COASTAL AND MARINE HABITATS

What you should know:

- Coastal areas are important habitats for a wide array of ocean and land-based species. While offshore wind development can disturb these habitats during the installation of export power cables, regulations and best practices help to substantially minimize potential disturbances.
- Some species move vertically within the water column (surface to seafloor) at different life stages or in response to changes in ocean temperatures, prey availability, or day/night cycles. Alterations to the ocean environment can hinder the ability of these species to navigate the water column effectively.
- Climate change poses a major threat to coastal and marine ecosystems through rising sea levels and increased ocean acidity. Elevated atmospheric carbon dioxide (CO_2) levels led to ocean acidification, which impairs coral growth and impacts organisms that rely on calcium carbonate to form shells and exoskeletons.
- Studies have found that offshore wind structures may influence local ocean circulation, depending on the surrounding environment and the size and scale of the offshore wind farm (visit Deeper Dive: Ocean Hydrodynamics to read more). These changes have the potential to alter phytoplankton productivity and larvae distribution. However, distinguishing the impacts of offshore wind from those caused by the broader effects of climate change remains challenging.
- Offshore wind infrastructure is subject to review by state agencies under the Coastal Zone Management Act and other regulations. For an overview of federal and state jurisdictional roles in offshore wind development, see this Congressional Research Service summary report.

Habitats Overview

Estuarine and Coastal

Although coastal habitats comprise only 3% of all marine ecosystems in the U.S. (Pew Charitable Trusts, 2022), they are highly biodiverse and provide essential ecosystem services. Key coastal habitats in the U.S. include rocky shorelines, wetlands (salt marshes and mangrove forests), estuaries, seagrass meadows, kelp forests, oyster reefs, and coral reefs. These diverse habitats support a wide array of species, including terrestrial and marine invertebrates, fishes, marine and terrestrial mammals, plants, reptiles, amphibians, and birds. Estuarine and coastal ecosystems offer a variety of services, from erosion and pollution control to serving as nursery habitats for a wide range of wildlife (Barbier et al., 2011). For example, seagrass beds along U.S. coastlines are designated as Essential Fish Habitat (EFH) per the National Oceanic and Atmospheric Administration's (NOAA) Fishery Management Plans (NOAA, n.d.-a). The estimated value of the ecosystem services provided by seagrass vary, with some valuations reaching as high as $141,000 per hectare. This includes contributions to commercial and recreation fisheries, tourism, and coastline protection (Dewsbury et al., 2016). A significant portion of this value is attributed to the essential habitats seagrass provides for juvenile, economically-important fish species such as Atlantic cod, pollock, winter flounder, white hake, and red hake.

Seafloor

The seafloor is the ground surface beneath ocean waters. It begins at coastal shorelines and transitions to the shallow continental shelf and slope, extending to the bottom of submarine canyons and trenches (Figure 1). Seafloor habitats, also known as benthic habitats, vary based on depth, substrate type, and the amount of light that reaches them. Coastal zone and continental shelf habitats, such as coral reefs and kelp forests, are typically highly productive and nutrient-rich, supporting a wide diversity of marine life. In contrast, deeper regions of the ocean tend to be nutrient-poor and less biodiverse (Carney, 2005). While gently sloping, soft-bottom habitats are common in deep-sea environments, the ocean floor can also feature rocky outcrops, steep sea mounts, and hydrothermal vents. These complex habitats host a range of marine organisms specially adapted to the conditions of deep, dark benthic zones (Levin & Dayton, 2009). Benthic organisms include species that live on the surface of the seafloor (e.g., coral, algae, seaweed, barnacles, crabs, and sea stars), as well as those that burrow into seafloor sediment or other substrate (e.g., microorganisms, worms, clams, and certain types of crustaceans). Certain fish and invertebrate species are exclusively found in specific benthic habitats (e.g., tube worms at hydrothermal vent sites) and rely on these habitats for feeding, spawning, and protection.

