SEER

U.S. OFFSHORE WIND
SYNTHESIS OF ENVIRONMENTAL
EFFECTS RESEARCH

INTRODUCTION OF NEW OFFSHORE WIND FARM STRUCTURES: EFFECTS ON FISH ECOLOGY

MAIN TAKEAWAYS

- The placement of new structures during offshore wind (OSW) farm construction can temporarily or permanently alter the habitat directly beneath and in the vicinity of fixed-bottom turbine foundations, depending on the foundation type, materials used, and sediment type.
- Artificial reef effects have been documented at OSW farms based on the observed attraction of certain fish and invertebrate species to the turbine structures which provide a combination of hard vertical and horizontal substrates.
- Floating OSW farms are still a relatively nascent technology and less is known about their potential effects on fish and shellfish. Based on the technology type, they may have less of a direct effect on fish species and habitats because of the limited vertical profile of the floating foundation and smaller footprint associated with mooring and anchoring.
- Monitoring for changes in the biological community at OSW farms should be driven by specific objectives and hypotheses. Effective monitoring practices for understanding potential changes in fish communities at OSW farms include implementation of the BACI approach (before-after/control-impact) or the BAG approach (before-after gradient) and data collection from trawl, trap and habitat surveys, fish tagging, and other methods.
- Examples of best management practices include siting projects away from sensitive habitats and minimizing seafloor disturbance during construction of the facility and associated infrastructure. Structures have the potential to be beneficial if they are specifically designed to meet the life requirements of a target population or a habitat need.

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

TOPIC DESCRIPTION

Structures introduced into the marine environment can cause shifts in fish distributions and potentially serve as fish attraction devices. These structures alter habitat by introducing new hard surfaces into an environment of soft sediment and are rapidly colonized by epifaunal organisms. Through colonization, the structures can introduce a different community of organisms and alter the food web for fish within the local ecosystem. The structures also add vertical habitat that attracts fish, which establishes a new food web of predator/prey relationships. These shifts have been considered both an enhancement of the environment by supporting local biodiversity and a detriment because they alter the local ecological system.

The long history of studies at offshore structures in the United States and Europe, including energy structures, provides analogies that inform our understanding of offshore wind (OSW) energy development and the possible effects on fish ecology. Many of these analogous studies have documented the colonization of the newly introduced habitat by hard substrate species. Offshore energy structures can introduce surfaces throughout the full water column, from the splash zone to the seafloor, providing a novel hard substrate that would otherwise be absent in the natural environment. The hard surface introduced by submerged structures is initially colonized by epifaunal organisms, including invertebrates such as mussels and barnacles. Over time, the initial set of species often develops through succession into a biodiverse community comprising a variety of species. In many cases, fish and shellfish species are attracted to the structures for shelter and to feed on the epifaunal organisms. The fish species identified at structures typically vary with depth and include species in the water column and near the seafloor. With relevance to both fixed and floating OSW energy, lessons learned from oil and gas infrastructure imply that the physical presence of structures may protect fished species or habitats by excluding fishing, establishing new reef habitat, and functioning as fish aggregating devices.

This brief focuses on the placement of new OSW structures and effects on fish ecology, including colonization, aggregation, and potential artificial reef effects. However, the effects on fish ecology are a consideration for each phase of OSW farm development and include other topics such as underwater noise and electromagnetic fields that are the focus of separate research briefs.

> The colonization of newly introduced habitat by hard substrate species (such as mussels and barnacles) has been documented in several studies.

