Offshore Wind Development in the Northeast US Shelf Large Marine Ecosystem

Ecological, Human, and Fishery Management Dimensions

By Elizabeth T. Methratta, Anne Hawkins, Brian R. Hooker, Andrew Lipsky, and Jonathan A. Hare

Photo courtesy of HDR RODEO Team (BOEM Contract #M15PC00002)

ABSTRACT. Offshore renewable energy development is being sought by US coastal states to meet their renewable energy goals. Numerous offshore wind development projects are being proposed along the Atlantic coast, and additional areas are being explored in the Pacific. Commercial-scale offshore wind will share the seas with marine fisheries that provide immense economic, recreational, and cultural value as well as local food security. An acceleration in the number of proposed wind projects combined with a lack of clarity on how fishing activities are to be incorporated into the planning process has created numerous challenges for the fishing community and for fisheries managers. This paper explores ecological, human, and fishery management interactions with wind development, focusing on the Northeast US Shelf Large Marine Ecosystem. With an emphasis on a regional perspective, we identify key challenges to and opportunities for the goal of coexistence of offshore wind energy development and fishing activities, and we make several recommendations toward achieving this goal. Although the challenges to achieving coexistence of these two industries are significant, we argue that they are surmountable and can be overcome through a combination of collaboration, regional approaches, and innovation.

INTRODUCTION: STATE OF PLAY IN THE UNITED STATES

In the United States, offshore wind is an important component of the renewable energy goals being set by coastal states. At the end of 2019, offshore wind capacity commitments summed across states was 19,968 MW by 2035. In some states without offshore wind-specific targets, such as California and Hawai'i, 100% renewables portfolio standards and carbon reduction policies are driving the creation of new offshore wind lease areas (DOE, 2019). This has led to an increase in proposed projects (i.e., wind farms) in recent years, particularly in the northeastern United States, with seven plans currently under review and an additional eight plans expected by the summer of 2021. All of these projects are proposed to be built within the 16 areas of ocean bottom currently leased to developers. In total, these areas cover 6,880 km^2 located off of the US Atlantic (Figure 1) and Pacific coasts.

Wind development in the offshore zone will overlap with fisheries that contribute important economic, recreational, and cultural resources to American society. The initial focus of US wind energy development is in the northeastern region of the country where commercial and recreational fishing were underway long before the nation formed. The historical and cultural importance of commercial fisheries in the region is reinforced by its economic importance, with \$3.7 billion in value added to the economy in 2016, supporting over 260,000 jobs (NMFS, 2018). Recreational fishing, which was initially a form of subsistence, has grown in economic importance in the region over the past 50 years, with over \$5.3 billion added to the economy in 2016, supporting more than 69,000 jobs (NMFS, 2020). Marine fisheries are managed both by the states (Atlantic States Marine Fisheries Commission) and the federal government (NOAA Fisheries and Regional Fishery Management Councils). Both state and federal management are legally structured to have stakeholders among the decision-makers, with management decisions implemented by state and federal governments.

Wind energy development is a new ocean use in the United States that competes with longstanding activities. It will have significant impacts on fishery activity, fishery resources, and fishery science and management (BOEM, 2020), and trade-offs among these sectors can be explored in an integrated ecosystem assessment framework (Levin and Lubchenco, 2008). For offshore wind in the United States, the Bureau of Ocean Energy Management (BOEM) is the lead agency for the approval of projects in federal waters. However, multiple state and federal agencies have authorities for different aspects of permitting and responsibilities for reviewing and assessing the potential impacts of projects. Sites to be developed have been chosen based on multiple factors to reduce competition, including mitigation of viewshed impacts, avoidance of areas used for military operations and sensitive radar systems, and availability of wind resources. The planning process does not automatically exclude competing use areas like fishing grounds; rather, it mandates that decisions include "consideration" of fishing activities (Energy Policy Act of 2005 Section (p)(4)(J)(ii)). How fisheries are considered under this requirement is largely left to the discretion of the Department of the Interior. This has led to a great deal of confusion and concern among fishery participants because there is no threshold of impacts to commercial fishing activities that would affect offshore wind energy siting and development decisions. Lack of fishery stakeholder participation in the wind development decision-making process contrasts with the participatory governance structure of fisheries management (Figure 2), which has been in place for decades and clearly defines the involvement of stakeholders. Fishery stakeholders have been included to some degree on a state-by-state basis; for example, a state purchasing energy from a development may include fishers in their state in the wind development process. However, wind energy development sites are in federal waters and may impact fishers and fishing communities from multiple states. This disconnect further amplifies the differences between the governance processes of fisheries and wind energy development.

