U.S. OFFSHORE WIND
SYNTHESIS OF ENVIRONMENTAL
EFFECTS RESEARCH

BENTHIC DISTURBANCE FROM OFFSHORE WIND FOUNDATIONS, ANCHORS, AND CABLES

MAIN TAKEAWAYS

- Foundations, anchors, and cables associated with offshore wind (OSW) energy development may alter the benthic environment during and after construction. Potential effects include alteration of habitat that displaces some invertebrate species, creation of new habitat that may increase invertebrate abundance and biodiversity, and physical and chemical changes to sediment structure.

- Most physical effects on benthic habitat are localized to the areas closest to OSW farm infrastructure and not spread throughout the entire wind farm area. Individual wind turbines occupy a small percentage of the total area of a wind farm, though the development of multiple wind farms would create more areas of change across a larger area.

- Benthic disturbance from displacement and suspension of seafloor sediment during construction tends to be temporary and recovery of the physical and biological conditions on the seafloor typically occurs within a few years.

- OSW foundations, anchors, exposed cables, and scour (or erosion) protection can alter the diversity and abundance of benthic organisms throughout the operational life of a wind farm. The components provide new hard substrate on the seafloor and in the water column that will favor some organisms over others, possibly leading to habitat conversion.

Please visit **Tethys** to view the literature reviewed to inform the development of this research brief.

TOPIC DESCRIPTION

All offshore wind (OSW) farms will have some interaction with the seafloor (Figure 1). In the United States, the Atlantic Coast is characterized by nearshore shallow waters, whereas along the steep shelf of the Pacific Coast or the deep basins of the Gulf of Maine, waters are deeper. In shallow waters, turbine foundations are typically installed directly onto or into the seabed and scour protection may be used near the turbine base to limit erosion around the foundation. In deeper waters, floating turbine foundations use mooring lines attached to anchors embedded in the seafloor to keep the floating platform in place. Regardless of how the foundations are installed, OSW farms will connect back to shore with electrical export cables that are buried or laid on top of the seafloor and protected by rocks or concrete mattresses. During construction, operation, and decommissioning of an OSW farm, the foundations, anchors, and cables will alter benthic habitat and organisms.

The understanding of benthic effects relies on research from existing OSW farms in Europe, the U.S. Atlantic Coast, and other human-made infrastructure at sea. Lessons learned from environmental monitoring of other analogous industries that have long been part of the marine environment, such as subsea telecommunications cables and offshore oil and gas platforms, can inform the expected benthic effects from OSW farm development.

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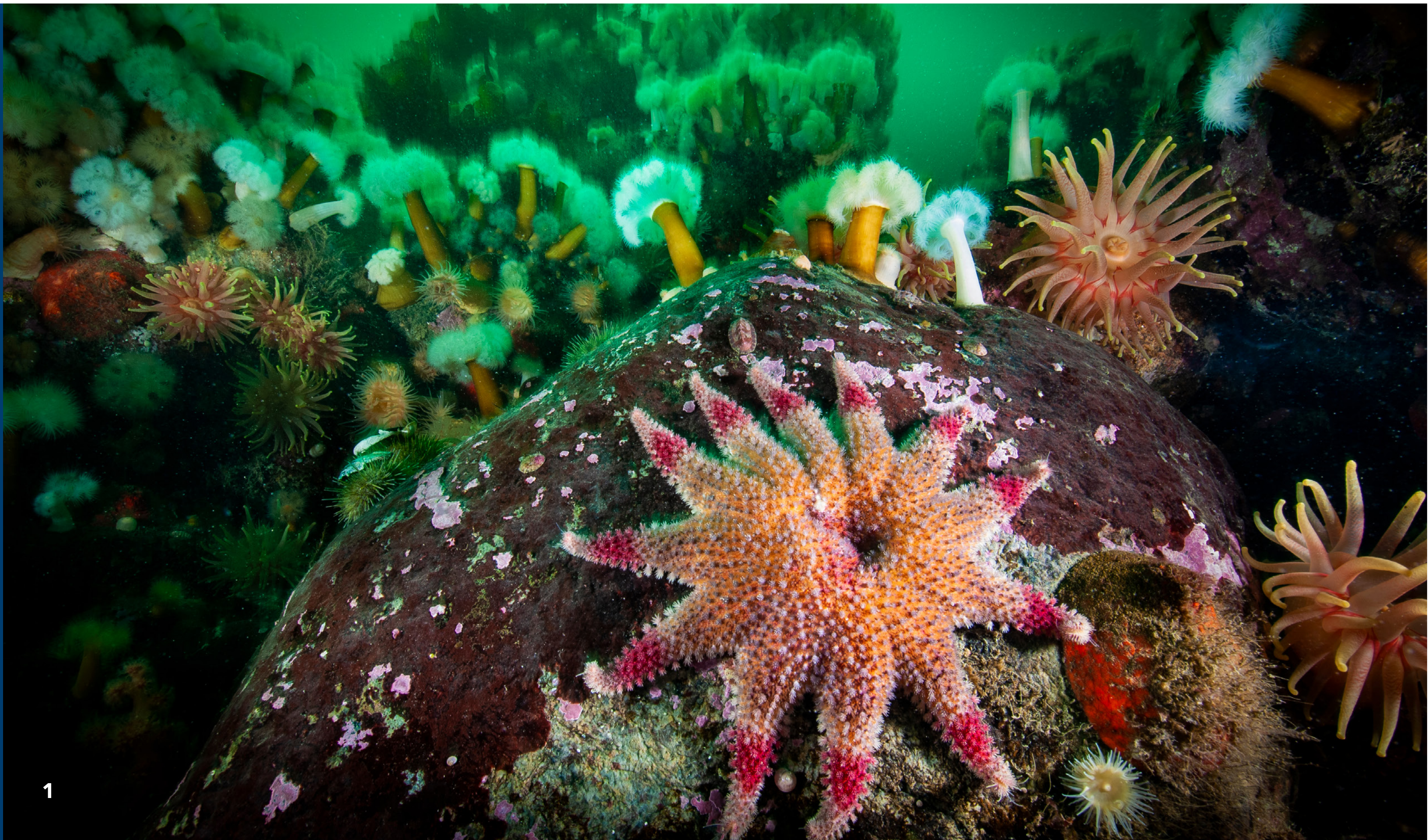