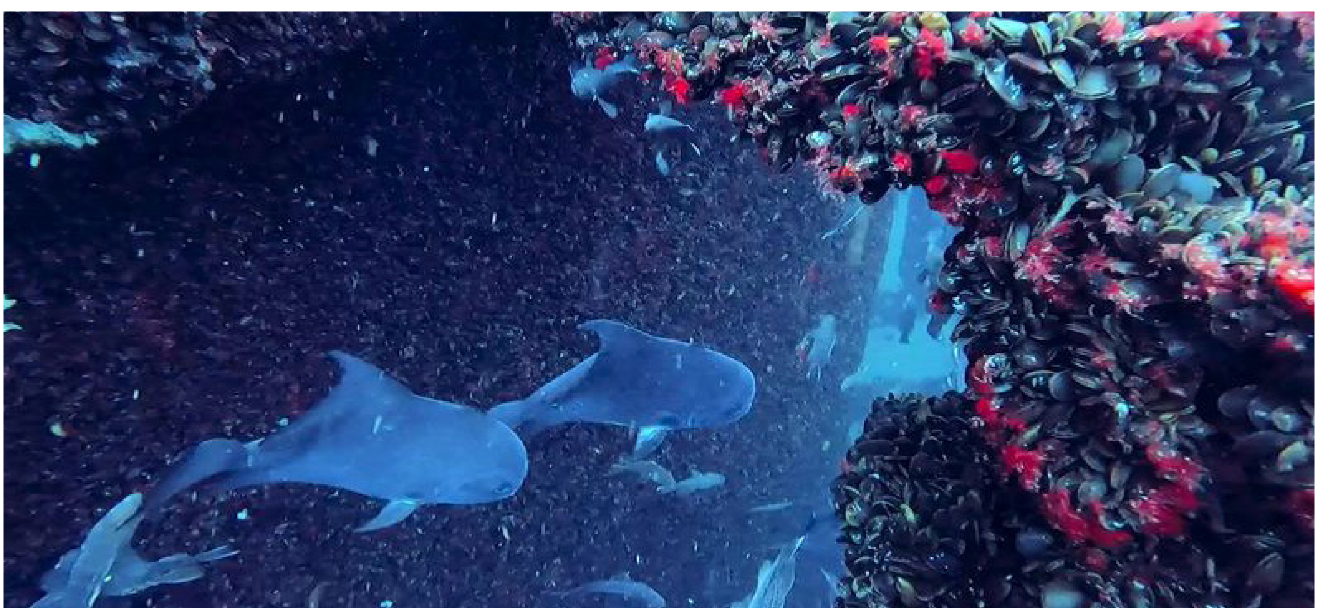
Types of Fish and Invertebrates Present at Offshore Structures

- **Epifaunal organisms:** Organisms that grow on the surfaces of submerged structures, including stationary and mobile invertebrates (mussels, barnacles).
- **Demersal fishes:** Groundfish (flounder, haddock) that spend most of their time living and feeding on or near the seafloor.
- **Benthopelagic fishes:** Fish that live in close association with the bottom of the sea but can move to the upper parts of the water column (cod, pouting).
- **Pelagic fishes:** Fish that occupy mid and surface waters with the ability to perform daily vertical migrations (mackerel, sea bass).

MAIN RISKS & EFFECTS

The implications for fish communities that result from the placement of OSW energy farms depends on a complete understanding of both the effects on fish habitat and resources as well as the broader ecological consequences. Benthic communities and associated fish and shellfish populations can be affected by the temporary or permanent habitat alteration caused by the space occupied by the OSW farm, installation of scour (erosion) protection, and temporary disturbance of the seabed during construction of turbines and associated components. In terms of turbidity effects, increased levels of suspended sediment during construction would be short-lived and intermittent, spread out over the duration of construction, and primarily limited to several meters around the construction activity. Seabed disruption can release contaminants into the water column, with the potential to cause toxicological effects in fish and other species. This issue has not been considered a concern in offshore environments away from point sources of pollution. In the United Kingdom, there was no evidence of contaminant loading in oysters during OSW farm construction at Kentish Flats. The footprint size and habitat effects of wind turbines depend on the turbine foundation type and materials and on the sediment type where the turbines are constructed. For fixed-bottom foundations, sediment footprints range in size (measured in area) from the smaller footprints of jacket foundations to the larger footprints of monopiles and gravity-based foundations with their associated scour protection layers. Floating OSW turbines will affect fish habitat and species differently because they are located in deeper waters and have floating structures that are anchored to the seafloor via mooring lines.

> Reef effects have been reported at several offshore wind farms based on observations of increased abundance of certain fish and shellfish species in the direct vicinity of wind turbines.



Underwater image of fish and mussels gathered near offshore wind turbine foundations at the Coastal Virginia Offshore Wind farm (photo from Dominion Energy).