Our objective in this paper is to broadly define the potential interactions between offshore wind energy development and fishing, with a focus on the Northeast US Shelf Large

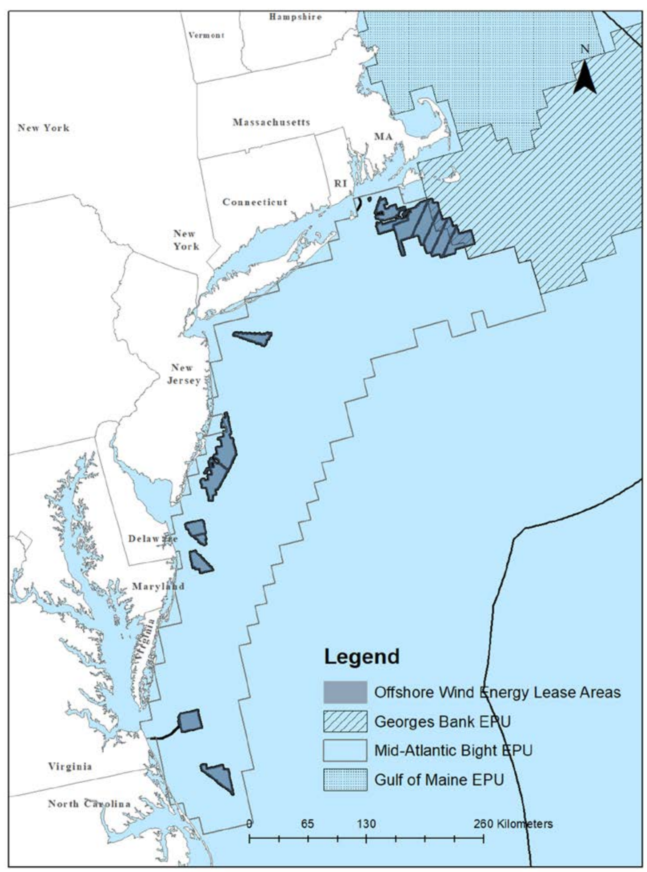

FIGURE 1. Map of the 16 currently existing wind energy lease areas in the Northeast US Shelf Large Marine Ecosystem. Fishing activity overlaps with the entirety of the Ecological Production Units (EPUs) presented on the map. Total area of leases = 6,880 km^2.

