COASTAL AND MARINE HABITATS

What you should know:

- Coastal areas are very important habitats for supporting a wide array of ocean and land-based species, as well as protecting coastlines from the effects of erosion. Offshore wind development can disturb coastal habitats with its related submarine cabling infrastructure, but regulations and best practices can substantially minimize potential disturbance.
- Some species move up and down in the water column (area from water surface to seafloor) at different stages of life or in response to changes in ocean temperatures, prey availability, or day/night cycles. Changes to the ocean environment can alter the movement of species in the water column.
- Climate change poses a major threat to coastal and marine ecosystems through rising sea levels and increased acidity in the ocean. Increased atmospheric carbon dioxide (CO_2) levels cause the oceans to become more acidic, which prevents coral growth and impacts organisms that create calcium carbonate shells and exoskeletons.
- Studies have found that offshore wind structures can cause varying changes to the hydrodynamics of the water column depending on the local environment (visit Deeper Dive: Ocean Hydrodynamics to read more). These changes have the potential to alter the productivity of phytoplankton and the distribution of larvae in the water column. However, it is often difficult to determine whether such changes are caused by offshore wind turbines or by the broader effects of climate change.
- Offshore wind farm infrastructure is located in coastal areas, prompting the review of state agencies via the Coastal Zone Management Act and other regulations. For a summary of the role of federal and state jurisdictions with respect to offshore wind, review this Congressional Research Service summary report.

Habitats Overview

Estuarine and Coastal

Although coastal habitats only make up 3% of all marine ecosystems in the U.S., covering approximately 146,000 square miles (Pew Charitable Trusts, 2022), they are biodiverse and provide essential ecosystem services. The coastal habitats of concern in the U.S. are coastal dunes, rocky shorelines, wetlands (salt marshes and mangrove forests), estuaries, seagrass meadows, kelp forests, oyster reefs, and coral reefs. These diverse habitats are home to a myriad of wildlife groups, including terrestrial and marine invertebrates, fishes, marine and terrestrial mammals, plants, reptiles, amphibians, and birds. Estuarine and coastal ecosystems are responsible for ecosystem services, including erosion control, pollution control, and providing nursery habitats for a wide range of wildlife (Barbier et al., 2011). For example, seagrass beds on both U.S. coasts are defined as Essential Fish Habitat (EFH) per the National Oceanic and Atmospheric Administration's (NOAA) Fishery Management Plans (NOAA, n.d.-a). Valuations of the ecosystem services provided by seagrasses vary, but estimates taking into account their connection to revenue from commercial/recreation fisheries, tourism, and coastline protection have valued seagrass services as high as $140,752 per hectare (Dewsbury et al., 2016). Seagrasses also provide essential habitat for the juvenile life stage of a variety of important fish species, including Atlantic cod, pollock, winter flounder, white hake, and red hake.

Seafloor

The seafloor is the solid surface underlying ocean waters. It begins in shallow coastal zones and transitions to the deeper continental shelf and slope, extending all the way to the bottom of submarine canyons and trenches (Figure 1). Habitat types on the seafloor, also known as benthic habitats, differ based on depth, bottom type, and the amount of light reaching these habitats. Coastal zone and continental shelf habitats, like coral reefs and kelp forests, are usually very productive and nutrient-rich with a high diversity of marine organisms. One reason deeper parts of the ocean and seafloor tend to be less productive and less biodiverse due to lower light penetration. While soft-bottom habitats are a predominant feature in the deeper ocean, there are also rocky outcrops, sea mounts, and hydrothermal vents. These more complex habitats host a variety of marine organisms adapted to deeper, darker benthic zones (NOAA, n.d.-b). Benthic organisms include those that live on top of the seafloor (e.g., coral, algae, seaweed, barnacles, crabs, and sea stars), as well as those that live within the sediment or substrate (e.g., microorganisms, worms, clams, and certain types of crustaceans). Other fish and invertebrate species are closely associated with benthic habitats, meaning they are exclusively found near these seafloor habitats. They use these habitats for feeding, spawning, and/or protection.