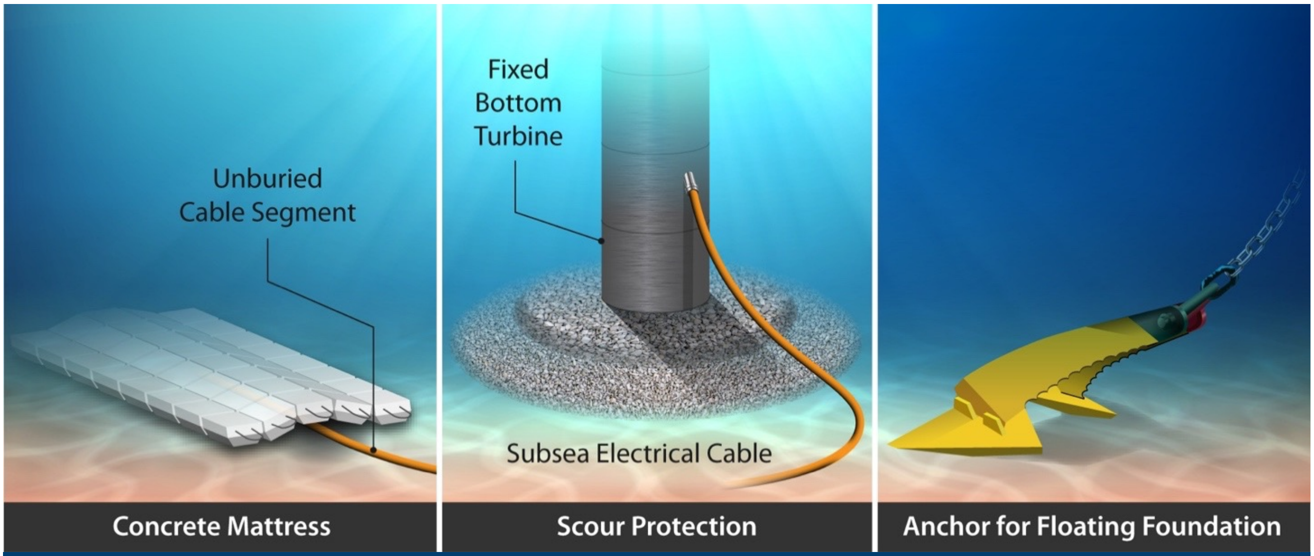

Figure 1. *Components of an offshore wind farm that can interact with the seafloor. Not to scale. Illustration by Alfred Hicks, National Renewable Energy Laboratory.*

Under natural conditions, the benthic environment experiences changes as sediment and nutrients shift following underwater currents and as benthic communities cycle through life stages and seasonal shifts in abundance. Adding OSW components to the seafloor can temporarily or permanently disrupt environmental conditions, causing the benthic community to respond and adapt in different ways. The significance of each disturbance depends on the type of substrate present, permanence of the environmental effect, spatial extent—or footprint—of the disturbance, speed and extent at which the seafloor and organisms recover back to their predisturbance state, and the ability of organisms to adapt to habitat in the disturbed areas. Further, the deployment of multiple OSW farms throughout a region can have cumulative effects that may be further multiplied by other activities.

Benthic Habitat

Benthic habitat is the combination of physical, chemical, and biological conditions that together create a home for a variety of invertebrate organisms that are located on or in the seafloor. Flora and fauna found within a benthic habitat consist of a diverse set of organisms that differ in size, mobility, and other characteristics. Organisms living on top of the seafloor are called **benthic epifauna** and include crabs, mussels, coral, kelp, anemones, sponges, and sea stars. Organisms that burrow themselves into the seafloor are called **benthic infauna** and include clams, worms, and small crustaceans. In the benthic environment, there are both **mobile organisms** that can move throughout their habitat and **sessile organisms** that are permanently attached to a substrate in their adult life stages. Mobile and sessile organisms may be affected differently by OSW development because some mobile creatures can vacate or enter an OSW area to suit their preferences, whereas adult sessile organisms cannot.

The type of substrate in a given area highly influences the composition of the benthic community. Soft sediments such as sand or mud are inhabited by organisms like worms and amphipods that burrow or build tubes below the surface. Rocky substrates provide hard bottom habitat for various benthic epifauna that attach to hard substrate or use the habitat as shelter or nursery grounds.

This research brief discusses the effects of OSW on benthic invertebrate organisms. While many fish live and interact within the benthic environment, the effects on fish ecology are discussed in another ***research brief***.

MAIN RISKS & EFFECTS

Changes to benthic habitats and associated biological communities can be caused directly and/or indirectly by OSW farms during preconstruction surveys, construction, operations and maintenance, and/or decommissioning (see table below). Some of these effects are likely to create changes while other are unlikely to occur or create significant impacts. Each effect is described below.