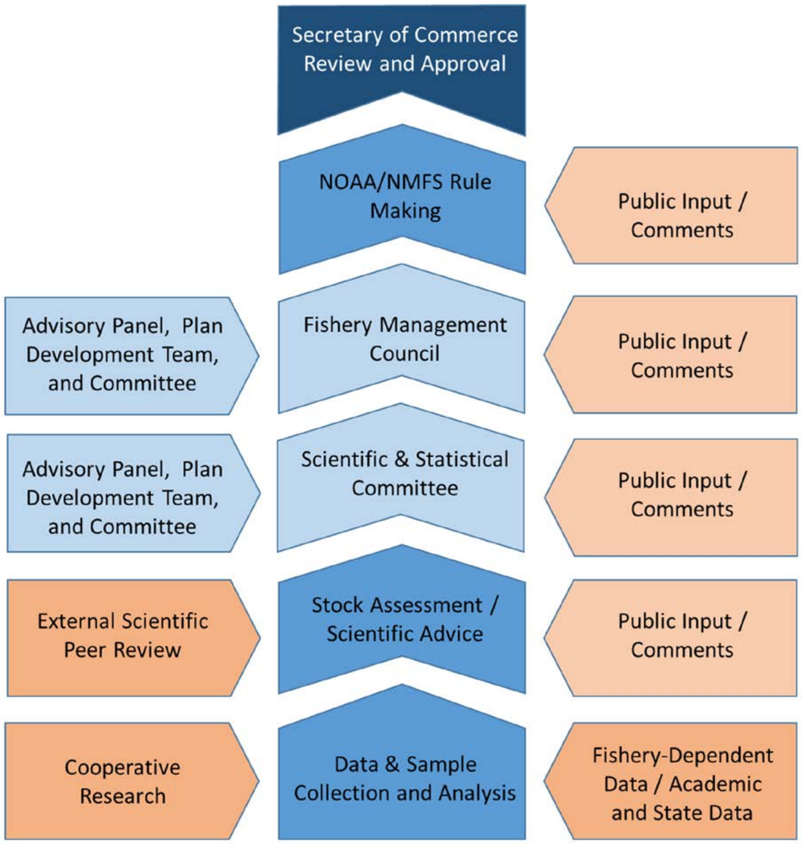

FIGURE 2. Overview of the participatory governance structure of fisheries management in the United States. Dark blue: National Marine Fisheries Service (NOAA/NMFS) and Department of Commerce-led activities. Light blue: Regional Fishery Management Council-led activities. Orange: Opportunities for engagement in the science and management process.

Marine Ecosystem (NEUS-LME). We take a regional perspective, recognizing the regional scale of wind energy development, fishing activities, and fisheries management. From this summary of interactions, we identify challenges to and opportunities for the goal of coexistence of offshore wind energy development and fishing activities. In this regard, the goal is renewable energy *and* sustainable seafood—our future depends on both.

EFFECTS OF OFFSHORE WIND DEVELOPMENT ON MARINE ECOSYSTEMS IN THE UNITED STATES

Interactions with Ecological Communities

Ecological interactions can occur during each phase of offshore wind development, from pre-construction site assessments to decommissioning (Birchenough and Degraer, 2020). Multiple stressors are associated with offshore wind development, and a comprehensive review of each of these stressors is provided by separate papers in this special issue. Table 1 describes the potential effects for eight species from the NEUS-LME that are emblematic of the challenges faced in this system. These eight species were chosen to be highlighted because of their importance to key ecosystem functions, their significance to the commercial and recreational fishing communities, and/or because of their status as endangered or critically endangered species. While these species may be unique to the NEUS-LME, they have analogs in ecosystems around the world. Adverse effects are expected for some species, others are expected to benefit, and the outcome for others remains uncertain due to lack of information. Currently, few stressors are understood with a high degree of certainty either because so few studies have been conducted or because those that have been conducted have shown conflicting results. This underscores the urgent need for further research to understand each of these stressors and their integrative effects in the marine environment.

Interactions with Human Communities: Fisheries and Socioeconomics

Fishing communities have numerous concerns associated with offshore wind, including increased risk of collision with fixed structures (turbines and cables) and non-fixed structures (other vessels and gear) due to changes in routing patterns and increased vessel traffic, as well as potential for interruption of fishing by wind development activities, regulatory uncertainty (new fishing restrictions), and diminished economic opportunity resulting from competition between commercial and recreational fisheries (Gray et al., 2016). Fishers have also expressed concern about impacts to traditional fishing practices due to predicted shifts in resource distribution that may require significant changes to current fishing methods and locations.

Although wind projects in the United States are planned to be open to commercial fishing, there are many logistical challenges associated with operating vessels in and around fixed and non-fixed wind energy structures, particularly vessels using mobile fishing gear. The challenges include difficulties with navigation, physical obstruction, traffic, safety, gear loss, and possible insurance changes. Together with shifts in target stock distribution, these potential obstacles may make wind facilities de facto fishery exclusion areas, potentially leading to redistribution of fishing effort and stock-wide changes in quotas or catch limits. Such exclusions will not only have direct effects on excluded vessels but will also have indirect effects on vessels as well as ecosystems elsewhere as displaced effort will increase competition in remaining

TABLE 1. Potential interactions of offshore wind development with species representing major groups from the Northeast US Shelf Large Marine Ecosystem (NEUS-LME).

