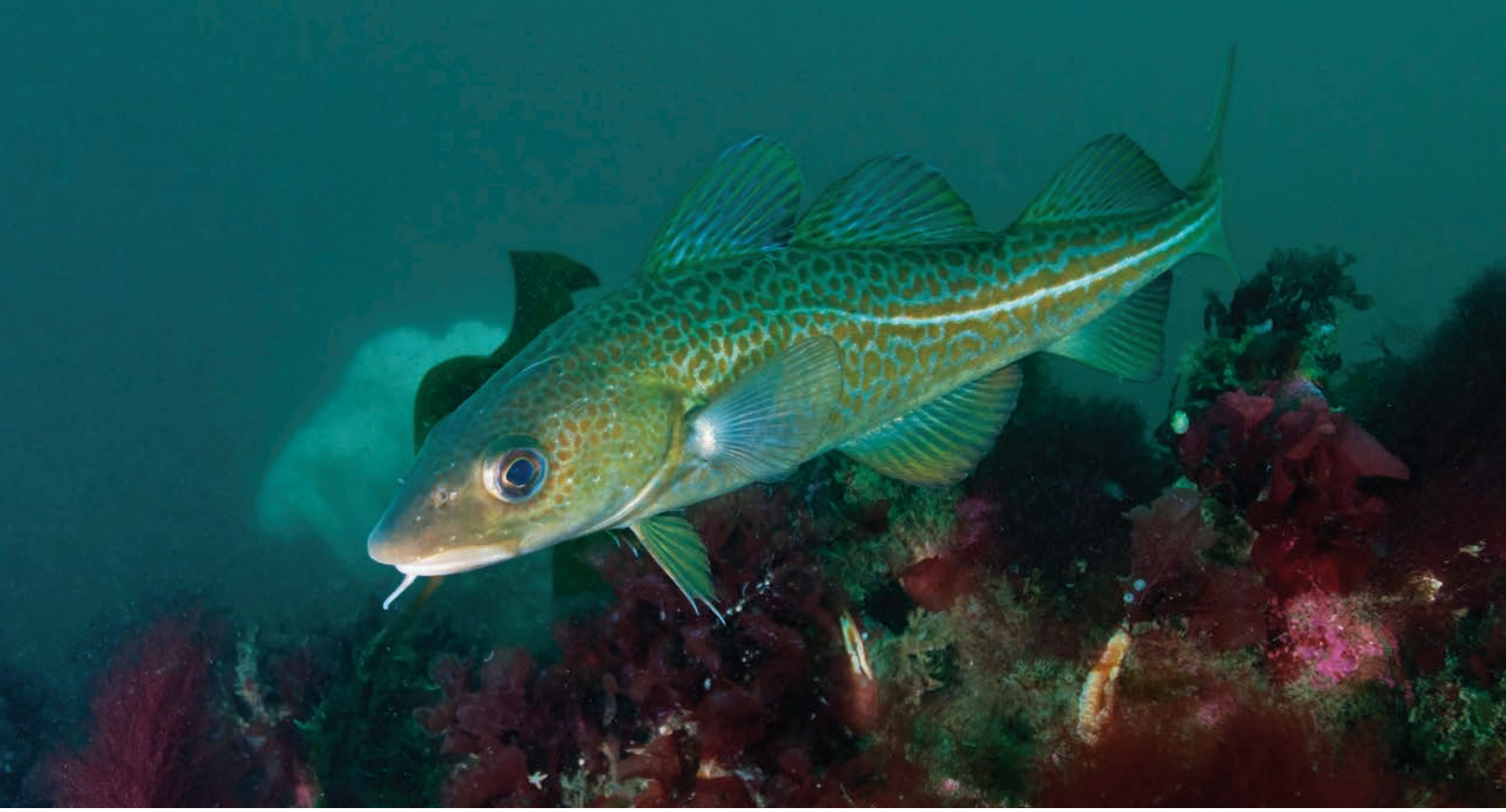
B. Monitoring and Research

Long-term and multi-species monitoring and data collection programs are essential for understanding and managing the impacts of marine industrial activities on benthic habitats and species. Monitoring of benthic habitats and species is highly important before, during, and after cable installation. Scientists at the Pacific Northwest National Laboratory conducted a comprehensive literature review and found a total of 120 different monitoring technologies are used to monitor for impacts from marine energy development, offshore wind, oil and gas sites, and other marine industrial activity. The reviewed technologies fell into 12 broad technology classes (acoustic, corer, dredge, grab, hook and line, net and trawl, plate, remote sensing, scrape samples, trap, visual, and others) to monitor for impacts within six habitat categories (seafloor, sediment, **infauna, epifauna, pelagic,** and **biofouling**). This highlights the wide and diverse way data can be collected and tracked to monitor ecological impacts.[153]

Achieving effective and comprehensive monitoring and research is far more feasible when industry stakeholders, agencies, and environmental organizations work together to prioritize research and streamline data collection efforts. In 2021, the Regional Wildlife Science Collaborative for Offshore Wind (RWSC) was collaboratively formed by offshore wind developers, state and federal agencies, and eNGOs to help coordinate research efforts on wildlife impacts of offshore wind. The RWSC recently developed and published their Integrated Science Plan for Offshore Wind, Wildlife, and Habitat in U.S. Atlantic Waters, which outlines science priorities.[154] The Science Plan, through its

Achieving effective and comprehensive monitoring and research is far more feasible when industry stakeholders, agencies, and environmental organizations work together to prioritize research and streamline data collection efforts.