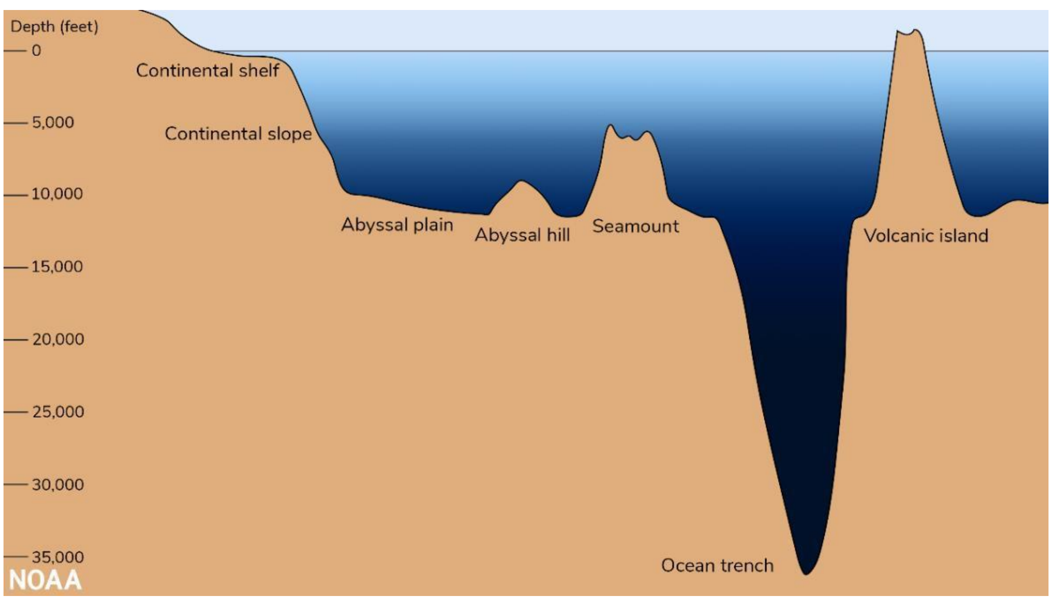

Figure 1. Seafloor features from a depth of 0 to 35,00 feet (NOAA, n.d.-b).

Open Water Column

The water column, which is the mass of water extending from the seafloor to the ocean surface, is also home to a wide variety of marine organisms. Species that live and feed exclusively within the water column are referred to as pelagic species, although some species are considered pelagic only during specific life stages. The pelagic environment is divided into two zones: the neritic zone and the oceanic zone (Figure 2). The neritic zone spans from the ocean surface down to a depth of about 660 feet (Boaden & Seed, 1985). The abundance of light, phytoplankton, and nutrients in this upper region of the water column supports a high diversity of organisms that are vital to ocean ecosystems. In contrast, the deeper oceanic zone, extending from 660 feet to the seafloor, supports lower biodiversity and organism abundance. This is largely because the distribution of species in the water column is highly dependent on light, nutrient availability, temperature, salinity, and pressure, which all vary with depth (Sayre et al., 2017).

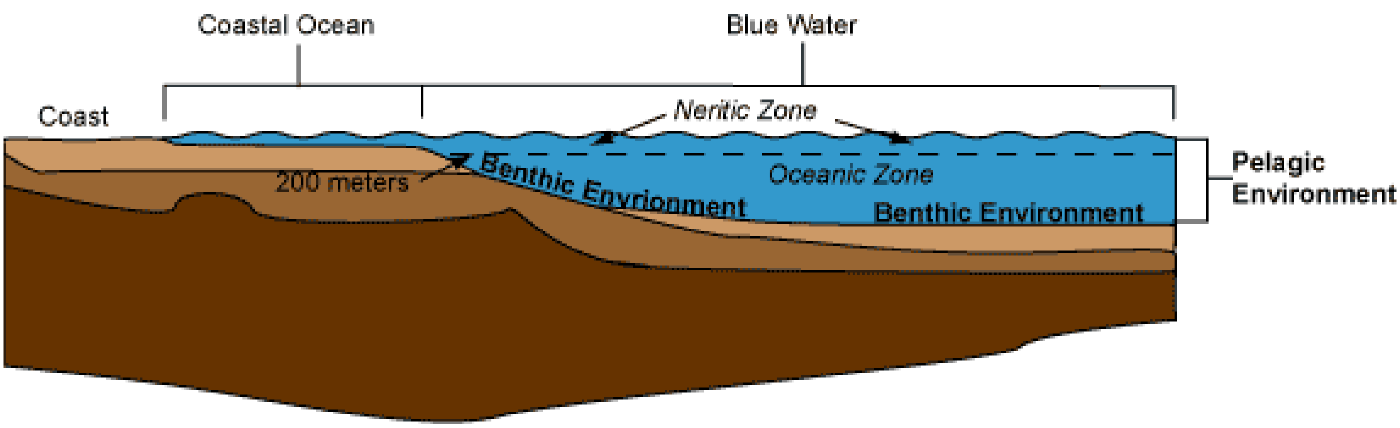

Figure 2. Pelagic and benthic environments in the ocean (Sayre et al., 2017).

Climate Change Effects

Climate change can impact coastal and marine ecosystems through ocean acidification, increased temperatures, and sea-level rise.

Ocean Acidification

Ocean acidification is the process by which atmospheric CO_2 is absorbed into the ocean, resulting in increased acidity. As atmospheric CO_2 levels rise, the ocean absorbs approximately 40% of this excess CO_2, playing an important role in regulating the global climate (Cao et al., 2009; Feely et al., 2004; Sabine et al., 2004).

Reef-building organisms, which construct skeletons or shells from calcium carbonate, are key components of benthic habitats and play a crucial role in supporting the function of these ecosystems. These organisms include corals and bivalves (e.g., mussels, clams, and oysters) and echinoderms (e.g., sea stars and sea urchins). Increasing ocean acidity poses a serious threat to these reef- and shell building organisms, as lower pH levels reduce the availability of calcium carbonate used to build and maintain their skeletons and shells. Furthermore, acidic conditions can erode existing shells and skeletons, resulting in weaker, deformed structures (Figure 3) (Foster et al., 2016). As acidification intensifies, these organisms will face greater challenges, likely leading to significant shifts in the composition of benthic communities (Birchenough et al., 2015).