	ECOLOGY	FISHERIES AND SOCIOECONOMICS		MANAGEMENT
	ECOLOGICAL EFFECTS	COMMERCIAL FISHERIES IMPLICATIONS	RECREATIONAL FISHERIES IMPLICATIONS	MANAGEMENT/ REGULATORY IMPLICATIONS
Large Mammals [1,2,3] e.g., North Atlantic right whale (*Eubalaena glacialis*)	Pile driving and vessel noise affect species' behavior, movements, and migratory patterns. Ship strikes cause serious injury or mortality. Altered hydrodynamic patterns around wind farms may affect distribution of zooplankton prey.	Changes in fishing practices and fisheries displacement can increase fishing industry/ marine mammal interactions. Changes in behavior and habitat could also increase interactions between animals and fishing industry. Increases in pot fishing would increase entanglement risk.	N/A	Vessel speed restrictions; noise mitigation during construction.
Endangered Finfish [3,4] e.g., Atlantic sturgeon (*Acipenser oxyrhynchus oxyrhynchus*)	Pile driving and vessel noise affect species' behavior, movements, and migratory patterns. Ship strikes cause serious injury or mortality. Altered hydrodynamic patterns around wind farms may affect distribution of zooplankton prey.	N/A	N/A	Vessel speed restrictions; noise mitigation during construction.
Demersal Round Fish [3,4,5] e.g., black sea bass (*Centropristis striata*)	The artificial reef effect provides food and habitat. Fish are attracted by increased local abundance. Modified hydrodynamic patterns change larval dispersal.	Local increase in abundance could increase commercial fisheries effort at wind farms, particularly for those using pots or rod/reel. Limited trawling is expected due to challenges of towing near turbines and cables. Increased local competition for space among vessels.	Local increases in abundance at wind farms may increase recreational fisheries effort. Gear type near turbines will likely be rod/reel rather than trawl for logistical reasons. Increased local competition for space among vessels is expected.	Modified scientific assessments, spatial/temporal management areas, and catch quotas.
Demersal Flatfish [3,5] e.g., summer flounder (*Paralichthys dentatus*)	The amount of soft bottom habitat is reduced locally. Local abundance declines. Modified hydrodynamic patterns change larval dispersal.	Locally decreased abundance at wind farms may reduce commercial fisheries effort there. Decreased catch expected. Lower income, revenue, and economic viability of the fishery anticipated.	Locally decreased abundance at wind farms may decrease recreational fisheries effort there. Lower catch expected. Lower income and economic viability of the charter vessel industry anticipated.	Modified scientific assessments, spatial/temporal management areas, and catch quotas.
Small Pelagic Finfish [3,5] e.g., Atlantic mackerel (*Scomber scombrus*)	Altered hydrodynamic patterns may affect zooplankton prey abundance and larval dispersal.	Uncertain effects on abundance at or near wind farms may affect catch.	Uncertain effects on abundance at or near wind farms may affect catch.	Modified scientific assessments, spatial/temporal management areas, and catch quotas.
Highly Migratory Finfish [6] e.g., blue shark (*Prionace glauca*)	EMF affects behavior, movement, and migratory patterns. Attraction to prey species associated with structure may increase local abundance of highly migratory species.	Local increases in abundance could increase commercial fisheries effort at wind farms. Increased local competition for space.	Local increase in abundance at wind farms may increase recreational fisheries effort. Charter vessel industry revenue may increase.	Modified recreational catch limits.