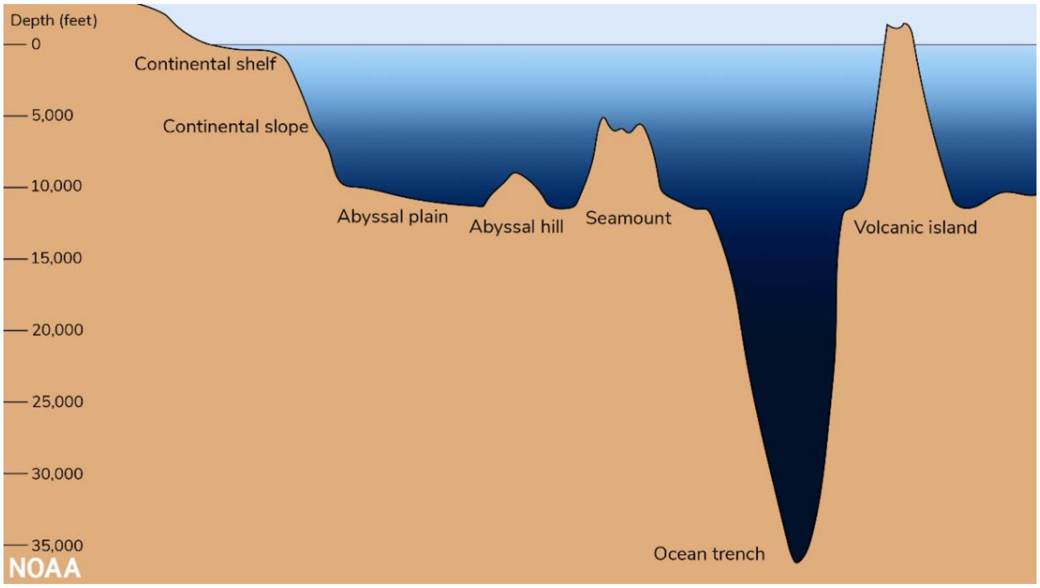

Figure 1. Seafloor features from a depth of 0 to 35,00 feet (NOAA, n.d.-b).

Open Water Column

The water column, which is the mass of water that extends from the seafloor to the ocean surface, is also home to many marine organisms. Species that occupy this water column are referred to as pelagic (some species are pelagic only during specific life stages). The pelagic environment can be further divided into two zones, the neritic zone and the oceanic zone (Figure 2). The neritic zone ranges from the surface of the ocean down to a depth of about 660 feet. The abundance of light, phytoplankton, and nutrients in this upper water column zone support a diverse array of organisms that are essential to ocean ecosystems. In the deeper oceanic zone, which starts at the depth of 660 feet and extends to the ocean floor, the diversity and abundance of marine organisms decreases. This is because species distribution in the water column is highly dependent on light, nutrient availability, temperature, salinity, and pressure, which all vary with depth (Sayre et al., 2017).

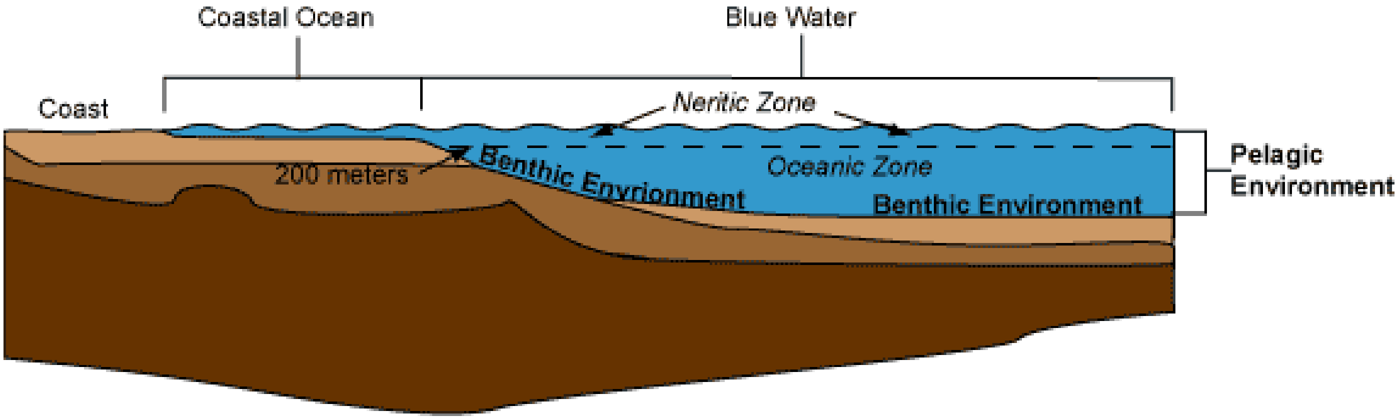

Figure 2. Pelagic and benthic environments in the ocean (Sayre et al., 2017).