Overview of Benthic Effects From Offshore Wind Farms During Project Phases

EFFECT	PROJECT PHASE			
	P	C	O&M	D
Primary Considerations				
Loss of Habitat		●	●	●
Conversion of habitat: introduction of hard substrate		●	●	
Introduction of nonnative species		●	●	●
Seabed disturbance and recovery	●	●		●
Water quality, sediment, and turbidity	●	●		●
Other Considerations				
Contaminant release from sediment and offshore components	●	●	●	●
Noise and vibration		●	●	●
Heat emissions from cable			●	
Electromagnetic field emissions from cable			●	

P = Pre-construction surveys

C = Construction

O&M = Operations & Maintenance

D = Decommissioning

Loss of Habitat

Building OSW farms will invariably take up space on the ocean floor that may otherwise be used as habitat by benthic organisms. OSW components remove a small amount of existing habitat on the seafloor, which results in a loss of the habitat. OSW farms also introduce a new, artificial habitat to an area, which can result in a conversion of habitat to a different state (as discussed in the next section).

Fixed-bottom turbine foundations have the largest footprint of any wind farm component on the seafloor. Depending on the foundation design, the interface with the seafloor can be as large as a gravity foundation with a heavy base up to 30 meters in diameter or as small as a jacket foundation that has three cylindrical legs, each with a diameter of a few meters (Figure 2). The area where the foundation interfaces with the seafloor cannot be used in the same way by existing benthic organisms. Additionally, the seafloor underneath a tripod or jacket foundation may be altered because of the presence of the structure above the footprint in the water column.

The seabed immediately surrounding the foundation may be subject to erosion (or scour) in soft bottom locations depending on the strength of the ocean current and type of sediment. Scouring creates depressions and pits on the seafloor that alter habitat and can affect the stability of the foundation structure. When conditions in the wind farm are conducive to erosion, scour protection is installed around the turbine bases or subsea cables to limit the effects. Scour protection includes layers of rocks, mats, or other hard surfaces that improve the stability of the sediment. While scour protection is needed to protect the physical structure of the seafloor, it also increases the extent of altered seafloor, which may be considered a loss and/or gain of habitat depending on conditions.

In deeper waters, where floating OSW turbines would be used, anchors are installed on the seafloor and rest on a small area of potential habitat. Mooring lines made of steel chain, cable, or synthetic rope connect the anchors to the floating turbine platform. Some mooring designs use a taut cable that does not contact the seabed other than through the anchor. However, other designs, such as conventional catenary moorings, drape through the water column and have the potential to interact with the seabed. If anchors are left in place after decommissioning, they will create a permanent alteration of the benthic habitat.

Overall, loss of habitat from an OSW farm only occurs in small areas within the wind farm boundary, not throughout the entire area. While cumulative impacts may extend throughout and across multiple wind farms, the footprint of foundations and scour protection typically cause direct habitat loss of less than 1% of the wind farm area, but some foundation designs, such as gravity foundations, have a larger base that may cover more area on the seafloor especially after considering the footprint of scour protection.

Mobile organisms can potentially move to new locations to avoid effects, but sessile organisms may be crushed or smothered directly at the installation site depending on activities. Siting OSW farms to avoid sensitive or critical habitat (e.g., rocky reefs or other hard bottom habitats) and species of interest (e.g., endangered, threatened, or species with high ecological or economic value) is an important consideration during the early phases of the siting and permitting process.