[1] Marine Mammals, Endangered and Protected Species; [2] Knowlton and Kraus, 2001; [3] Floeter et al., 2017; [4] Popper and Hawkins, 2019; [5] Stenberg et al., 2015; [6] Gill et al., 2012; [7] Causon and Gill, 2018; [8] Jones et al., 2020

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TABLE 1. *Continued…*

	ECOLOGY	FISHERIES AND SOCIOECONOMICS		MANAGEMENT
	ECOLOGICAL EFFECTS	COMMERCIAL FISHERIES IMPLICATIONS	RECREATIONAL FISHERIES IMPLICATIONS	MANAGEMENT/ REGULATORY IMPLICATIONS
Benthic Macro-invertebrate [3,7] e.g., Atlantic sea scallop (*Placopecten magellanicus*)	Species may be displaced from habitat and experience habitat loss. Modified hydrodynamic patterns affect larval dispersal. Increased predation if local predator abundance increases at structures adjacent to scallop beds.	Locally reduced abundance at wind farms and difficulty using scallop gear near turbines and cables may reduce commercial fisheries inside of wind farms. This could lead to lower catch rates, income, revenue, and economic viability of the fishery.	N/A	Modified scientific assessments, spatial/temporal management areas, and catch quotas.
Pelagic Invertebrate [3,8] e.g., longfin squid (*Doryteuthis pealeii*)	Modified hydrodynamic patterns, wind wakes, turbulence change species distribution. There is potential for short-term habituation to the sound frequencies produced by pile driving during wind farm installation, which may interfere with species' ability to evade predators and communicate with conspecifics.	Locally modified abundance at wind farms may affect commercial fisheries effort there. Reduced catch expected. Lower income, revenue, and economic viability of the fishery anticipated.	N/A	Modified scientific assessments.

[1] Marine Mammals, Endangered and Protected Species; [2] Knowlton and Kraus 2001; [3] Floeter et al., 2017; [4] Popper and Hawkins, 2019; [5] Stenberg et al., 2015; [6] Gill et al., 2012; [7] Causon and Gill, 2018; [8] Jones et al., 2020

fishable locations. Fishing cessation and its effect on the benthic community could also have significant feedback effects on population indices (Roach et al., 2018) and "multiplier effects" that ripple through coastal businesses, communities, and the downstream seafood trade. Understanding these issues requires gathering finer-scale fisheries data (i.e., landings per tow), which are often proprietary, as well as gaining a better understanding of the economic value of seafood once it enters the supply chain. Indeed, offshore wind developers and management authorities have attempted to quantify direct effects on commercial fishing as part of compensatory mitigation programs and/or environmental effects analyses (e.g., Livermore, 2017; Fugate, 2019). However, these assessments are controversial and do not include the full suite of fishing interests impacted by development. Within some sectors of the recreational fishing community, there is a perception that offshore wind facilities will enhance fishing (Hooper et al., 2017). While it is well documented that offshore structures are utilized by the recreational fishing community (Smythe et al., 2018), few publications show that these enhancements are an actual benefit to fish at the population level.

Fisheries impacts in the United States are expected to differ from those observed in Europe because of disparities in fisheries infrastructures, markets, and ecosystem conditions. For example, the fleets most affected in the UK consist of smaller day-boat vessels, and there is more uniformity among target fisheries and locations among vessels from a given port. In contrast, the US fleet is highly mobile and more diverse with regard to vessel size and locations fished.

Interactions with Fisheries Management

Under current US law, regional fishery management councils will continue management of fisheries in wind energy areas, which are sited in federal waters. Changes in fishing locations, effort, and gear types may require additional management actions by councils. In addition, competition between commercial and recreational fishing may have implications for fisheries management that need to be addressed by the councils. The Mid-Atlantic and New England Fishery Management Councils, which manage fisheries in the Northeast, have developed management measures for application to specific areas (e.g., Habitat Closed Areas, Gear Restricted Areas, Special Management Areas), and changes to the management of these areas or the implementation of new site-specific regulations could be called for in and around wind energy development areas.

Much of fisheries management involves establishing catch levels that are based on stock assessments. A number of data sources are used in stock assessments, including scientific fishery resource surveys, and these surveys will be impacted by wind energy developments. In the Northeast United States, a number of scientific surveys overlap with wind devel-

TABLE 2. Characteristics of core NMFS scientific surveys in the Northwest Atlantic and their overlap with offshore wind development. Overlaps are the percentage of survey strata that overlap with wind energy leases and wind planning areas as calculated in a spatial analysis. SNE = Southern New England. MAB = Mid-Atlantic Bight.