Climate Change Effects

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

Ocean Acidification

Ocean acidification is the process in which CO_2 in the atmosphere is absorbed into the ocean; as atmospheric CO_2 levels increase, the oceans become more acidic. In fact, the ocean absorbs about 30% of the CO_2 that is released into the atmosphere (NOAA n.d.-c; Feely et al., 2004; Sabine et al., 2004) and therefore plays a crucial role in mediating the global climate. Reef-building organisms are a major component of benthic habitats, playing a crucial role in supporting ecosystem function. As the oceans become more acidic, organisms that form skeletons or shells out of calcium carbonate, such as corals, bivalves (e.g., mussels, clams, oysters), and echinoderms (e.g., sea stars, sea urchins) will struggle, leading to major changes in the composition of benthic communities (Birchenough et al., 2015). The increasing acidification of the ocean is problematic for organisms that create calcium carbonate shells and skeletons because more acidic water means there is less available calcium carbonate in the water for these organisms to use. A more acidic environment can also make maintaining these calcium carbonate structures more difficult. For example, Foster et al. (2016) found that juvenile corals that were exposed to more acidic waters had less structurally complex, deformed, and weaker skeletons overall (Figure 3).

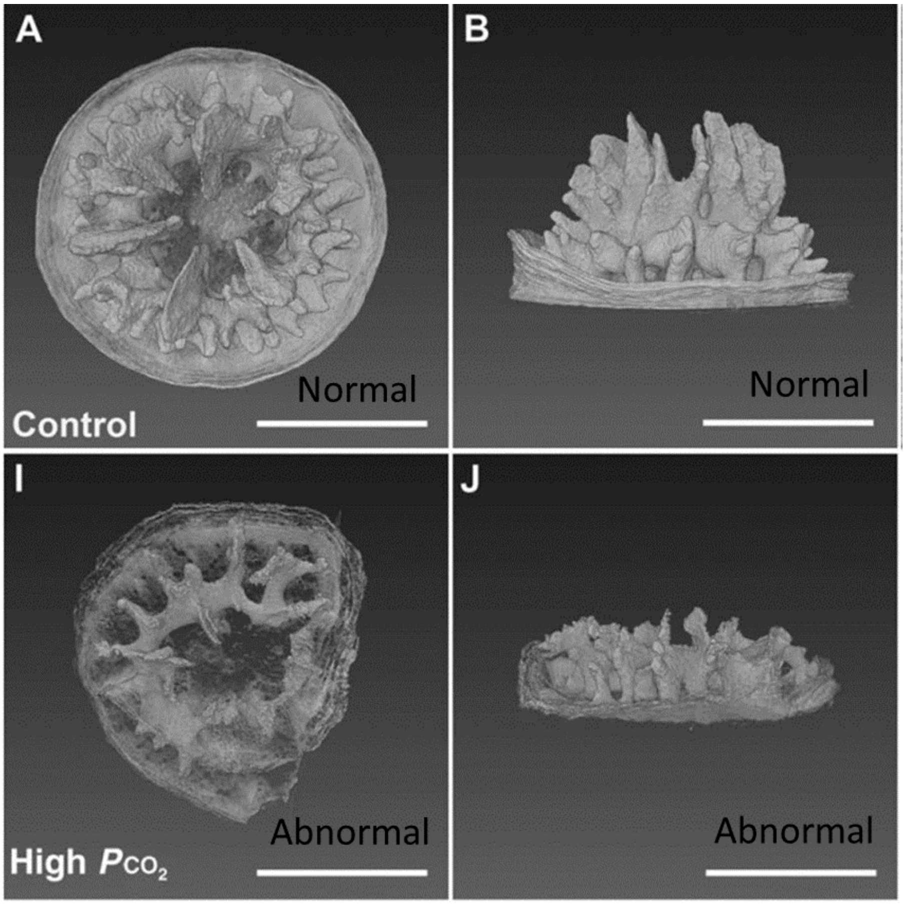

Figure 3. A and B represent x-ray and scanning electron microscope (SEM) images of a normal single polyp juvenile coral skeleton and I and J represent x-ray and SEM images of a single polyp coral skeleton exposed to high levels of carbon dioxide, or acidic conditions (Foster et al., 2016).