A widely studied consideration for OSW farms has been the potential "artificial reef" effects of turbine foundations, which refers to their ability to mimic characteristics of a natural reef, including the associated attraction of fish and invertebrates (Figure 1). OSW turbine structures provide a combination of hard vertical and horizontal substrates, depending on the foundation type, which can attract various fish species based on available shelter and food. The food web impacts on fish ecology at several Belgian OSW farms have been linked to changes in demersal and benthopelagic fish diets. In Europe, reef effects have been reported at several OSW farms based on observations of an increased abundance of certain fish and shellfish species in the direct vicinity of wind turbines and their scour protection (e.g., crabs, cod, sea bass, and mackerel). However, not all species of fish appear to be attracted to the structures of the studied wind farms. For example, studies at North Sea wind farms have shown that Atlantic cod are attracted to foundations, but there

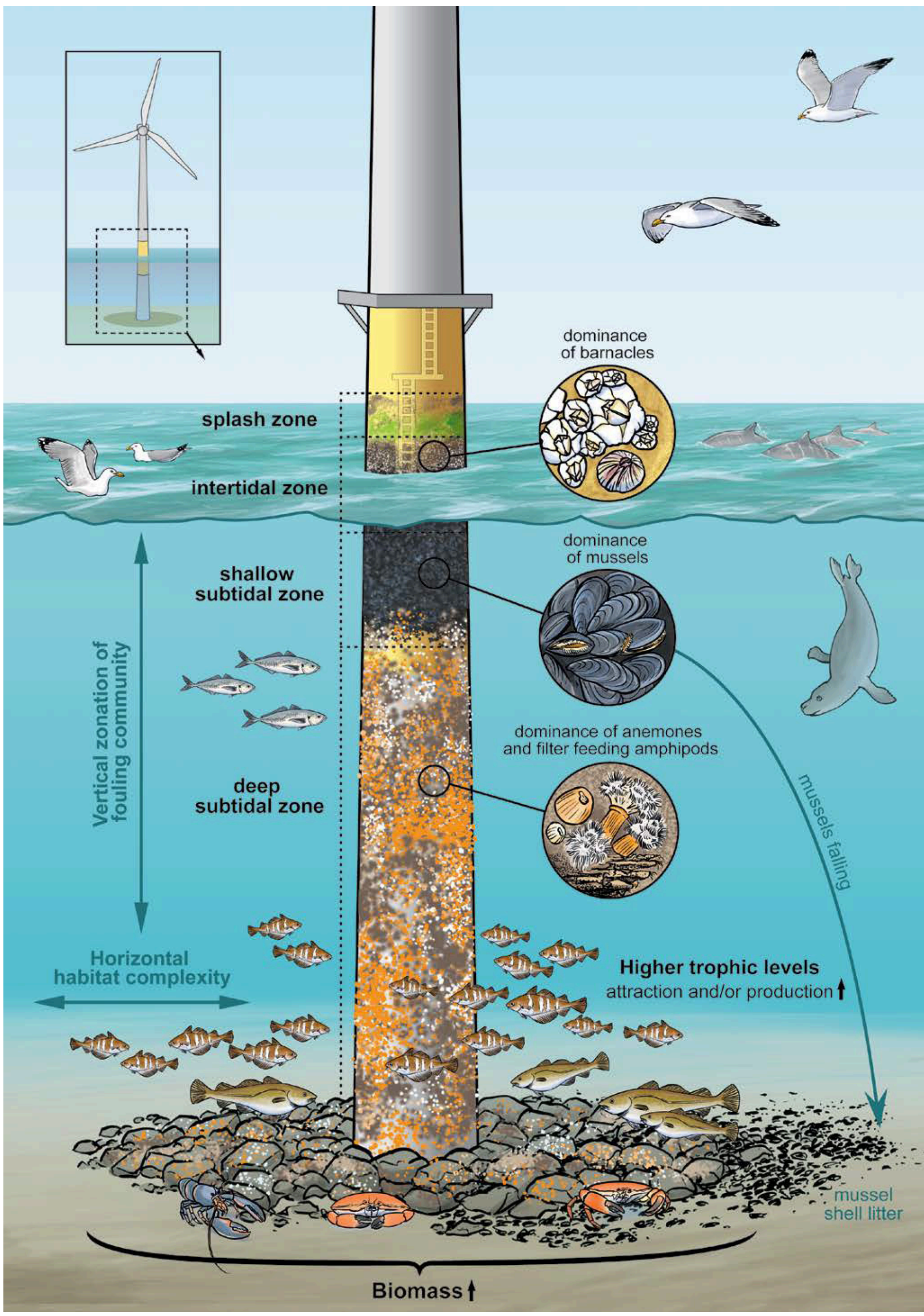


Figure 1. *Offshore wind farm foundations provide habitat for epifaunal organisms along a depth gradient, which attracts fish and other species. Illustration by Hendrik Gheerardyn (reprinted with permission from [Degraer et al., 2020](#)).*

was no evidence that common sole were attracted to similar monopile habitats. Considering the larger OSW farm as a whole, preliminary studies from Denmark, the Netherlands, Japan, and Sweden found that fish abundance has either increased (e.g., cod, whiting, sole) or has not been affected.