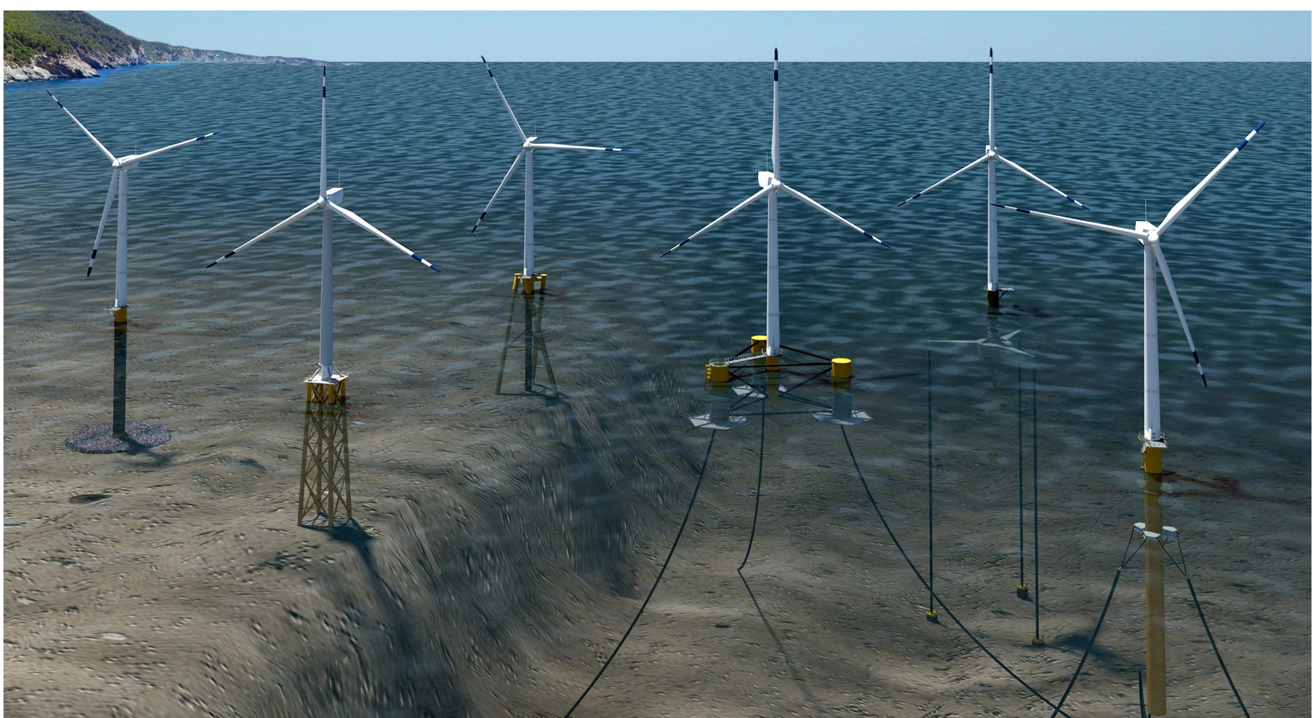

Figure 2. *Some example types of offshore wind turbine foundations. The image shows three fixed bottom foundations and three floating foundations, from right to left: monopile, jacket, twisted jacket, semi-submersible, tension leg platform, and single-point anchor reservoir (SPAR). Several more foundation types are not pictured here. Illustration from Joshua Bauer, National Renewable Energy Laboratory.*

Conversion of Habitat

Introduction of New Hard Substrate

While OSW components cover portions of the seafloor, they also introduce new types of habitat that can benefit some benthic organisms that favor hard bottom habitats. Wind turbine foundations, anchors, and scour protection all create new hard substrate and potential habitat. Benthic communities have been found to rapidly establish on hard substrate, such as turbine foundations and rocky scour protection, after installation. The new substrate also introduces shelter and nursery grounds that increase habitat complexity and attract some species that are considered prey for some foraging animals. Depending on the location, crabs, mussels, barnacles, sea stars, and snails have all been found in high abundance on, near, or at the base of wind turbine foundations. These organisms use the new substrate as either a habitat or feeding ground (Figure 3).

> Wind turbine foundations, anchors, and scour protection can create new hard substrate habitat that is rapidly populated by benthic communities after installation.

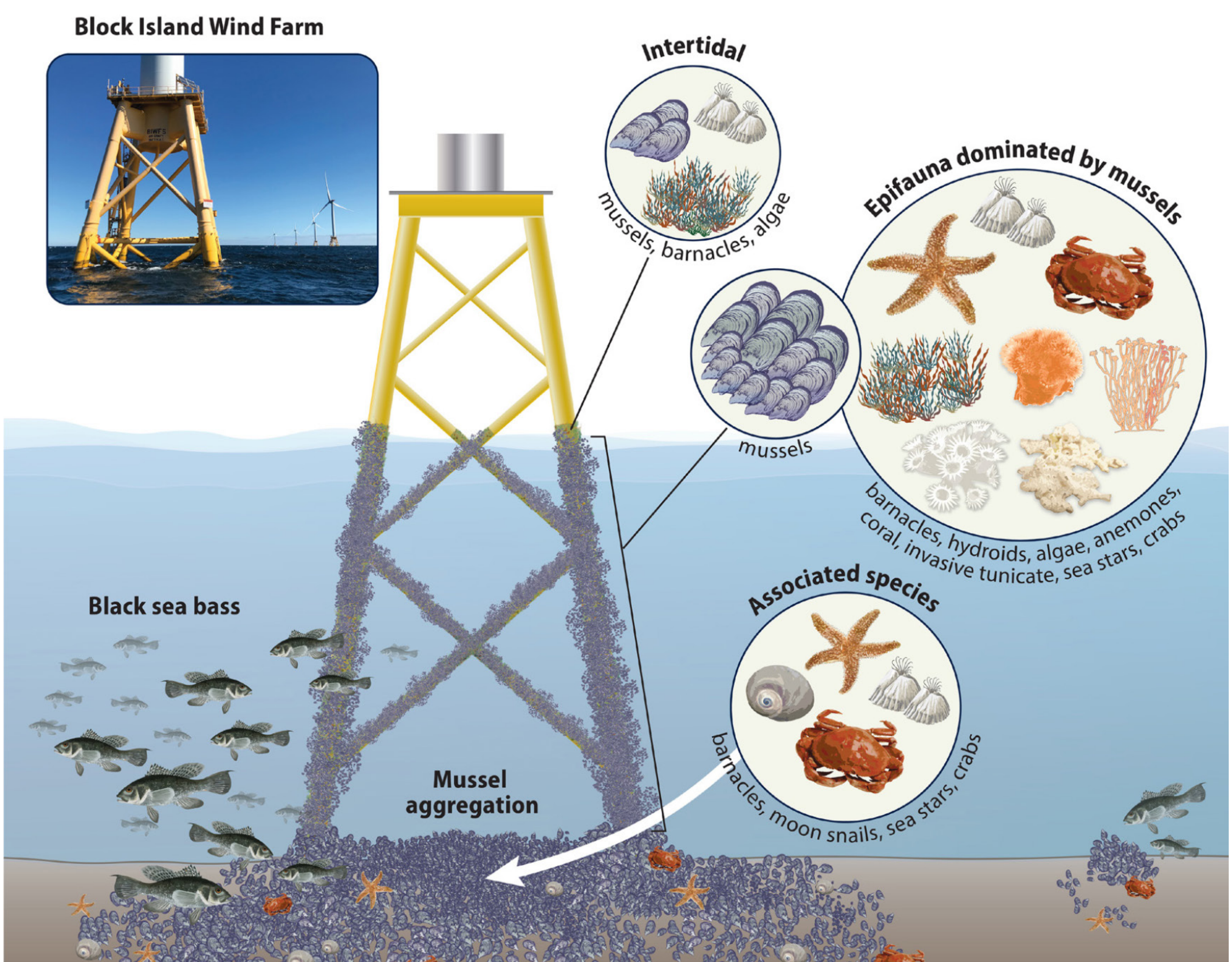

Figure 3. *Various organisms can be attracted to new habitat created by offshore wind farm components. Illustration from **Hutchison et al. (2020).***

The influx of animals around turbine foundations can increase the diversity and abundance of benthic organisms during the operational life of an OSW farm and result in changes to the benthic habitat and associated communities. While there are benefits, introduction of new hard substrate into a predominately soft sediment area also has the potential to displace existing species and associated prey. These changes can affect the ecosystem functions and dynamics of the food web around the turbine components.