Increased Temperatures

Higher ocean temperatures will also affect the distribution of benthic species, shift the timing of reproduction, and may even result in mortality (Birchenough et al., 2015). In a meta-analysis of the responses of European benthic organisms to climate change impacts on a regional scale, Hoppit and Schmidt (2022) found that calcifying organisms (as discussed above) were the most vulnerable to the effects of ocean acidification and warming through decreased growth rates, reproduction, and survival; while fleshy algal species appeared to be resilient to climate change stressors.

In response to warming ocean temperatures, Beaugrand and Kirby (2018) predicted that pelagic marine organisms would demonstrate behavioral or physical adjustments and changes in distribution and abundance. Changes in ocean temperature would lead to shifts in the vertical distributions of species such as pelagic copepods (a type of zooplankton) which may affect the feeding behaviors of larger organisms that depend on them. For example, pelagic copepods may move downward in the water column, further from the surface, to escape temperatures that are too warm. When habitat conditions (e.g., temperature, salinity, and nutrient availability) become unsuitable for a given pelagic species, they will spend energy and time finding more suitable habitat. This could cause populations to diminish, disappear or, if capable, completely relocate. Thermal habitat modeling by Morley et al. (2018) on over 600 marine species predicted that many species would undergo poleward distribution shifts in search of cooler waters as a result of rising global temperatures. At an ecosystem level, climate change impacts in the pelagic environment may lead to changes in biodiversity and ecosystem functioning, changes in food web dynamics, and shifts in the locations of large-scale ecosystem boundaries (Beaugrand & Kirby, 2018).

Ocean circulation patterns may also be altered by rising sea surface temperatures (Goreau et al., 2005). Changes in regional circulation patterns affect both benthic and pelagic habitats through changes in water temperature, current, food availability, and changes in how pelagic larvae disperse and settle into benthic habitats (Przeslawski et al., 2008). Climate change stressors can affect reproductive success directly by altering the physical transport of larvae or indirectly via physiological effects on larval viability and development (Przeslawski et al., 2008). For benthic organisms already experiencing reproductive stress, altered patterns of mass transport could lead to extreme population reductions (Birchenough et al., 2015). Increased temperatures have also been linked to increased storm intensities and prolonged hurricane seasons (Buis, 2020; National Centers for Environmental Information [NCEI], 2021) which can threaten the persistence and resiliency of marine coastal habitats.

Sea-level Rise

Sea-level rise will also impact coastal habitats, especially salt marshes. Salt marshes are essential habitats for temperate coastal and estuarine species alike. They consist of salt marsh grass meadows on the banks of rivers and coastal inlets. These coastal wetlands act like sponges and reduce coastal flooding and erosion while providing valuable nursery habitat for commercially important shellfish and fishes (U.S. Environmental Protection Agency (EPA), 2022). Marsh grass keeps the mucky, fine sediment intact while trapping sediment suspended in the water column, allowing the marsh to grow both vertically and horizontally over time. For a marsh to survive, its surface must be able to rise in elevation at rates comparable to the local sea-level rise (Raposa, et al., 2016). Marsh surfaces can rise primarily through the accumulation of organic and inorganic matter (Raposa et al., 2016); however rising sea levels may outpace the growth of the marsh. When the high tide water level is higher than the top of the marsh, saltwater pools are formed and eventually kill the marsh grass. As the water evaporates, it leaves behind a briny pool. This prevents further growth and alters the habitat for local species, thus leading to the eventual degradation of marsh habitat (NOAA n.d.-d).

Offshore Wind Effects

Any infrastructure project, including the development of offshore wind farms, can have impacts on the immediate environment. Areas of impact can include estuaries and coastal habitats, the seafloor, and the water column.