The transferability of European study results to U.S. OSW farms needs to be considered in light of a variety of factors, including differences in fish species, oceanographic conditions, prevalence of hard bottom habitats, and the international differences in fisheries exclusions. To understand the environmental effects of OSW farms, the U.S. Department of the Interior Bureau of Ocean Energy Management (BOEM) initiated the Realtime Opportunity for Development Environmental Observations (RODEO) study in 2015 to inform management on how to avoid or mitigate undesired effects at future facilities and how to prioritize future monitoring efforts. This study was initially designed based on strategies and key findings from monitoring programs and studies in Europe. As part of RODEO, multiyear measurements were collected at the first OSW farm in the United States, Block Island Wind Farm. These measurements have demonstrated quick colonization of the structures and increased local diversity through increased habitat complexity provided by the wind turbine structures. Observations around the turbine foundations at Block Island Wind Farm have indicated dense mussel aggregations, organic rich sediments, and the presence of juvenile crabs, black sea bass, and other native benthopelagic fish.

Other effects that may occur from OSW foundations include the risk of spreading invasive species across a region via "stepping stones" — small areas with better environmental conditions — which is a risk that will vary by geographic location. There is also concern that the introduction of foundations where similar features may not exist could alter the migration patterns of some fish species by encouraging them to linger at OSW sites. This attraction effect will depend in part on the size (surface area and volume) of different foundation types. Floating foundations may have similar attraction effects at the floating components in the surface-water layer, but with reduced attraction at greater depths where only mooring lines and anchors are present. Additionally, OSW farms have the potential to alter hydrodynamic processes (movement patterns of water) in a localized and spatially limited area, with possible implications for fish ecology. Preliminary larval dispersal modeling results for sea scallops, hake, and flounder in U.S Atlantic waters suggests that OSW turbines can affect circulation and mixing in the vicinity of the turbines, with the potential to change larval abundance and settlement density in the area. European modeling studies have assessed the possible effects of OSW farms on larval transport, showing a range of connectivity depending on the location. In the North Sea, the potential aquaculture benefits of OSW farms have been considered for supporting oyster larval dispersal and restoration.

For floating OSW farms, relevant considerations for fish ecology include the choice of foundation type, mooring and anchoring configurations, and marine communities associated with deeper waters relevant to these projects (over 60 meters). The direct effects from presence of the foundation structure on benthic species and habitats are typically considered lower at floating foundations.

Artificial reef effects will differ with the type of floating foundation depending on depth and surface area of the submerged structures. There may be a risk of spreading invasive species with floating foundations because they are generally towed to the site from ports, which could increase the potential for the introduction of invasive species at the wind farm site. At the seafloor, the mooring anchors and subsea cables associated with floating structures may function as artificial reefs, if not fully buried. The artificial substrates may also invite colonization by nonnative species.

MONITORING & MITIGATION METHODOLOGIES

Guidelines for OSW project monitoring emphasize the importance of having clear research objectives and hypotheses to guide selection of experimental design and sampling methods. A combination of monitoring techniques can be used to assess changes in fish ecology around OSW turbines, including effects on species composition and the factors responsible for observed changes. To monitor potential impacts, the BACI approach is often used to investigate changes between the preconstruction (baseline) and postconstruction (operational) phases to account for both spatial and temporal changes. This approach requires sampling the wind farm project area as well as an appropriate reference area that is representative of the habitat and community but not impacted by the OSW farm (Figure 2). An alternative approach is the BAG design, which allows for assessment of the spatial