Horseshoe crab. Photo: Jennifer Idol/Getty Images



Yellow spotted Atlantic ocean cod. Photo: Mathieu Meur

seven expert subcommittees, has highlighted specific research needs for seafloor habitats and ecosystems. As an overview, the identified research needs focus on contextualizing environmental change, determining if offshore wind is a driver of that change, evaluating the effectiveness of monitoring and mitigation measures already deployed, and determining what gaps remain that need to be filled with additional data. Specifically, there should be a focus on distinguishing between shifts in seafloor/benthic community composition due to climate change versus those driven by offshore wind construction and operation. Monitoring efforts should leverage existing seafloor data collected by various entities for multiple purposes, developing consistent regional-scale habitat maps that include crucial variables for megafauna species distribution modeling. Evaluating the physical and ecological effects on benthic communities related to construction and operational activities is essential, including studying the impacts of heat, noise, and sediment disturbance from cable laying.

We strongly recommend that before new efforts for monitoring and research are created, the RWSC's Habitat and Ecosystem Subcommittee should be consulted.

The RWSC has already done extensive work to evaluate existing completed and ongoing research, compile recommendations for consistent data collection, and identify research gaps. We strongly recommend that before new efforts for monitoring and research are created, the RWSC's Habitat and Ecosystem Subcommittee should be consulted.

C. Recommendations

As the National Wildlife Federation engages on the offshore wind permitting process to promote responsible offshore transmission development, we offer the following general recommendations, informed by the available evidence and gaps in knowledge, to improve understanding of benthic impacts, enhance data sharing, explore new technologies, use best practices, and avoid, minimize, and mitigate impacts. Research gaps should be filled with research funded by both federal and state agencies, including BOEM, NOAA, and NSF, as well as by developers.

1. Biodiversity and Habitat Management

- Developers and agencies should adopt a biodiversity net-gain—not just net-neutral—model for monitoring and adaptive management frameworks.[155] Biodiversity net-gain, or net-positive, models strive to not just halt biodiversity loss, but to enhance and restore ocean health. It is important to note that large disagreements around what constitutes biodiversity net-gain still exist within the scientific and regulatory community; further research and strategic clarity is needed to ensure net-gain goals deliver positive outcomes for ocean health. Consistent monitoring and adaptive management frameworks are also crucial to ensure developers and agencies are actually measuring impacts, and adjusting their management based on that feedback.

- Further studies should be conducted to assess impacts of hard-bottomed structures on the seafloor.
- Further studies should be conducted on the impacts of offshore wind on complex seafloor habitats.
- Further studies should be conducted on the interactions between climate change impacts on benthic ecosystems and species, and offshore wind transmission.

2. Data Collection and Sharing

- Regulators should standardize and provide minimum requirements on data-sharing frameworks,[156] such as those recommended by the Regional Wildlife Science Collaborative for Offshore Wind.[157]
- BOEM should require robust pre-construction, construction, and post-construction monitoring plans from developers, which should be transparently shared with the public.
- All data should follow open science principles, and be deposited in a publicly available archive.

3. Innovative Technologies for Monitoring

- Regulators should incentivize the use and testing of lower impact technologies that can provide a comprehensive assessment of the seabed without requiring unnecessary **takes** of species.
- Regulators should collaborate with industry, especially international partners to apply lessons learned, share research from existing projects, and identify opportunities for shared, targeted research.

Manatee. Photo: Elizabeth Baillie

4. Construction Best Practices

- Regulators should require developers to use micrositing during construction to avoid sensitive habitats. Given challenges with identifying broadly applicable construction best practices, it is crucial

that construction practices are tailored to suit local physical conditions, ecological communities, and project goals.
- Regulators should use relevant species breeding information to inform potential seasonal suspension periods on cable installation to protect at risk species during times of highest vulnerability.

5. Environmental Impact Reductions

- More research is needed to assess:
  - The impacts from entrainment of eggs and larvae during cable installation and burial;
  - The impacts of floating offshore wind infrastructure and anchoring on the benthos; and
  - The tradeoffs between selecting monopile foundations (which require piledriving, while having a smaller footprint on the seafloor) versus quieter alternatives such as gravity-based (with a larger footprint on the seafloor).
- Regulators should work with developers to minimize turbidity whenever possible during construction activities.