Estuarine and Coastal

The submarine cables that feed power back to the mainland are the main way that offshore wind projects will interact with and impact coastal habitats and wildlife. As currently designed, each wind farm will have cables that export power from the wind turbines and service platforms to the shore. Depending on the project, landfall can be at one or multiple coastal locations. As cable corridors cross through the coastal waters, installation activities can become a concern. Installation activities can include the development of nearshore cable routes and the burying of the cables at onshore landfall sites. These activities can negatively impact habitats by disturbing the bottom sediment, or by causing direct mortality during cable-laying activities.

Seafloor

Activities during the construction phase of offshore wind farms may also affect the seafloor and associated marine organisms. Some of these activities include the installation of wind turbine foundations, seabed preparation (e.g., sand wave dredging, boulder clearance), and power cable emplacement. These activities can disturb habitats by causing the direct mortality of benthic organisms, converting habitats from soft-bottom to hard-bottom (or vice versa), and/or by causing sediment transport and deposition. Foundation installation typically occurs over soft-bottom substrates. If fish and invertebrates associated with soft-bottom seafloor habitats are unable to avoid the installation activity, they would be subject to potential impacts. Removal of seafloor features that serve as habitat for some fish species could lead to reduced habitat suitability and displacement. Cable installation activities would generate localized plumes of suspended sediments that may negatively affect benthic species, with egg and larval life stages being the most sensitive (Michel et al., 2013). Depending on the levels of sediment redeposition, impacts on benthic habitats and slow-moving or sessile (permanently attached i.e., polyps) benthic organisms are typically localized and temporary.

While direct impacts to benthic marine organisms may occur during the construction and installation phases, the recovery of most benthic habitats and new habitat formation are expected to occur relatively quickly after construction, as documented in several studies (Desprez, 2000; Dernie et al., 2003; de Marignac et al., 2009; HDR, 2020). For example, seafloor features such as sand waves and depressions are dynamically shaped by natural sediment transport processes (Dalyander et al., 2013) and thus, expected to recover from construction disturbances within a short period of time. Based on the monitoring programs at the Block Island Wind Farm, researchers concluded that direct environmental impacts from construction were negligible; however, at four years post-construction, the presence of the wind turbine foundations were found to have a variable localized impact on the benthos (the flora and fauna found on the bottom, or in the bottom sediments, of the seabed). These localized impacts include a super-abundance of blue mussels and other organisms growing on some of the turbine foundations, organic matter enrichment of the sediment immediately surrounding the turbines, and an influx of structure-oriented fish species, such as black sea bass (HDR, 2020). For more on the reef effect see Fish and Invertebrates or Recreational and Commercial Fishing.

Open Water Column

The post-construction effects of offshore wind farms on the water column and associated marine organisms include: impacts from cooling water intake systems (CWIS), the reef effect from added hard substructures, and potential changes in hydrodynamics (due to the presence of new structures). For further discussion on ocean hydrodynamics, refer to the Spotlight Question below.

Water intake at the CWIS of power plants have been found to have minimal effects on populations of benthic marine organisms and fish (White et al., 2010; Barnthouse, 2013) and heated effluent discharge from these systems is generally limited to the immediate vicinity of the offshore converter stations. As offshore wind development increases, each project will need to determine the potential level of impact and respective mitigation measures during the environmental permitting review. For more information on CWIS effects as part of offshore wind farm operations, see Fish and Invertebrates.

The added hard substrates from wind turbine foundations and the rocks placed around the base of the foundations to prevent sand erosion may increase populations of marine organisms attracted to such structures, potentially leading to increased biomass near the turbine foundations. Studies have found increases in the density, biomass, and diversity of benthic species attributed to the presence of offshore wind farm structures (Degraer et al., 2020; Methratta & Dardick, 2019).

Spotlight Question: Can offshore wind impact ocean hydrodynamics?