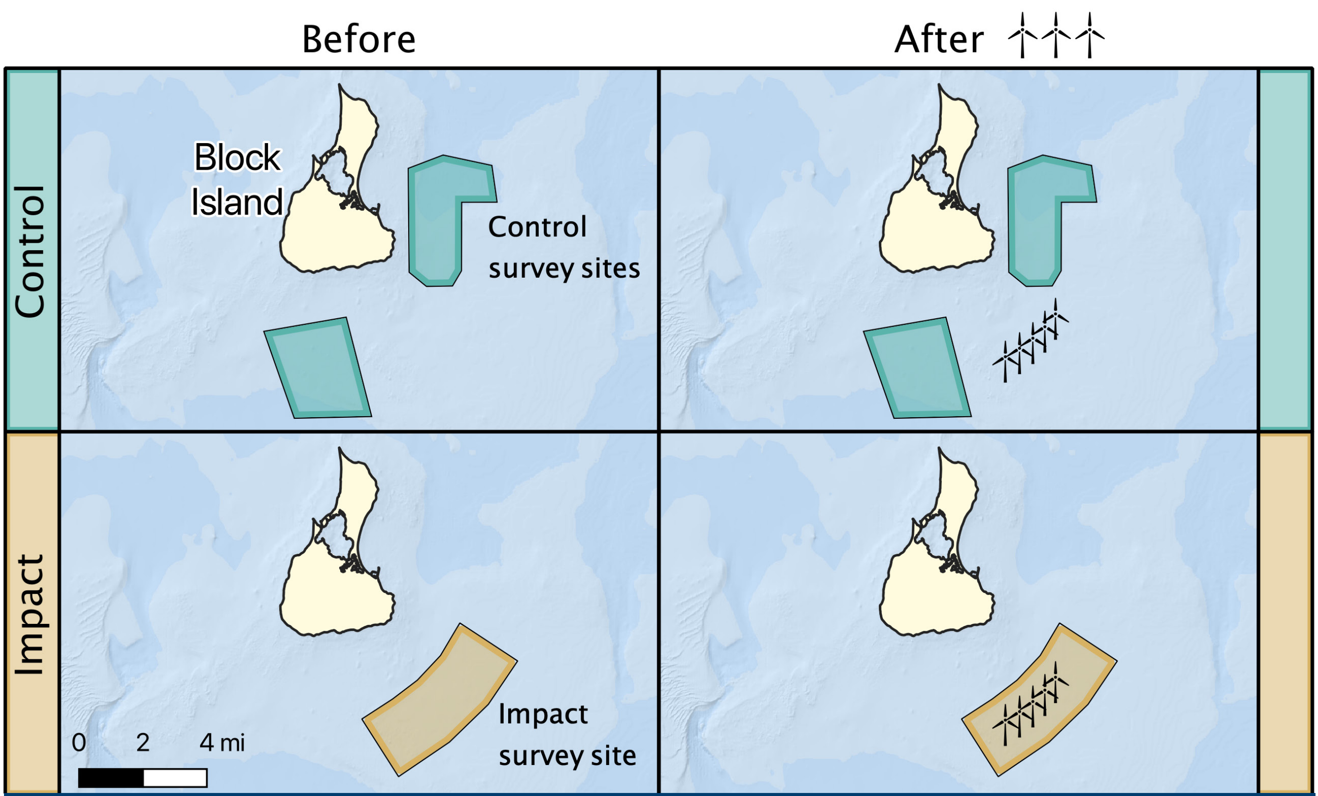


Figure 2. *Implementation of the before-after/control-impact (BACI) approach at offshore wind farms for understanding ecological change as a result of structure emplacement. In the BACI approach, surveys are conducted before construction (left) and after construction (right) at a control location (top) and location of impact (bottom). Sample locations based on* ***Carey et al (2020)****.*

variability and extent of wind farm effects and may improve statistical power by incorporating distance from the turbine directly into models.

In Germany, there are guidelines for fish monitoring in the North Sea and Baltic Sea that follow the BACI approach and recommend using trawl surveys to provide an assessment of the local fish fauna and possible changes in abundance, distribution, and community composition. In the United States, the National Oceanic and Atmospheric Administration (NOAA) Fisheries is responsible for conducting trawl surveys for fishery stock assessments, including on the Atlantic and Pacific Coasts. Trawl surveys use nets towed behind a boat to collect organisms at different depths in the water column (surface, midwater, and bottom) and provide fish samples for further analysis. In addition to trawl surveys, other monitoring concepts applied in Europe and considered in the United States include using data from existing sampling programs and data collection through gill nets, traps or pots, hydroacoustic surveys, scuba diving surveys, fish tagging (telemetry), and associated statistical analyses.