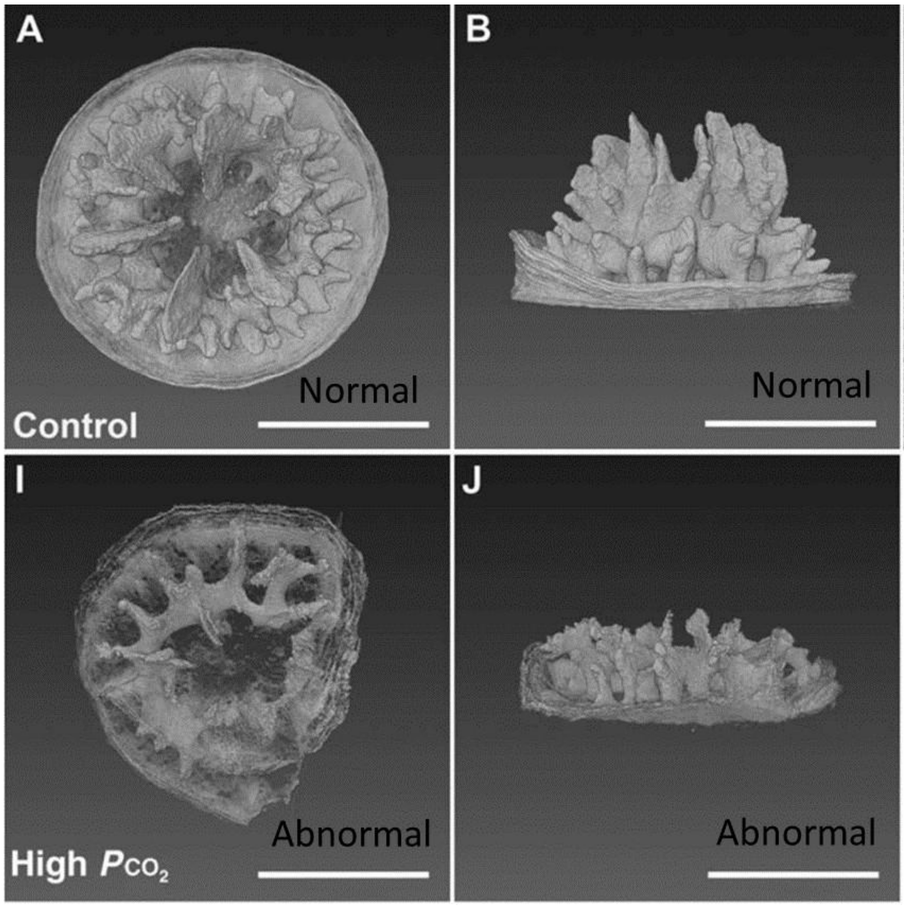

Figure 3. A and B represent x-ray and scanning electron microscope (SEM) images of a normal single polyp juvenile coral skeleton and I and J represent x-ray and SEM images of a single polyp coral skeleton exposed to high levels of carbon dioxide, or acidic conditions (Foster et al., 2016).

Increased Temperatures

Rising ocean temperatures may alter the distribution of benthic species, shift reproductive timing, and ultimately affect the survival of individual species (Birchenough et al., 2015). Reef-building species are among the most vulnerable to warming waters, often experiencing reduced growth, reproduction, and survival rates (Hoppit & Schmidt, 2022). In contrast, fleshy algae species appear to be largely resilient to climate change stressors.

Higher ocean temperatures may also affect pelagic marine organisms. Some species may change their behavior to avoid warmer water, while others may be redistributed by shifting ocean currents (Beaugrand & Kirby, 2018). For example, pelagic zooplankton may move deeper in the water column to escape warmer surface temperatures during the day. Larger organisms that feed on zooplankton may follow, leading to changes in species-specific feeding behaviors and broader disruptions to food web dynamics and ecosystem function (Beaugrand & Kirby, 2018). If temperature changes become too extreme, the added stress placed on pelagic organisms to locate suitable habitat could cause local populations to decline, disappear, or relocate to cooler waters if possible (Morley et al., 2018).

Rising sea surface temperatures may also alter ocean circulation patterns, as warmer conditions influence both the location and volume of freshwater input into the ocean—such as glacial meltwater (Goreau et al., 2005). These changes in circulation can affect both benthic and pelagic habitats by altering regional water temperatures, current patterns, food availability, and the dispersal and settlement of pelagic larvae (Przeslawski et al., 2008). For benthic organisms already under reproductive stress from warmer waters, disrupted larval dispersal patterns may result in significant population declines (Birchenough et al., 2015).