Ocean hydrodynamics (the scientific study of the motion of liquids) consists of a complex system of currents, occurring both in the surface waters of the first few hundred meters of the ocean and in the deeper waters below. The upper surface of the ocean is characterized by wind driven currents, where ocean water is pushed by moving air masses. Deep ocean circulation is referred to as “thermohaline circulation”, as it is largely dictated by the temperature (“thermos”) and salinity (“haline”) of sea water. Less dense, warmer water flows towards the surface, while denser, colder water sinks. Both current systems are driven by differences in air or water temperature on regional and global scales. As climate change continues to cause global temperatures to rise, these currents may change, which will have repercussions on weather patterns across the planet. Such impacts can lead to changes in species distributions, food production, and water availability (Toggweiler & Key, 2001; Luo & Rothstein, 2011).

Current knowledge on the effects of offshore wind farms on hydrodynamics is primarily based on modeling studies focused on European wind farms. The regional oceanography and wind farm structure geometries of these wind farms differ significantly from the wind energy areas and planned offshore wind developments in the U.S. (NASEM, 2023). In general, hydrodynamic effects can be categorized based on the affected spatial scale and consist of localized turbine effects, wind farm effects, and regional effects (Figure 4) (NASEM, 2023).

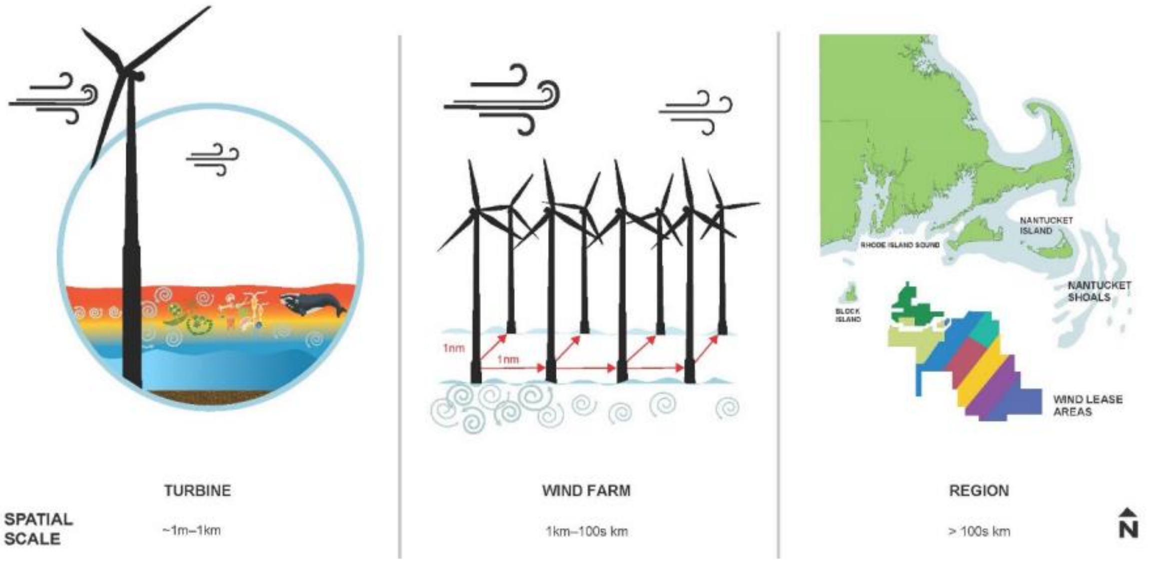

Figure 4. Spatial scales of wind energy development hydrodynamic effects (NASEM, 2023)

Hydrodynamic effects on a turbine scale may include:

- turbulent mixing;
- weakened stratification;
- temperature change;
- and an increase in suspended sediments (Dorrell et al., 2022; Schultze et al., 2020; Vanhellemont & Ruddick, 2014).

On the wind farm scale, the cumulative effect of multiple wind turbines may include:

- ocean surface wind speed reductions (Golbazi et al., 2022);

- ocean current speed reductions (Christiansen et al., 2022); and
- reduced stratification over a region within the vicinity of a wind farm (Floeter et al., 2017).

The National Academies of Sciences, Engineering, and Medicine (NASEM) evaluated potential hydrodynamic impacts on regional ecology from offshore wind developments off the U.S. East Coast (specifically around Nantucket Shoals) and determined that the impacts on ecosystems from the installation and operation of offshore wind farms would be difficult to distinguish from natural variability on a regional scale (NASEM, 2023). This is largely due to major oceanographic changes already occurring on the East Coast from 20+ years of climate change, including warming of surface and bottom temperatures that alter the intensity of seasonal stratification of the water column. The NASEM study emphasizes that more research is still needed to understand the effects of offshore wind energy projects on regional hydrodynamics and ecology. The oceanography in this region is dynamic and constantly evolving, and more complex hydrodynamic models need to be developed and/or validated.