Many years of monitoring at European OSW farms has provided valuable guidance for assessing fish, invertebrates, habitat, and other environmental considerations as the U.S. OSW industry grows. At Block Island Wind Farm, multiyear studies were required as part of lease agreements with the state of Rhode Island and were conducted to separate the effects of construction and operation from regional changes in environmental conditions on hard-bottom habitats, demersal fish, lobsters, and crabs. Study elements to evaluate fish and fisheries resources included early engagement with stakeholders, adaptive monitoring, cooperative research with commercial fishermen, use of methods consistent with regional surveys, sampling within a BACI design, and various statistical analyses. Replicated sampling was conducted during baseline,

Methods Used To Study How Offshore Wind Farms Affect Fish Ecology

- **Before-after/control-impact (BACI):** An approach that compares an impact location with an unaffected control both before and after the intervention (e.g., construction of the OSW farm).
- **Before-after gradient (BAG):** An approach that samples along a gradient with increasing distance from the wind turbines both before and after the intervention.

construction, and operational phases for demersal fish (trawls and video surveys), lobster (ventless trap sampling), recreational boating activities, and hard-bottom habitat (Figure 3).

In U.S. federal waters, OSW development is overseen by BOEM in four distinct phases: planning, leasing, site assessment, and construction and operations. Conceptual decommissioning plans for all planned facilities are also submitted to BOEM as part of the construction and operations plan. Early considerations during the OSW planning process are intended to help minimize impacts on fisheries resources and habitat, including a requirement for seafloor surveys. Example best management practices recommended by BOEM to address the effects on fish resources and essential fish habitat include siting projects away from sensitive habitats and minimizing seafloor disturbance during construction and installation of the facility and associated infrastructure. Appropriately sited projects minimize the alteration of protected or critical habitat, such as spawning and foraging habitat, and known fish migration routes. Project siting depends, in part, on benthic habitat mapping to avoid siting in sensitive habitats that are critical for important taxa, such as American lobster, Atlantic cod, and longfin squid. Following leasing, developers are required by BOEM to submit biological assessments, including for fish populations, and benthic habitat monitoring plans as part of the construction and operations plan for their planned development. These biological assessments help inform appropriate siting for the wind farm, including micrositing to avoid specific sensitive habitats within the wider site.