The effects of introducing new substrate develop over the lifetime of the wind farm and become more pronounced as the benthic community continues to adapt to the altered conditions. The conditions change over time as new species interact or compete with initial colonizing communities. Vertical foundation structures that support colonizing communities can impart changes to the surrounding seabed and benthic community. For example, blue mussels, which attached to the turbine foundations at Block Island Wind Farm in Rhode Island, fall off as well as disperse their larvae onto the surrounding seabed, leaving dense mussel aggregations extending beyond the foundation footprint. Further, fecal matter from mussels or other epifaunal organisms on the vertical structures becomes deposited in the surrounding sediment and increases the total organic carbon and mineralization rate—or the amount of time for organic matter to decompose into chemicals that can be used by benthic organisms. Following these changes, the sediment surrounding one of the foundations at Block Island has transitioned into a fine grain, organically enriched sediment, which supports a different benthic community than before the installation.

Changes to benthic ecology may be linked to colonizing organisms on the OSW turbine components and organic enrichment of the nearby area. Increases in biomass and organic content and decreases in sediment grain size have been observed within 15 meters of OSW turbines in Europe. Similar changes occur in benthic communities near oil and gas structures. However, these effects are not found at all wind farms. For example, monitoring of two OSW farms in Belgium found changes in organic enrichment and smaller sediment size at only one wind farm. Thus, the changes to benthic habitat are site specific and depend on the local sediment conditions and OSW foundation type. Further, these changes develop over time and current knowledge is based on monitoring that occurs during the first 10 years of a wind farm, not the entire lifetime of a project (up to 20–30 years). Ongoing observations and new studies will help build the understanding of the expected long-term changes to benthic communities in OSW farms.

Scour Protection

Following installation of fixed-bottom wind turbines in soft sediment, scour protection may be installed around the turbine base to limit erosion. When required, the type of scour protection used varies depending on local site conditions but typically involves laying rocks or mats. Installation of scour protection initially causes localized disturbances to

benthic habitats and associated communities by crushing or smothering benthic resources. These areas undergo habitat conversion, as they will not recover back to their natural state (e.g., a bare, sandy environment). This transformation could be considered ecologically beneficial, detrimental, or neutral, depending on the circumstances and response of the local organisms.

Introduction of Nonnative Species

Species not native to the OSW farm area can colonize artificial structures—in particular, hard substrates including foundations or scour protection. OSW turbines and their associated components could serve as stepping stones for nonnative species to expand their range into new areas. Nonnative species can be introduced through operations and maintenance vessels or when bringing turbine components from port facilities to the OSW farm location. Nonnative species have been identified on OSW turbine foundations in the North Sea near the water surface but not on the seafloor. A nonnative species, which was already widespread in the region, was identified on the turbines at Block Island Wind Farm. Studies of subsea cable routes at marine renewable energy facilities indicated very low occurrence of nonnative species, and these species did not provide evidence of out-competing native species or using the infrastructure as stepping stones to occupy other locations. Nonnative species can put additional stress on native species, particularly threatened species, but monitoring results have not shown evidence of nonnative species colonizing OSW structures.

Seabed Disturbance and Recovery

Disturbances to the benthic community occur at various stages during the installation and decommissioning of an OSW project. The extent and overall impact of these disturbances vary depending on activity, local conditions, and overall recovery.

Disturbance

Unlike the long-term effects resulting from habitat changes throughout the operational life of a wind farm, seabed disturbance from construction or decommissioning activities happens quickly and is often followed by a natural recovery of the seabed in soft sediment habitats. Construction of an OSW project includes activities to install foundations, anchors, moorings, and electrical cables, as discussed below.

- **Foundation Installation:** Each foundation type (Figure 2) has its own installation process that influences the extent of sediment disturbance. Piled foundations that are driven directly into the seafloor, such as a monopile, tripod, or jacket foundation, require little to no preparation of the seabed and the foundation can be lowered directly into place. On the other hand, gravity foundations rest on top of the seafloor and require more site preparation to create a level surface for the foundation base, which can generate higher levels of local disturbance.

  Floating foundations that are stabilized with anchors and mooring lines require no preparation of the seabed. The extent and frequency of disturbances depend on the type of anchor and mooring used, but are typically limited to the area surrounding the anchor throughout the lifetime of the project. Catenary moorings can result in periodic disturbances if the mooring chain sweeps across the seafloor under certain oceanographic conditions. Other anchor and mooring systems can temporarily disturb benthic habitat upon installation, but swift recovery of the habitat is expected under most conditions where sediment becomes suspended and redistributed through natural cycles.

- **Cable Installation:** Electrical export cables that connect the OSW farm to the onshore power grid are typically buried and protected within the seabed. Interarray cables that connect individual wind turbines are often buried in fixed-bottom OSW installations. Buried cables are less susceptible to damage from external sources, such as vessel anchors or trawling gear. Ecologically, burial reduces the exposure of organisms to the electromagnetic field emitted by the cables and allows the benthic community to recolonize the area above the cable after installation. However, during cable laying and burial, construction equipment is used to create a trench (via plowing, jetting, horizontal drilling, or other mechanical methods) that directly disturbs the seabed along the cable route. This activity may cause direct mortality of organisms, temporary loss or disruption of habitat, and suspension of sediment into the water column. When passing through rocky areas or other locations where burial is challenging, portions of the cable may be left partially exposed and may require physical protection instead of burial. Exposed cable can be protected through the strategic deployment of rocks, concrete mattresses, or half-shell pipes. These protection methods avoid the physical disturbance associated with burial but introduce new hard substrate to the seafloor (Figure 4).