Increased temperatures have also been linked to more intense storms and longer hurricane seasons (Buis, 2020; National Centers for Environmental Information [NCEI], 2021). Shoreline erosion and shifts in rainfall caused by these storms may push coastal habitats to the limit, threatening the resilience and persistence of ecosystems already under stress from ocean acidification and sea-level rise (Zedler, 2010). Increased shoreline erosion may trap coastal habitats between advancing shorelines and fixed urban infrastructure, significantly reducing the future extent of these critical ecosystems (Pontee, 2013).

Sea-level Rise

Sea-level rise will impact coastal habitats, such as wetlands (i.e., salt marshes and mangrove forests), as rising seas force these habitats to migrate landward to keep pace or risk drowning. Salt marshes are essential habitats for both temperate coastal and estuarine species, serving as valuable nurseries for commercially important shellfish and fish and providing diverse habitat for terrestrial species (Teixeira et al., 2014). Salt marsh meadows along rivers and coastal inlets act like sponges, reducing coastal flooding and erosion and trapping sediment suspended in the water, allowing the marsh to grow both vertically and horizontally over time (U.S. Environmental Protection Agency [EPA], 2022). For a marsh to persist, it must be able to rise in elevation by accumulating suspended sediment and building on top of old marsh grasses at a rate that matches local sea-level rise (Raposa et al., 2016). If rising sea levels outpace the vertical marsh growth, standing saltwater left behind after each tide may inhibit the growth of marsh grasses and substantially alter habitat conditions for local species (Gedan et al., 2011).

Offshore Wind Effects

Any infrastructure project, including offshore wind development, can impact the surrounding environment. Affected areas may include estuaries, coastal habitats, the seafloor, and the water column..

Estuarine and Coastal

Offshore wind projects primarily interact with coastal habitats and wildlife through the placement of subsea export cables that transmit power from offshore wind turbines and service platforms back to land. As these power cables cross coastal waters, the effects of cable installation can pose concerns for coastal habitats. Installation activities, including burying cables or laying them atop the seafloor, can negatively impact habitats by temporarily disturbing bottom sediments, altering shoreline erosion patterns near cable landings, or causing direct mortality to coastal species during the cable-laying process. These effects are relatively understudied; however, designs and permits are intended to minimize coastal disturbance to the greatest extent feasible.

Seafloor

The construction of offshore wind farms, including installing turbine foundations, clearing boulders and sand waves, and laying subsea power cables, can impact seafloor habitats and benthic marine organisms. Foundations and power cables are typically installed on soft-bottom sediments. Cable installation in these areas can create local plumes of suspended sediment, which may adversely affect benthic species, particularly during sensitive egg and larval stages (Michel et al., 2013). However, unless a large volume of sediment is redeposited on the seafloor, these impacts on benthic habitats and slow-moving or “sessile” organisms (i.e., permanently attached organisms such as polyps) are generally localized and temporary. The most significant effects usually arise from the removal of seafloor features, like rocky outcrops, that provide habitat for specialized marine organisms; removing these features may cause local populations to relocate.

Although construction and installation can directly impact benthic marine organisms, most benthic habitats recover relatively quickly (Desprez, 2000; Dernie et al., 2003; de Marignac et al., 2009; BOEM, 2020). Seafloor features such as sand waves and depressions are shaped by natural sediment transport processes (Dalyander et al., 2013), allowing these habitats to naturally recover from construction disturbances within a short period.

The introduction of hard substrates by offshore wind turbine foundations and the surrounding scour protection, can enhance local marine ecosystems by creating new habitat, an effect known as the “reef effect.” This phenomenon often results in increased biomass and greater habitat diversity following construction (Degraer et al., 2020, Methratta et al., 2019). At the Block Island Wind Farm, for example, researchers observed minimal direct environmental impacts from construction and noted a significant rise in habitat complexity and biological activity over time. Four years post-construction, the site exhibited a super-abundance of blue mussels colonizing turbine foundations, enriched sediments from organic matter, and growing populations of structure-oriented fish like black sea bass (BOEM, 2020). Similarly, South Fork Wind (SFW), located off the coasts of Block Island and Montauk Point, has shown promising early results through a comprehensive benthic monitoring program led by INSPIRE Environmental and Marine Imaging Technologies. Surveys conducted before, during, and after construction (2022–2024) found no significant disturbance to soft sediments or infaunal communities (i.e., benthic organisms that live within the sediment) and documented robust epifaunal (i.e., benthic organisms that live on the substrate) colonization and increased presence of key marine species near the new structures. These consistent findings from two separate locations reinforce the idea that offshore wind infrastructure can not only coexist with marine ecosystems but may also enhance them. Monitoring at SFW will continue through at least 2029 (INSPIRE Environmental, 2025).

To learn more about the reef effect see Fish and Invertebrates.