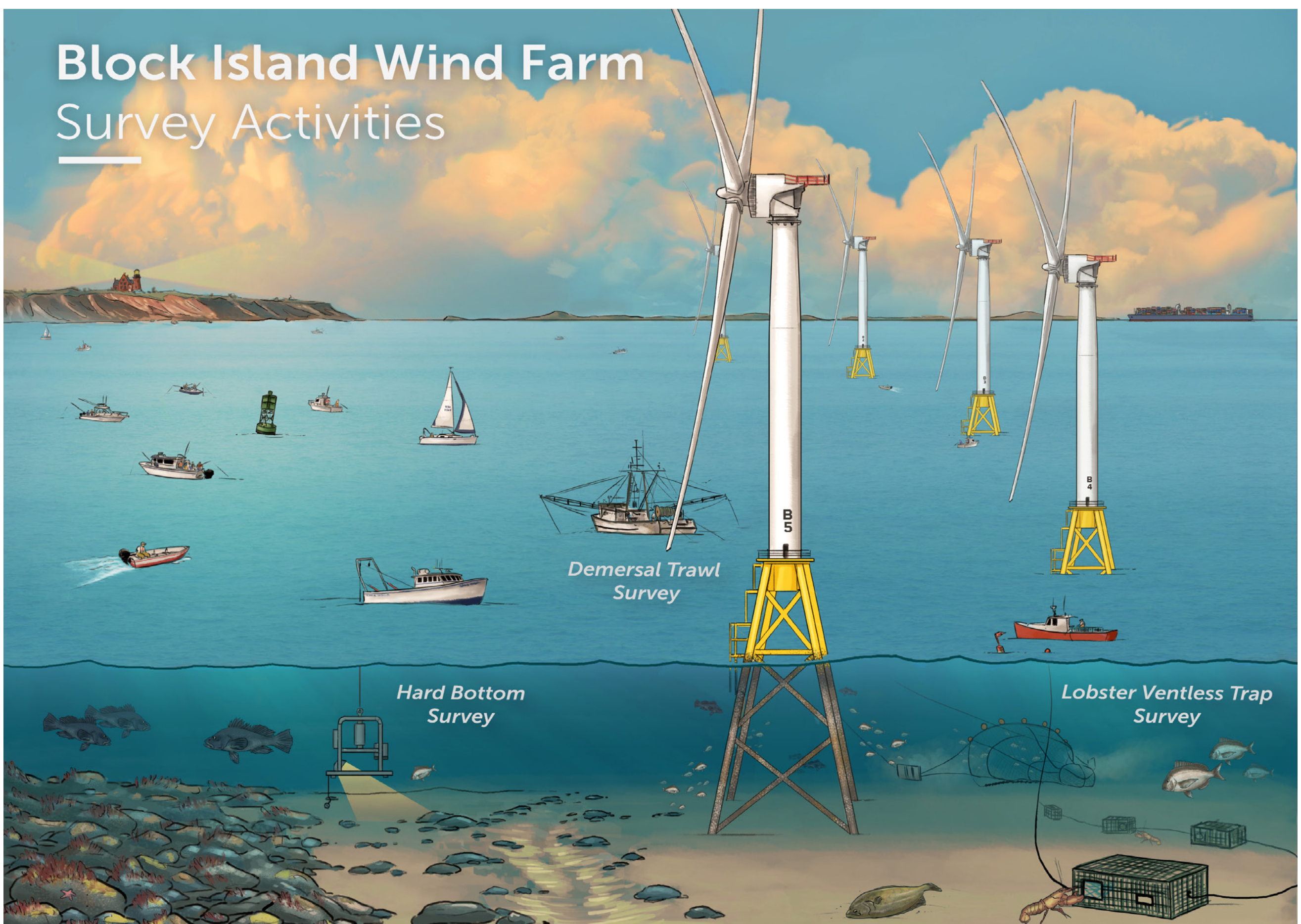


Figure 3. *Survey methods used at Block Island Wind Farm for studies related to fish and fisheries resources. Illustration by Steven Sabo, INSPIRE.*

NOAA Fisheries is responsible for providing scientific and regulatory review, conducting an official consultation on the potential impacts of proposed wind farm developments on essential fish habitat, and providing conservation and mitigation recommendations. For example, NOAA Fisheries scientists and colleagues are performing studies of Atlantic cod and other commercial fish species in southern New England. Their goal is to gather baseline data to address how OSW development in the region could affect these animals.

Moving forward, there are emerging considerations for the potential use of nature-inclusive foundation designs, dependent on the landscape context for these enhancements to fulfill life stage requirements of target species. Nature-inclusive designs include "measures that are integrated in or added to the design of offshore wind infrastructure to increase suitable habitat for native species." Example designs developed for the Dutch North Sea include add-on options for foundations (e.g., "hotel" structures for fish egg attachment, Figure 4) and optimized scour protection designs to enhance ecological functioning. Structures have the potential to be beneficial if they are specifically designed to meet the life requirements of a target population or a habitat need.

> In the United States, as part of the offshore wind leasing process, developers are required to submit biological assessments and habitat monitoring plans as part of their construction and operation plans.

Monitoring and mitigation considerations are still being developed for floating OSW farms given the relatively nascent stage of the technology. In the United States, historical and on-going deep-water habitat surveys on both the Atlantic and Pacific Coasts will provide important baseline information for floating wind farm siting. Proper burial of the mooring anchors and subsea cables associated with floating structures may help alleviate the impacts of artificial reef effects, if considered deleterious in a region. In addition, appropriate siting of floating technologies will need to consider coral protection and habitat management areas established in deep waters.