The actual effects and recovery from the installation of undersea cables depends on a variety of factors, including the method (trenching or physical protection), sediment type, and other location-specific details like water depth, waves, and currents. The footprint of the physical disturbance also varies depending on method, length, and number of cables required to accommodate the power capacity of the wind farm. For instance, the tracks used to mobilize a plow for cable installation can create a 2- to 8-meter wide disturbance on both of the cable. While mobile organisms can move and avoid the area of disturbance, the impact to sessile organisms may result in mortality. Regardless of method, the disturbed area from cabling is small relative to the total area required for an OSW farm.

Water Quality, Sediment, and Turbidity

Installation of OSW turbine components can suspend sediment into the surrounding water column during construction. The resulting sediment plume could affect marine life by smothering or burying benthic sessile organisms, clogging filtration systems for filtering animals, and decreasing visibility for animals such as flatfish that hunt prey by sight. However, several monitoring campaigns during construction of OSW farms in Europe and Atlantic waters off the United States have found that drilling, piling, jetting, and plowing did not create significant sediment plumes in the surrounding area, and in

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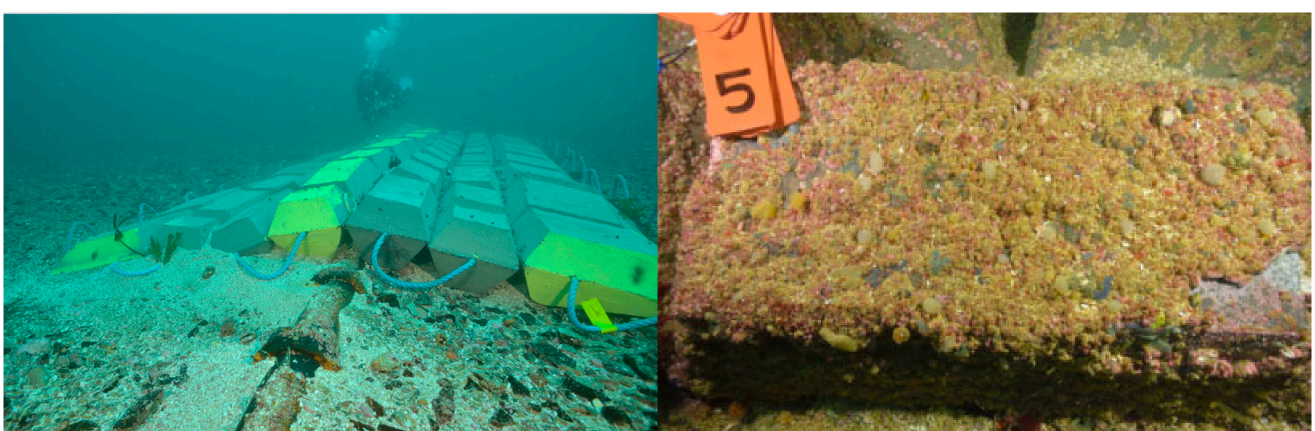

Figure 4. *(Left) Newly installed concrete mattress over partially exposed subsea cable. (Right) Close-up image of concrete mattress that has been colonized by organisms after installation. Images from* ***[Taormina et al. (2020).](#)***

many cases water turbidity did not increase above natural background levels. Increased levels of suspended sediment were found to be short-lived and intermittent, primarily limited to several meters around the construction activity. The effects from sediment dispersion and potential smothering have rarely been observed during OSW turbine construction and are generally considered negligible, because the footprint is limited in size and duration.

> After the initial recovery of the seabed, the conditions may continue to change over time as the benthic community adapts to the offshore wind infrastructure, which could result in habitat conversion.

Seabed Recovery

After physical disturbances during construction or decommissioning activities, sediment on the seabed becomes redistributed throughout the disturbed area and organisms repopulate. Post-construction monitoring campaigns of early soft bottom OSW farms in Europe found that within a few years of disturbance there were no significant differences in seabed topography near OSW turbines when compared to control sites outside the wind farm. After construction of the Block Island Wind Farm, bathymetric surveys found that much of the soft bottom areas that were disturbed from construction and trenching activities had physically recovered within 3 years. These observations show that physical disturbances during installation are typically followed by natural recovery of the benthic habitat as sediment moves back into disturbed areas.

Physical and biological recovery rates vary depending on sediment type, installation method, local oceanographic processes, and types of species present. Shallower waters with soft bottoms are more dynamic environments (e.g., have greater wave energy, current action, and natural variability) and tend to have faster recovery rates following cable or foundation installation. Seabed recovery in soft bottom locations can occur in less than 1 year on the inner continental shelf and within 2 years on the midshelf. At the Block Island Wind Farm, physical recovery of the seabed varied across the

wind turbine array, ranging from a few months to 3 years. The rate of recovery was primarily attributed to hydrodynamic conditions, where the deeper water sites with calmer conditions had a longer recovery period. In deeper waters where floating turbines would be installed, recovery is more complex and possibly slower because there is reduced wave energy, current action, sediment supply, and slow growing organisms such as deep-sea corals.

The initial recovery only reflects sediment redistribution and organisms repopulating the area. After the initial recovery of the seabed, the conditions may continue to change over time as the benthic community adapts to the OSW infrastructure, which could result in habitat conversion.