Open Water Column

Once offshore wind farms become operational, some may utilize offshore converter stations, which collect power from wind turbines and convert it to high-voltage direct currents (HVDC) for transmission to shore. These converter stations require the use of cooling water intake systems (CWIS), which take in sea water and discharge heated effluent (liquid waste) back into the surrounding environment. Although there are concerns about the potential effects of CWIS on fish and larvae, research has shown that these systems have minimal impact on populations of benthic marine organisms and fish (White et al., 2010; Barnthouse, 2013). Heated water discharged from the system is generally confined to the immediate vicinity of the converter stations. As offshore wind development expands, each project must assess the potential impacts of CWIS and thermal discharge and identify appropriate mitigation measures during the environmental permitting process. For more information on the effects of CWIS in offshore wind operations see Fish and Invertebrates.

Spotlight Question: Can offshore wind impact ocean currents or mixing?

Ocean currents and mixing patterns are complex and occur in both surface waters, typically within the first few hundred meters, and in the deeper waters below. In upper surface waters, currents and mixing are primarily driven by surface wind patterns, which moves the water in large circulating gyres. In contrast, deep ocean currents and mixing are largely influenced by differences in water density, which result from variations in temperature and salinity. Warmer, less dense water tends to rise, while colder, denser water sinks, creating vertical movement.

As climate change continues to cause global air and ocean temperatures to rise, both surface and deep ocean current patterns may shift in strength or direction. These changes could have far-reaching effects, including altered weather patterns, shifts in marine species distributions, and impacts on food production and freshwater availability on land (Toggweiler & Key, 2001; Luo & Rothstein, 2011).

Existing understanding of the effects of offshore wind farms on ocean mixing and currents is primarily based on modeling studies of European wind farms. These studies suggest that ocean flow around individual wind turbines may:

- Increase mixing of the surface ocean layer; and
- Increase the suspension of sediments (Dorrell et al., 2022; Schultze et al., 2020; Vanhellemont & Ruddick, 2014).

At the scale of entire wind farms, studies have suggested that the cumulative effect of multiple turbines may:

- Reduce ocean surface wind speeds (Golbazi et al., 2022);
- Reduce ocean current speeds (Christiansen et al., 2022); and
- Increase ocean mixing in the vicinity of a wind farm (Floeter et al., 2017).

Most of these wind farms are located in the North Sea, a region with depths similar to those of the U.S. East Coast continental shelf. However, it differs significantly in wind patterns and ocean circulation, as the North Sea is largely enclosed.

The National Academies of Sciences, Engineering, and Medicine (NASEM) recently evaluated the potential impacts of offshore wind development on ocean mixing, currents, and regional ecology off the U.S. East Coast, with a focus on the Nantucket Shoals area. The study concluded that the effects of offshore wind farm construction and operation on regional ecosystems will likely be difficult to distinguish, primarily because the region is already undergoing significant oceanographic changes driven by more than two decades of climate change (NASEM, 2023). The NASEM report highlighted the continued need for research to better understand how offshore wind energy projects may influence regional ocean circulation and ecological dynamics.

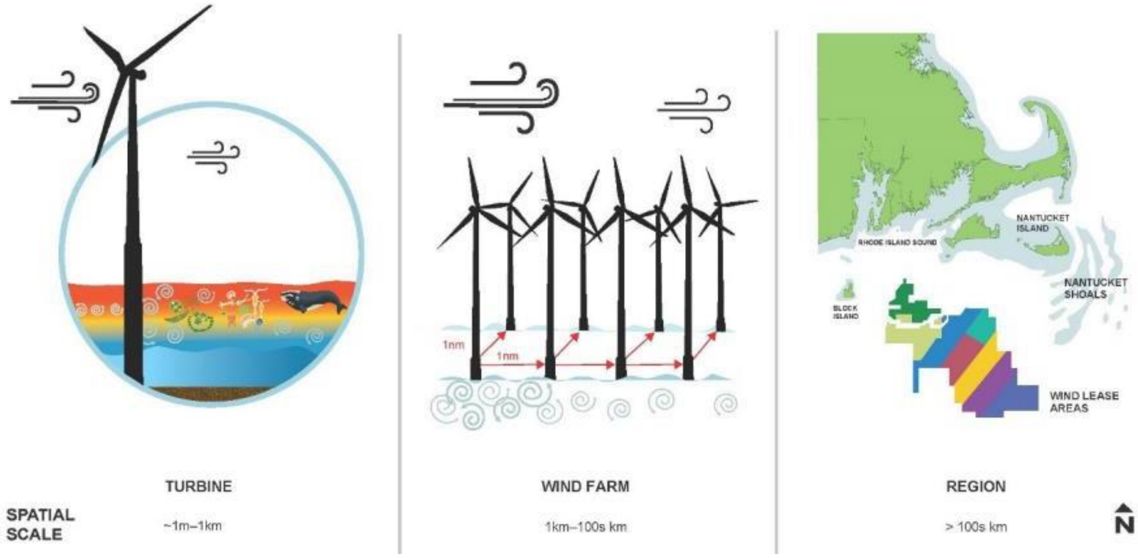

Figure 4. Spatial scales of wind energy development hydrodynamic effects (NASEM, 2023)