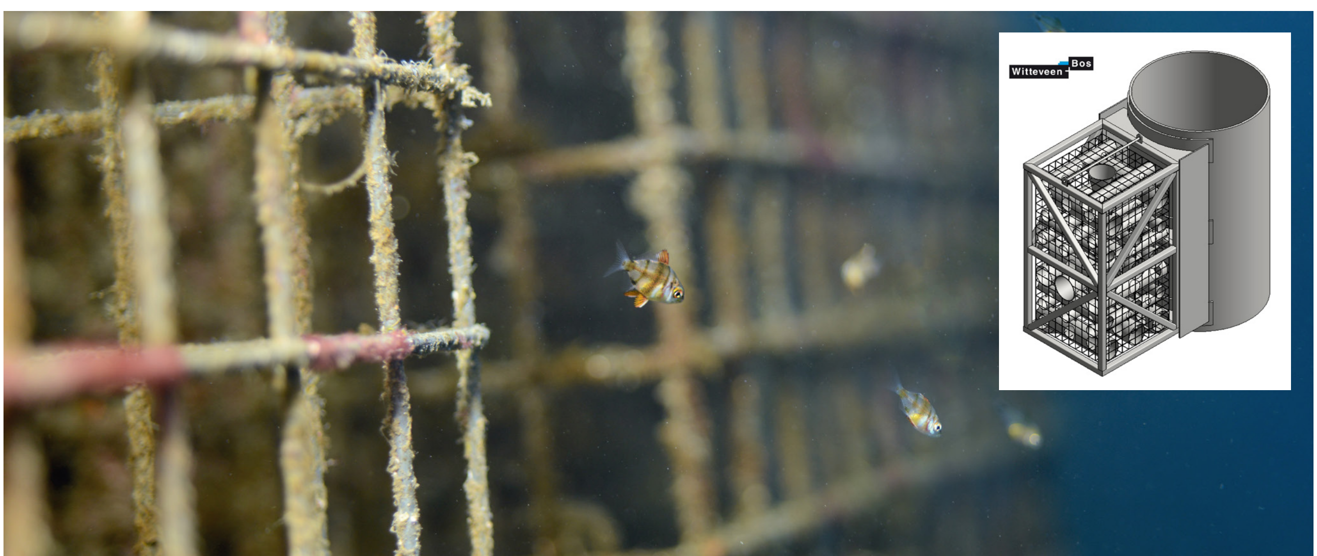


Figure 4. *Fish hotels are an example of nature-inclusive design add-on options for offshore wind foundations in Europe, including the Biohut© artificial fish nursery (photo) and a fish hotel designed to accommodate primarily Atlantic cod (inset). Photo and inset reprinted with permission. Photo by Remy Dubas/ECOCEAN©. Inset design by Witteveen+Bos (Hermans et al. 2020).*

KNOWLEDGE GAPS & RESEARCH NEEDS

As OSW deployment grows, there is a need for clear research questions and improved methods to understand the effects that various wind turbine structures can have on fish ecology. For example, it can be challenging to determine if and why changes occur in fish distributions at OSW structures given the requirements for quantifying change, including access to both adequate baseline and reference data. As baseline datasets, long-term stock assessment surveys may themselves be affected by the development of OSW farms but will need to continue in some form after construction to help assess wind farm effects on fish distributions, including at the regional scale. Understanding potential effects of new structures at OSW farms also requires the ability to separate the many variables, both physical and biological factors, which affect fish distributions on a cumulative basis. This will include expanded research to identify which environmental variables affect species assemblages associated with wind farms at a larger scale and to separate changes caused by natural variability and anthropogenic impacts, such as climate change. A need has also been identified to investigate longer term changes both at the assemblage and species levels using a combination of monitoring and modeling techniques.

Several key research questions remain important as OSW development expands into new regions off the U.S. Atlantic and Pacific Coasts. Examples of such questions include:

- Do fish density and species composition change significantly around OSW turbine structures in different regions and what are the differences based on foundation type?
- What processes are responsible for any observed changes in fish communities at turbine structures (e.g., food availability, shelter, predation)?
- How do we distinguish changes in fish communities due to OSW farms from those due to other environmental factors, such as a warmer and more acidified marine environment?
- In terms of consequences for ecosystem functioning, are fish communities on the turbine structures isolated from or connected to each other at the larger scale across turbines and multiple wind farms?
- Does the artificial reef effect export measurable amounts of energy and biomass to the wider ecosystem or only serve locally as aggregating devices?

Collaborative approaches with regional scientists and the fishing industry will be important to ensure sampling methodology can be assessed in a regional context. Linking monitoring at the local and regional scales will continue to be an effective means of collating the knowledge needed to understand the effects of OSW farms and inform effective mitigation of the potential impacts of wind structures on fish ecology.

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

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