Mitigation Innovations

While some effects may be unavoidable, all potential impacts from an offshore wind project are evaluated within a mitigation framework. The aim is to avoid, minimize, or mitigate adverse effects as much as is feasible. Offshore wind 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 offshore wind farm development. Seafloor and mapping surveys are used to identify habitat types in a project area, including potential sensitive habitats to avoid. Monitoring surveys are conducted to assess the baseline conditions of the marine environment, the impacts of construction activities, monitor the progress of habitat recovery, and document the development of new ecosystems around installed structures. All this information is used by developers to appropriately site offshore wind turbines and power cable routes, as well as to evaluate the state of affected areas and further mitigate negative impacts.

Onshore cable installation is strategically placed to avoid impacting natural habitats and minimize vegetation removal. For example, most onshore cable routes are planned to make use of previously developed land (e.g., burying cables under pre-existing roadways). To protect wetland habitats and waterbodies, onshore construction will be regulated to follow best management practices to control sediment and prevent erosion. Further construction impacts are avoided in potentially sensitive habitats near landfall sites by using horizontal directional drilling (HDD). The use of HDD involves a drill being placed underground in an entry point away from a sensitive habitat, then drilling horizontally underneath the habitat, before emerging on the other side of the habitat at a safe exit point. HDD allows cables to be placed underneath nearshore habitats such as eelgrass beds, oyster reefs, intertidal zones, and coastal dunes without causing any damage. Additionally, average burial depths of cable installation are between three to eight feet (1 to 2.5 m), well below the aerobic sediment layer where most benthic infauna live, substantially minimizing their exposure to electromagnetic fields (EMFs). To read more on EMFs, visit Deeper Dive: Electromagnetic Fields.

Fisheries and benthic habitat monitoring surveys are conducted to assess the baseline conditions of the marine environment prior to the installation of turbines and submarine cables. This data is used to monitor recovery of the environment after project installation, and inform the selection of the turbine locations and the cable route. The route of the export cables through the water is designed to avoid areas of known complex habitat. Complex habitat includes hard bottom, boulder, and reef locations where a large array of marine life live. Offshore wind developers design their projects so the turbines and the cable routes are located in soft bottom habitat, such as sand or mud, whenever possible. These habitats can recover more quickly after a disturbance compared to complex hard bottom habitat. If interactions with complex habitat is necessary, then turbines and cables may be micro-sited and carefully placed in between boulders or other structures. In the event that project infrastructure cannot be rerouted and boulders need to be removed, they may be relocated to similar habitat nearby to promote recolonization.

Construction activities generate sand and sediment suspension in the surrounding waters, known as turbidity. Modeling is conducted before construction to better understand the impacts turbidity and sedimentation will have on the environment. Sediment transportation is modeled so that the area experiencing turbidity is known before construction begins. The use of HDD is also expected to create minimal sedimentation near submerged vegetation, and therefore sedimentation can be expected to be comparable to natural levels near vegetated habitats.

Using a shared transmission system offshore is a potential method to efficiently facilitate the large-scale buildout of offshore wind farms. This approach could reduce the cumulative environmental impacts of offshore wind submarine cables by reducing the overall amount of cabling systems and installations needed in the offshore environment, as well as reducing the number of landfall locations in the coastal environment. There are several shared transmission projects proposed for offshore wind projects on the East Coast (National Renewable Energy Laboratory (NREL) & Pacific Northwest National Laboratory (PNNL, 2024).

Further, emerging technologies like ECOoncrete ECO Mats, the Reef Ball Foundation Layer Cake, and the Witteven + Bos Cod Hotel are being used to promote reef growth, act as shelter for benthic organisms, and/or provide ecosystem support for specific species. For more on these specific mitigation innovations see Fish and Invertebrates. For more on current and emerging mitigation technologies used in offshore wind farms visit Wind Energy Monitoring and Mitigation Technologies Tool | Tethys (pnnl.gov).

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