Decommissioning

Decommissioning activities may involve either full decommissioning (removing the entire OSW structure) or partial decommissioning (leaving parts of the OSW structure in place). In the United States, the government requires all OSW components be removed down to 15 feet below seabed unless authorization is received for partial decommissioning. Removal of components can cause similar effects to those incurred during the construction phase. Namely, sediment disturbance can occur when cables, foundations, anchors, or scour protection are removed. The effects are expected to follow the same recovery pattern as during the postconstruction phase. However, the removal of hard substrate during decommissioning may create another disruption to ecosystem dynamics, because by that time the benthic community will have established a new steady state during the operational phase of the wind farm (Figure 5). Post-decommissioning monitoring campaigns have been used after the end of life of some OSW farms, but long-term changes in benthic habitats were not observed, in part because very few OSW projects have been decommissioned to date.

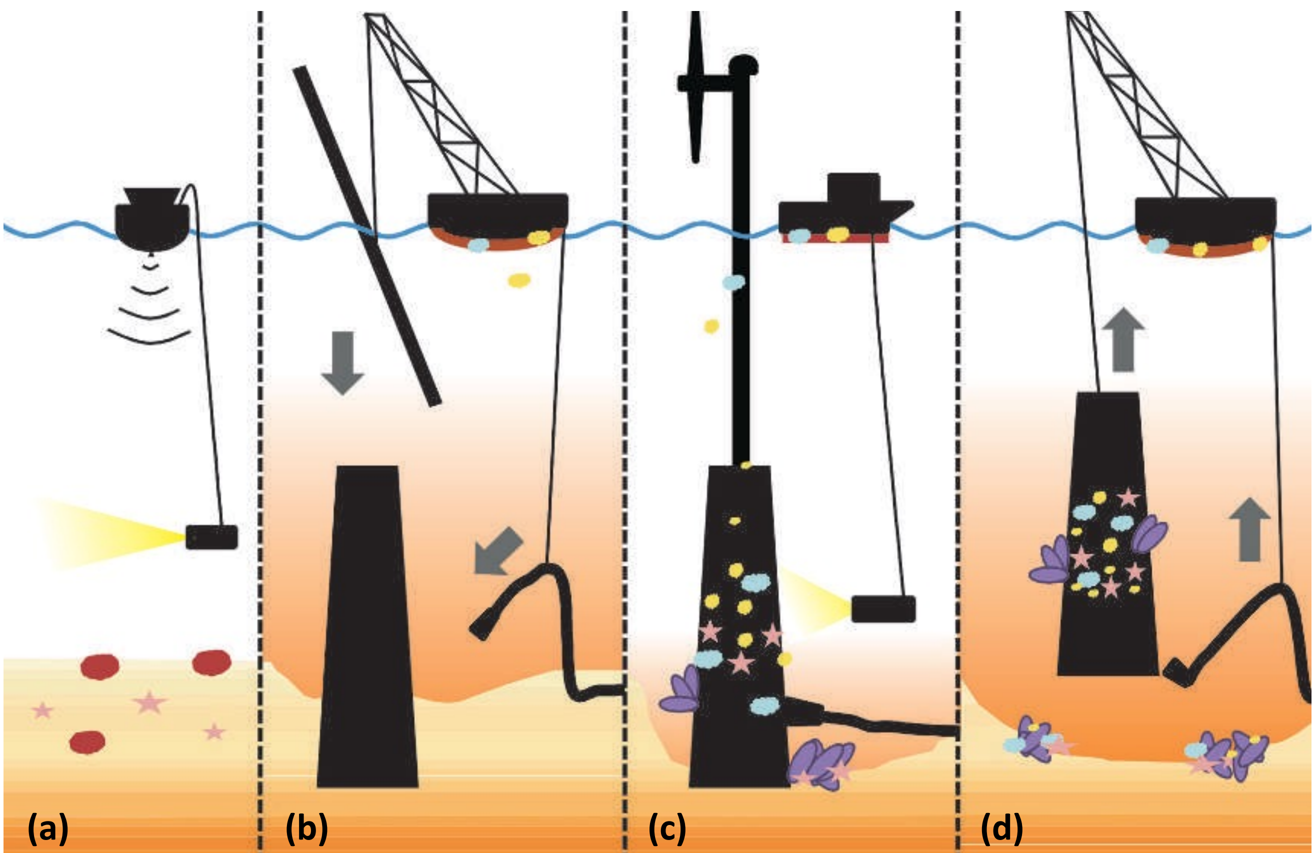

Figure 5. *Lifecycle of an offshore wind project that shows: (a) surveying, (b) installation, (c) operation, and (d) decommissioning. Illustration from **Miller et al. (2013).***

However, as more artificial structures that have been in the water for decades reach end of life, discussions arise about their full or partial decommissioning. While regulations often require full decommissioning, experts argue that the decision should be based on the net benefits that either option provides to the environment. With partial decommissioning, the benthic and reef communities established on and around the artificial structure would continue to provide their beneficial services to the ecosystem. Any negative effects from the artificial structures would also persist. The "rigs-to-reefs" approach encourages this option, where only shallower parts of an artificial structure (<85 feet deep) that would create a threat to navigation are removed, but deeper parts are kept as artificial reefs.

Additional Considerations

Noise

The highest levels of noise at an OSW farm occur during construction and are associated with pile driving for fixed-bottom turbine installation. Environmental assessments generally conclude that mortality of benthic invertebrates caused by noise or vibration during construction occurs in areas that will otherwise be impacted with temporary disturbance to the seabed. For instance, in areas where benthic organisms are vulnerable to noise from foundation installation, they are also likely to be impacted by the physical installation. Noise produced during operation of the wind farm is expected to be lower than during construction; however, some benthic organisms have shown behavioral response to continuous noise emissions that could lead to changes in benthic ecological functions.