Mitigation Innovations

While some effects may be unavoidable, all potential impacts from an offshore wind project are evaluated within a mitigation framework. The aim of this framework is to avoid, minimize, or mitigate adverse effects as much as is feasible. Offshore wind developers use best management practices, modeling, surveying, and monitoring to minimize impacts to coastal habitats during construction, installation, and operation. Seafloor mapping and monitoring surveys are conducted for multiple reasons during the pre-construction, construction, and post-construction phases of an offshore wind farm. Seafloor mapping surveys are used to identify habitat types within an offshore wind project area, including potentially sensitive habitats that should be avoided. Monitoring surveys help assess baseline conditions of the marine environment, evaluate the impacts of construction activities, track habitat recovery, and document the development of new ecosystems around installed structures. This information enables developers to appropriately site offshore wind turbines and export power cable routes, evaluate environmental changes in affected areas, and implement additional measures to mitigate negative impacts.

Estuarine and Coastal

During the planning and installation phases, onshore power cable routes are strategically designed to avoid natural habitats and minimize vegetation removal. For example, most cables are routed through previously developed land, such as beneath existing roadways. To protect wetlands and waterbodies, onshore construction must follow best management practices that control and prevent sediment erosion. In the coastal zone, further impacts to sensitive habitats near landfall sites are typically avoided by using horizontal directional drilling (HDD). HDD involves drilling horizontally beneath sensitive habitats to create safe entry and exit points outside the existing habitat footprint. This technique allows cables to be installed beneath beaches, eelgrass beds, oyster reefs, intertidal zones, and coastal dunes without disturbing the habitat. Additionally, HDD installation typically buries cables up to approximately 100 feet (30 meters) below the seafloor—well beneath the oxygen-rich (aerobic) sediment layer where most benthic infauna reside. This depth significantly reduces marine organisms' exposure to electromagnetic fields (EMFs). To read more on EMFs, visit Deeper Dive: Electromagnetic Fields.

Seafloor

Fisheries and benthic habitat monitoring surveys are conducted to assess baseline conditions of the marine environment prior to the installation of offshore wind turbines and subsea power cables. These data are used to monitor environmental recovery following project installation and to inform the selection of turbine locations and power cable routes. Offshore wind developers aim to site turbines and cables in soft sediments, such as sand or mud, whenever possible, as these habitats tend to recover more quickly after disturbance.

When interaction with complex habitats (e.g., hard seafloors, boulder fields, or reefs) is unavoidable, turbines and cables may be micro-sited and carefully positioned to avoid direct impacts. If the project cannot be rerouted, boulders may be removed and relocated to similar habitat nearby to promote recolonization. Further, emerging technologies like ECOncrete ECO Mats, the Reef Ball Foundation Layer Cake, and the Ecocean Biohut® are being used to promote reef growth, act as shelter for benthic organisms, and provide ecosystem support for specific species. For more information on habitat mitigation innovations see Fish and Invertebrates. To explore current and emerging mitigation technologies used in offshore wind farms, visit the Wind Energy Monitoring and Mitigation Technologies Tool | Tethys (pnnl.gov).

Open Water Column

Construction activities can suspend sand, mud, and silt in the surrounding waters, creating a condition known as turbidity. Modeling conducted prior to construction helps developers assess the potential environmental impacts of construction-related turbidity and sediment suspension. To minimize these effects, developers may use HDD at coastal landfall sites, where the subsea export cable comes ashore. HDD is expected to suspend sediments at levels comparable to natural baseline conditions.

One option to further reduce the cumulative environmental impacts of offshore subsea power cables is to implement a shared offshore transmission system. Such a system efficiently supports the large-scale and/or regional buildout of offshore wind farms while decreasing the overall number of cable systems and installations required. Notably, it also reduces the number of landfall locations along the coast. Several shared transmission projects have been proposed for offshore wind development on the East Coast (National Renewable Energy Lab [NREL] & Pacific Northwest National Laboratory [PNNL], 2024).