SURVEY NAME	YEAR STARTED	SURVEY METHOD	MAJOR APPLICATIONS	INTERACTION WITH WIND ENERGY AREAS
Autumn Bottom Trawl Survey	1963	Random Stratified Design – North Carolina to Nova Scotia (bottom trawl)	Components of Ecosystem Monitoring Survey: abundance, length, age, sex, weight, diet, maturity samples, distribution	Range (%) survey strata overlaps calculated for SNE and MAB: 0.87–60.0%. New design and methods within wind energy will be required.
Spring Bottom Trawl Survey	1968	Random Stratified Design – North Carolina to Nova Scotia (bottom trawl)	Components of Ecosystem Monitoring survey: abundance, length, age, sex, weight, diet, maturity samples, distribution	Range (%) survey strata overlaps calculated for SNE and MAB: 0.87–60.0%. New design and methods within/outside wind energy will be required.
Scallop Survey	1979	Random Stratified Design (dredge); line transect (HabCam)	Biomass, abundance, distribution, size, and sex of sea scallops and other benthic fauna	Range (%) survey strata overlaps calculated for SNE and MAB: 0.59–95.53%. New design and methods within/outside wind energy will be required.
Atlantic Surfclam and Ocean Quahog Surveys	1980	Random Stratified Design (hydraulic dredge)	Biomass, abundance, distribution, size, and sex of Atlantic surfclam and ocean quahog	Range (%) survey strata overlaps calculated for SNE and MAB: 8.17–33.40%. Surf clam survey strata overlaps: 3.28–27.21%. New design and methods within/outside wind energy will be required.
Northern Shrimp Survey	1983	Random Stratified Design (commercial shrimp trawl)	Biomass, abundance, length	Overlaps with areas now being considered and planned for wind development in the Gulf of Maine that are in early phases of pre-leasing process. Survey strata impacted: to be determined.
Gulf of Maine Cooperative Bottom Longline Survey	2014	Random Stratified Design (bottom longline)	Abundance, biomass, length, age, sex, weight, maturity samples, distribution, focused on hard-bottom habitat data	Overlaps with areas now being considered and planned for wind development in the Gulf of Maine that are in early phases of pre-leasing process. Survey strata impacted: to be determined.
Ecosystem Monitoring Survey	1977	Random Stratified Design (linked to Trawl Survey Design); fixed stations embedded in design (plankton and oceanographic sampling)	Phytoplankton, zooplankton, ichthyoplankton, carbonate chemistry, nutrients, marine mammals, seabirds	Range (%) survey strata overlaps calculated for SNE and MAB: 1.40–44.13%. New design and methods within/outside wind energy will be required.
North Atlantic Right Whale Aerial Surveys	1998	Aerial line transects	Right whale population estimates; dynamic area management	Overlaps estimated for wind energy leases, wind energy planning areas, and Gulf of Maine. Survey strata overlap: 60%. New design and possible methods within/outside wind energy will be required.
Marine Mammal and Sea Turtle Ship-Based and Aerial Surveys	1991	Line transects for ship and aerial surveys; opportunistic biological and physical oceanographic sampling from shipboard surveys	Abundance and spatial distribution of marine mammals, sea turtles, and seabirds	Overlaps with wind energy leases, wind energy planning areas, and Gulf of Maine. Survey strata overlaps: to be determined. New design and methods within/outside wind energy will be required.