6. Infrastructure Optimization

- Where possible, regulators must encourage developers to co-locate transmission infrastructure or implement a transmission backbone or mesh configuration.
- Where possible, regulators should encourage investment into alternative cooling water intake systems for the AC to DC converter equipment.

7. EMF Specific-Recommendations

- More research is needed to assess:
  - The impact of EMF from both floating and fixed cables on marine life, particularly species with the highest sensitivities and exposures such as elasmobranchs and benthic invertebrates; and
  - How co-located cables generate EMF.
- BOEM should determine, implement, and require monitoring for clear EMF thresholds.
- Regulators should standardize cable capacity configurations to ensure shared transmission infrastructure is possible and practical.
- Wherever possible, regulators should work with developers to bury cables to reduce and mitigate EMF.
- Regulators should require post-construction studies of EMF on all existing projects and future projects.

8. Regulatory/Policy Recommendations

- BOEM should formalize the Draft Wind Energy Area Comment Period so that the public and experts can provide information and input on concerns related to the benthos during the process of winnowing the selected sites.
- BSEE and BOEM should move expeditiously to conduct the Offshore Wind Decommissioning PEIS to enumerate required and expected BMPs and mitigation measures regarding benthic impacts.
- Grid planners should plan for offshore power grid needs now to accommodate the massive amounts of energy that will be brought online.
- Developers should coordinate with grid planners and grid operators to co-locate and share use of transmission infrastructure.

Green sea turtle. Photo: Santana Navarrette

Conclusion

Developing an offshore power grid is integral to a just, clean energy transition that benefits wildlife and people. Applying the best available science and practicing adaptive management is integral to ensuring that this new, offshore power grid has minimal impacts to wildlife, given the changing climate and the resulting effects on marine ecosystems. This is especially important for benthic resources and habitats, which are the anchors of marine ecosystems. Healthy benthic resources and habitats, much like properly sited transmission lines, are critical for a robust renewable energy transition that supports thriving ecosystems.

Glossary

- **Anthropogenic:** Activity relating to how humans affect nature.
- **Artificial Reef Effect:** Phenomenon where structures such as shipwrecks, oil rigs, offshore infrastructure, and other human-made structures attract species.
- **Biofouling (fouling):** The settlement and growth of marine organisms on human-made structures in marine environments such as offshore wind turbines and cables.
- **Biogenic Structures:** formed by ecosystem engineering species with often rough surfaces.
- Coelomocyte: Circulating cells that are a part of the immune system in echinoderms and perform diverse activities such as nutrient transport and defense.
- **Congested power grid:** A section of the power grid reaches its capacity and cannot carry more electricity
- **Dead end:** When an ecosystem begins to die because there are not enough sustaining populations to allow for a healthy ecosystem.
- **Detritivores**: A marine organism that feeds on dead organic material.
- **Demersal:** A marine organism that lives near the bottom of the sea.
- **Echinoderms:** An invertebrate marine organism characterized by its hard, spiny covering or skin.
- **Elasmobranchs:** Fish with skeletons made of cartilage instead of bone.
- **Epibenthic:** The ecosystem living on the sea bottom between low tide and 100 fathoms.
- **Epifauna:** Benthic organisms (fauna) living upon the substrate or upon other benthic organisms.
- **Infauna:** Benthic organisms (fauna) living in the substrate, particularly in soft sea bottoms.
- **Megafauna:** Large organisms, generally weighing over 50 kilograms.
- **Mooring Line:** Line securing floating offshore wind turbines to the seabed and keeps them in place.
- **Natural seasonality:** The predictable and cyclic variation in the environment that occurs over the course of a year.
- **Pelagic:** The open ocean; pelagic organisms that live near the upper layers of the ocean.
- **Phytoplankton:** Microscopic marine algae.
- **Polychaetes:** A class of marine annelid worms.
- **Primary entanglement:** Becoming directly entangled with a floating offshore wind cable system.
- **Sessile:** An organism that is naturally immobile, and fixed to a substrate.
- **Take:** As defined under the U.S. Endangered Species Act, to "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct."

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[110] When the lessee submits their COP, they are required to also submit a Subseacable Risk Assessment. This document is not available to the public. *See FINAL Information Needed for Issuance of a Notice of Intent (NOI) Under the NEPA for a Construction and Operations Plan (COP)* 12 (Aug. 2023), www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/BOEM%20NOI%20Checklist.pdf#page=12.

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[116] Projects include: New England Wind, Sunrise Wind, Revolution Wind, Vineyard Wind 1, South Fork Wind, Atlantic Shores South, Empire Wind, US Wind, Coastal Virginia Offshore Wind-Commercial, and Ocean Wind.

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