References

- Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. Ecological Monographs, 81(2), 169-193.
- Barnthouse, L.W. (2013). Impacts of entrainment and impingement on fish populations: A review of the scientific evidence. Environmental Science & Policy 31:149–156.
- Beaugrand, G., & R.R. Kirby. (2018). How do marine pelagic species respond to climate change? Theories and observations. Annual Review of Marine Science 10(1):169–197.
- Birchenough, S.N.R., H. Reiss, S. Degraer, N. Mieszkowska, Á. Borja, L. Buhl-Mortensen, U. Braeckman, et al. (2015). Climate change and marine benthos: A review of existing research and future directions in the North Atlantic. Wiley Interdisciplinary Reviews: Climate Change 6:203–223.
- Boaden, P.J.S. & R. Seed. (1985). The Neritic Province. In: An Introduction to Coastal Ecology. Tertiary Level Biology. Dordrecht: Springer.
- Buis, A. (2020). How climate change may be impacting storms over earth's tropical oceans. Global climate change: vital signs of the planet. https://climate.nasa.gov/explore/ask-nasa-climate/2956/how- climate-change-may-be-impacting-storms-over-earths-tropical-oceans/
- Bureau of Ocean Energy Management (BOEM). (2020). Benthic and epifaunal monitoring using wind turbine installation and operation at the Block Island Wind Farm, Rhode Island – project report. OCS Study BOEM 2020-044. Final Report by HDR to the U.S. Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs. 263 pp.
- Carney, R. (2005). Zonation of Deep Biota on Continental Margins. In: Oceanography and Marine Biology. Boca Raton, FL: CRC Press.
- Cao, L., Eby, M., Ridgwell, A., Caldeira, K., Archer, D., Ishida, A., Joos, F., et al. (2009). The role of ocean transport in the uptake of anthropogenic CO2. Biogeosciences 6, 375–390.
- Christiansen, N., U. Daewel, B. Djath, & C. Schrum. (2022). Emergence of Large-Scale Hydrodynamic Structures Due to Atmospheric Offshore Wind Farm Wakes. Frontiers in Marine Science 9:818501.
- Dalyander, P.S., B. Butman, C.R. Sherwood, R.P. Signell & J.L. Wilkin. (2013). Characterizing wave- and current- induced bottom shear stress: U.S. middle Atlantic continental shelf. Continental Shelf Research, 52: 73–86.
- Degraer, S., D. Carey, J. Coolen, Z. Hutchison, F. Kerckhof, B. Rumes, & J. Vanaverbeke. (2020). Offshore wind farm artificial reefs affect ecosystem structure and functioning: A synthesis. Oceanography 33:48-57.
- de Marignac, J., J. Hyland, J. Lindholm, A. DeVogelaere, W.L. Balthis, & D. Kline. (2009). A comparison of seafloor habitats and associated benthic fauna in areas open and closed to bottom trawling along the Central California Continental Shelf. Marine Sanctuaries Conservation Series ONMS-09-02. Silver Spring, Maryland: U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), Office of National Marine Sanctuaries.
- Dernie, K.M., M.J. Kaiser, E.A. Richardson, & R.M. Warwick. (2003). Recovery of soft sediment communities and habitats following physical disturbance. Journal of

Experimental Marine Biology and Ecology 285–286:415–434.

- Desprez, M. (2000). Physical and biological impact of marine aggregate extraction along the French coast of the eastern English Channel: Short and long-term post-dredging restoration. ICES Journal of Marine Science 57(5):1428–1438.
- Dewsbury, B. M., M. Bhat, & J. W. Fourqurean. (2016). A review of seagrass economic valuations: gaps and progress in valuation approaches. Ecosystem Services, 18, 68-77.
- Dorrell, R.M., C.J. Lloyd, B.J. Lincoln, T.P. Rippeth, J.R. Taylor, C.P. Caulfield, J. Sharples, J.A. Polton, B.D. Scannell, D.M. Greaves, R.A. Hal & J.H. Simpson. (2022). Anthropogenic mixing in seasonally stratified shelf seas by offshore wind farm infrastructure. Frontiers in Marine Science 9:830927.
- Feely, R. A., Sabine, C. L., Lee, K., Berelson, W., Kleypas, J., Fabry, V. J., & Millero, F. J. (2004). Impact of anthropogenic CO2 on the CaCO3 system in the oceans. Science, 305(5682), 362-366.
- Floeter, J., J. E. E. van Beusekom, D. Auch, U. Callies, J. Carpenter, T. Dudeck, S. Eberle, A. Eckhardt, D. Gloe, K. Hänselmann, M. Hufnagl, et al. (2017). Pelagic effects of offshore wind farm foundations in the stratified North Sea. Progress in Oceanography 156:154–173.
- Foster, T., Falter, J. L., McCulloch, M. T., & Clode, P. L. (2016). Ocean acidification causes structural deformities in juvenile coral skeletons. Science advances, 2(2), e1501130.
- Gedan, K.B., Altieri, A.H., & M.D. Bertness. (2011). Uncertain future of New England salt marshes. Marine Ecology Progress Series 434:229-237.
- Golbazi, M., Archer, C. L., & Alessandrini, S. (2022). Surface impacts of large offshore wind farms. Environmental Research Letters, 17(6), 064021.
- Goreau T.J., R.L. Hayes, & D. McAllister. (2005). Regional patterns of sea surface temperature rise: implications for global ocean circulation change and the future of coral reefs and fisheries. World Resource Review 17:350–374.
- Hoppit, G. & D.N. Schmidt. (2022). A regional view of the response to climate change: a meta-analysis of European benthic organisms' responses. Frontiers in Marine Science 9:896157.
- INSPIRE Environmental. (2025). South Fork Wind Benthic Monitoring Program. ArcGIS StoryMaps. https://storymaps.arcgis.com/stories/43138bdb3826449bbc4ce2b3eba49bb0
- Levin, L.A. & P.K. Dayton. (2009). Ecological theory and continental margins: where shallow meets deep. Trends in Ecology & Evolution, 24(11), 606-617.
- Luo, Y. & L. M. Rothstein. (2011). Response of the Pacific Ocean circulation to climate change. Atmosphere-ocean, 49(3), 235-244.
- Methratta, E.T., & W.R. Dardick. (2019). Meta-analysis of finfish abundance at offshore wind farms. Reviews in Fisheries Science & Aquaculture 27:242-260.
- Michel, J., A.C. Bejarano, C.H. Peterson, & C. Voss (2013). Review of Biological and Biophysical Impacts from Dredging and Handling of Offshore Sand. U.S. Department of the Interior, Bureau of Ocean Energy Management, Herndon, Virginia. OCS Study BOEM 2013-0119. 258 pp.