opment areas and represent more than 315 years of cumulative survey effort which are supported by dedicated NOAA ship and aircraft resources (Table 2). Information gathered from these surveys represents some of the world's most comprehensive data on marine ecosystems (e.g., Despres-Patanjo et al., 1988; McClatchie et al., 2015). The surveys support fisheries and protected species assessments and management actions, ecosystem-based fisheries management, and regional and national climate assessments, as well as a number of regional, national, and international science activities. Offshore wind development will impact these scientific survey operations and consequently the scientific and management products produced for a wide variety of users. Within offshore wind areas, survey operations will be curtailed or eliminated under current vessel and aircraft capacity limits, safety requirements, and assessment protocols. Without robust investment in a plan to adapt these data collection and analysis programs to offshore wind development, the programs will suffer from survey bias, a reduction in information, increased uncertainty in stock assessments, and resulting poorly informed management decisions. When uncertainty is introduced into stock assessments, management decisions are less well informed, and the likelihood of inappropriate management actions increases. Poorly informed management actions could lead on the one hand to overfishing of stocks and on the other hand to underfishing of stocks. Both have significant economic impacts on commercial and recreational fishing industries.

THE CHALLENGES

Keep Learning on Pace with Development

The rate of offshore wind construction and technological advancement is extremely fast-paced. At the same time, numerous analyses are needed in order to understand biological and human interactions with offshore wind. One of the greatest challenges is to keep these analyses on pace with the offshore wind development because they provide vital information for permitting and management decisions. From a regulatory perspective, challenges include a high number of project plans, multiple intersecting state and federal mandates, contrasting missions of cooperating federal agencies, and budget limitations imposed on cooperating agencies to address these challenges. From a science perspective, reconciling the time and resources needed to identify and conduct scientific investigations at ecosystem and development scales with the timetables of wind projects is a huge challenge. Keeping science on pace with development will require an adaptive approach in which learning occurs simultaneously with development and our tools for monitoring and mitigating effects are adapted as our knowledge base grows and evolves.

Assessing Cumulative Impacts

Grappling with the effects of a single wind project is challenging. Understanding the cumulative impacts of multiple wind projects at full build-out in combination with other past, present, and reasonably foreseeable stressors operating over several decades is much more difficult. Cumulative impact analysis (CIA) for offshore renewable energy development (Willsteed et al., 2018) is particularly arduous because of the high levels of analytical complexity and uncertainty associated with offshore wind interactions with marine ecosystems. In the United States, multiple offshore wind projects are slated for construction over the next decade, and operations will continue for an additional 25+ years per project (BOEM, 2019). Climate-driven changes in the distributions and abundances of marine species, variability in the energy and seafood markets, and evolving wind and fishing technologies (Nye et al., 2009; BOEM, 2019) lead to highly uncertain outcomes in cumulative impacts analyses; the focus tends to be on a maximum impact scenario. Evaluating existing CIAs to identify strengths and weaknesses of current practices (Willsteed et al., 2018) and the development of new methodologies such as those implementing risk-based approaches (Stelzenmueller et al., 2018) are moving CIAs toward practicable applications.

Potential Effects of Evolving Turbine Technologies

Fixed foundation technologies are currently most feasible in waters ≤60 m deep, yet more than 58% of the offshore wind energy in the United States occurs beyond this depth (Beiter and Musial, 2016). The most promising technology for deepwater offshore wind is floating turbine systems that are anchored to the seabed using mooring lines and anchors. Floating turbines are connected to each other by an intra-array network of subsea electrical cables and to land by sub-bottom export cables (Statoil, 2015). In the United States, a demonstration-scale floating wind turbine was deployed in the Gulf of Maine between 2013 and 2014, and deployment of a full-scale turbine off the coast of Monhegan Island, Maine, is planned. In addition to the Gulf of Maine, floating technology is also currently being explored for use off the US West Coast and Hawaiʻi.

Compared to fixed foundation technology, floating wind facilities will encounter a different set of marine species and fisheries in deeper waters and will create a different set of stressors. For instance, as with fixed foundation facilities, floating facilities are still likely to limit or exclude fishing vessels with towed gear, stir up sediment into the water column during burial of export cables, and support epifaunal growth on associated structures. Floating offshore wind may also present new effects related to the mooring or cabling systems that are not yet fully understood (Statoil, 2015). However, the noise associated with pile driving would be eliminated, and floating wind systems could also allow for greater flexibility in siting because of their broader depth allowances.