Emissions From Cable

During the operation of an OSW project, the power flowing through interarray and export cables generates heat and produces electromagnetic fields. (Electromagnetic fields are covered in a separate ***research brief***.) When cables are unburied, heat dissipates into the flowing water surrounding a cable. By contrast, when cables are buried, heat emitted from a buried cable can increase the temperature of the surrounding seabed (by 0.15–2.5°C) and seawater (by a negligible amount). Benthic infauna, which typically inhabit the top 10 centimeters of the seabed, are outside the volume of sediment affected by significant temperature changes from cables that are generally buried below 1–3 meters of sediment. Temperature changes resulting from power cable heat emissions are within the range of natural temperature variations and, although there are limited studies of local effects of small temperature changes on benthic infauna, heat emissions are expected to have an insignificant effect on benthic organisms because of the low temperature change and limited spatial extent affected.

Contaminant Release from Sediment and Offshore Components

If OSW turbines are not properly sited, resuspending contaminated sediment during construction could introduce undesired particles (such as toxins or metals) into the food chain. Contamination usually occurs near current or former industrial sites, sites with agricultural runoff, or sites around natural oil seeps such as off the coast of Southern California. Careful planning and site assessment for both the wind farm and cable route(s) should make sure that contaminated locations are avoided.

Additionally, OSW turbines use corrosion protection (anodes), often made from aluminum-zinc-indium alloys or other metals, that are slowly released into the ocean throughout the lifetime of the project. Some of the metals (aluminum and indium) can accumulate in crustaceans, potentially creating a pathway for contamination in the trophic web.

MONITORING & MITIGATION METHODOLOGIES

Measuring changes to the benthic habitat and associated community before and after construction, throughout operation, and after decommissioning of an OSW farm provides information for understanding the environmental effects throughout the lifecycle of a specific project. Monitoring campaigns are typically designed to gather physical and biological baseline information before construction and monitor changes in the years following installation and decommissioning. The duration of monitoring campaigns and frequency of surveys should depend on the natural variability of the benthic community. For example, locations with soft sediment and strong current may need multiple years of monitoring to develop a baseline assessment and provide an understanding of natural variations.

As part of the environmental review process for OSW farms in the United States, the Bureau of Ocean Energy Management (BOEM) requires the developer to complete benthic habitat surveys as part of site characterization. This preconstruction survey is used to establish baseline conditions, characterize the benthic communities, and locate different seafloor substrate types. BOEM and other agencies review the methods of the survey to confirm that the approach collects sufficient information about the physical and biological components of the seafloor. Based on the survey conditions, the developer is required to describe all measures that will be taken to minimize or eliminate potential effects to benthic resources. The site characterization survey results are used to support turbine siting decisions that minimize impact to benthic habitat and develop a detailed plan for benthic monitoring during operation of the OSW farm that is proposed during the project's environmental review period.

Benthic monitoring methods at OSW farms include collecting samples and remote sensing data to document environmental conditions. Data are typically gathered at several distances away from OSW farm components and often include control locations outside of the wind farm for comparison. Observations from control sites help determine if changes are caused by natural variation or the presence of an OSW farm. Some monitoring techniques are described below.

- Seabed disturbance and recovery can be monitored using high-resolution acoustic sonar surveys (such as multibeam or side-scan sonar) that identify small changes in depth and surface characteristics of the seafloor.
- During construction, water quality samples and other techniques such as optical sensors are used to identify sediment plumes and suspended solids.
- For soft substrates, biological samples can be obtained from bottom grab samples or cores to assess benthic infauna community structure, including species composition, abundance, and diversity. Bottom trawls can also be used to obtain epifaunal samples from soft sediments.
- Sediment samples can be obtained from grab samples or cores to assess particle size distribution, total organic content, and contaminant concentrations.
- Video and photographic surveys can be used to characterize the habitat and identify organisms. Imaging surveys can also be used to monitor changes over larger spatial scales, provide a more holistic view of the study area, and verify measurements from sonar surveys.

Reducing environmental impacts to benthic habitats and associated communities can be accomplished through careful siting and selection of appropriate construction methods. Siting wind turbines, anchors, and cables to avoid areas with sensitive benthic habitats and/or species is an effective approach to reducing risk. Construction activities can be timed to avoid seasons with sensitive biological processes such as spawning or migration. Construction methods that limit benthic effects should be chosen to the extent possible. For example, a cable route can be trenched using jet plowing, which suspends less sediment than other methods, and cables can be buried at the landfall location to go underneath sensitive intertidal habitat. When scour protection is needed, nature-inclusive designs can be considered to align with suitable habitat for native species.

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KNOWLEDGE GAPS & RESEARCH NEEDS

As early OSW farm projects age, monitoring campaigns should continue to measure the changes in benthic habitat and biological community characteristics, including diversity, abundance, and seasonal uses. OSW farms provide an opportunity to learn how benthic ecosystems react to changes in their environment while also improving the understanding of direct effects between OSW farms and benthic communities. Recent workshops and synthesis activities have identified research gaps about benthic disturbances from OSW farms. Some examples of research topics that can further the understanding of how OSW farms interact with the benthos include:

- How are population dynamics and community structure affected throughout the lifecycle of an OSW farm?
- Are energy pathways and trophic interactions altered by the presence of OSW farm development?
- What is the net effect of new hard substrate provided by OSW structures for benthic communities in both soft and rocky habitats?
- How is this new habitat used by larval stages of local species and potentially invasive, nonnative species?

These research questions should be considered in the design of future monitoring and assessments. Emphasizing hypothesis-driven research can improve the understanding of benthic interactions with OSW farms.

For more information on the literature reviewed to develop this Research Brief, visit: [Tethys]

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