- Morley, J.W., R.L. Selden, R.J. Latour, T.L. Frolicher, R.J. Seagraves, & M.L. Pinsky. (2018). Projecting shifts in thermal habitat for 686 species on the North American continental shelf. PLoS ONE 13(5): e0196127.
- National Academies of Sciences, Engineering, and Medicine (NASEM). (2023). Potential Hydrodynamic Impacts of Offshore Wind Energy on Nantucket Shoals Regional Ecology: An Evaluation from Wind to Whales. Washington, DC: The National Academies Press.
- National Centers for Environmental Information (NCEI). (2021). 2020 North Atlantic hurricane season shatters records: Putting the most active season in recorded history in context. https://www.ncei.noaa.gov/news/2020-north-atlantic-hurricane-season-shatters-records
- National Oceanic and Atmospheric Administration (NOAA). (n.d.-a). Essential fish habitat. https://www.fisheries.noaa.gov/national/habitat-conservation/essential-fish-habitat
- National Oceanic and Atmospheric Administration (NOAA). (n.d.-b). Office of Education resource collections: Ocean floor features. Ocean floor features | National Oceanic and Atmospheric Administration (noaa.gov).
- National Renewable Energy Laboratory (NREL) & Pacific Northwest National Laboratory (PNNL), (2024). Atlantic Offshore Wind Transmission Study. March, 2024. https://www.nrel.gov/docs/fy24osti/88003.pdf
- Pew Charitable Trusts. (2022). America's coastal habitats are beautiful, vital, and worth protecting.
- Pontee, N. (2013). Defining coastal squeeze: a discussion. Ocean & Coastal Management 84, 204- 207.
- Przeslawski, R., S. Ahyong, M. Byrne, G. Worheide, & P. Hutchings. (2008). Beyond corals and fish: the effects of climate change on non-coral benthic invertebrates of tropical reefs. Global Change Biology 14:2773–2795.
- Raposa, K. B., Kutcher, T., Ferguson, W., Ekberg, M. C., Weber, R. L., & Chaffee, C. (2016). A strategy for developing a salt marsh monitoring and assessment program for the State of Rhode Island. Final report to the Rhode Island Department of Environmental Management and the Rhode Island Coastal Resources Management Council. p, 27.
- Sabine, C. L., Feely, R. A., Gruber, N., Key, R. M., Lee, K., Bullister, J. L. et al. (2004). The oceanic sink for anthropogenic CO2. Science, 305(5682), 367-371.
- Schultze, L. K. P., L. M. Merckelbach, J. Horstmann, S. Raasch, & J. R. Carpenter. (2020). Increased mixing and turbulence in the wake of offshore wind farm foundations. Journal of Geophysical Research: Oceans 125(8):e2019JC015858.
- Sayre, R. G., Wright, D. J., Breyer, S. P., Butler, K. A., Van Graafeiland, K., Costello, M. J., Harris, P.T., Goodin, K.L., Guinotte, J.M., Basher, Z., Kavanaugh M.T., Halpin, P.N., Monaco, M.E., Cressie, N., Aniello, P., Frye, C.E., & Stephens, D. (2017). A three-dimensional mapping of the ocean based on environmental data. Oceanography, 30(1): 90-103.
- Teixeira, A., Duarte, B., & I. Caçador. (2014). Salt Marshes and Biodiversity. In: Sabkha Ecosystems. Tasks for Vegetation Science, vol 47. Dordrecht: Springer.
- Toggweiler, J. R., & R. M. Key. (2001). Thermohaline circulation. Encyclopedia of ocean sciences, 6, 2941-2945.
- U.S. Environmental Protection Agency (EPA). (2022). Why are wetlands important? https://www.epa.gov/wetlands/why-are-wetlands-important.

- Vanhellemont, Q. & K. Ruddick. (2014). Turbid wakes associated with offshore wind turbines observed with Landsat 8. Remote Sensing of Environment 145: 105-115.
- White, J.W., K.J. Nickols, L. Clarke, & J.L. Largier. (2010). Larval entrainment in cooling water intakes: spatially explicit models reveal effects on benthic metapopulations and shortcomings of traditional assessments. Canadian Journal of Fisheries and Aquatic Science 67: 2014–2031.
- Zedler, J.B. (2010). How frequent storms affect wetland vegetation: a preview of climate-change impacts. Frontiers in Ecology and the Environment, 8: 540-54