THE OPPORTUNITIES

Cross-Sectoral Collaboration

The development of offshore wind in the NEUS-LME brings enormous challenges, but it also creates equally immense opportunities for collaboration and innovation. Collaborative efforts among federal agencies, the commercial and recreational fishing communities, and the wind industry are already underway. In March 2019, NOAA, BOEM, and the Responsible Offshore Development Alliance (RODA) entered into a 10-year memorandum of understanding (MOU), setting the stage for collaborative work between regional commercial fishing communities and federal regulators on areas of mutual interest. RODA, a commercial fishing industry coalition with members from North Carolina to Maine as well as from the west coast of the United States, formed in response to the considerable challenges fishers have faced in their efforts to be effectively involved in offshore wind energy planning. The organization is working with NOAA Fisheries and BOEM to enhance engagement with the commercial fishing industry in the offshore wind development process, identify optimal approaches for incorporating fishing expertise into the planning and development process, and support regional research and monitoring efforts that include fishers' ecosystem knowledge. As one early effort under the MOU, the three entities are collaborating to develop a synthesis-of-the-science report and workshop to compile and integrate existing scientific knowledge about offshore wind and fisheries interactions. In addition, RODA is also formally engaged directly with a group of eight wind developers to create a standing Joint Industry Task Force in order to improve communication between the two industries and bring commercial fishing industry expertise to bear on major issues of concern such as wind project siting and layout design. Together, these collaborations create opportunities for applying improved marine planning techniques so that wind projects better match expectations of US fishing communities. They also aspire to create new opportunities for research and collaboration, to spur innovation, and to develop new mitigation strategies.

Regional Coordination of Scientific Study

There is a critical spatial mismatch between wind project-level data (hundreds of square kilometers) collected by developers and the potential uses of these data, uses that include studies of impacts on (1) ecological communities (10 m to thousands of meters), (2) regional fisheries resources, (3) fishing communities and seafood industries (local, state, and regional), and (4) the scientific enterprise that supports fisheries management (Table 3). These spatial mismatches are further complicated by the wide geographic ranges of fisheries resources (up to thousands of kilometers) and the regional nature of fisheries management structures. Thus, a regionally coordinated framework is greatly needed for collection, analysis, and sharing of information from offshore wind facilities. Such a framework is essential for addressing conflict between fishing communities and developers. A regional approach to science would standardize monitoring methods (sampling gear, experimental design, spatial and temporal scales that more closely match the resource, and reporting standards) within a region to make data comparable within and among projects. Individual regions could incorporate regionally specific studies into the larger research framework, and the research questions and their answers would complement one other in much the same way that puzzle pieces fit together to give a full picture.

Collaboration will be the cornerstone

TABLE 3. Examples of pathways through which offshore wind development could modify ecosystems and the expected scales of direct effects on fisheries resources, fisheries/socioeconomics, and fisheries management. Spatial scales are categorized as local (within the footprint of the wind farm or adjacent neighborhood), regional (at the scale of managed populations/stocks, which may be thousands to tens of thousands of meters from wind farms), or ecosystem (more than 100,000 meters from a wind farm).

	EXAMPLE PATHWAYS OF ECOSYSTEM MODIFICATION	EXPECTED SPATIAL SCALE OF EFFECTS
FISHERIES RESOURCES	Benthic habitat modification	Local
	Oceanographic changes (local upwelling, wind wakes, turbulent flow, nutrients, temperature, stratification)	Local to ecosystem
	Food provision/foraging opportunity	Local to regional
	Aggregation of fisheries resources	Local
	Biodeposition	Local
	Effects on migration	Local to ecosystem
	Entanglement	Local to regional
	Electromagnetic fields	Local to regional
	Acoustic disturbance from construction, operation, maintenance	Local to regional
FISHERIES AND SOCIOECONOMICS	Fisheries displacement	Local to regional
	Change in fishing behavior	Local to regional
	Navigation	Local to regional
	Gear damage	Local
	Collision/allision; vessel operator safety	Local
	Gear switching	Local to regional
	Change in catch per unit effort	Local to regional
	Change in revenue from landings	Local to regional
	Changes in shoreside/fishing communities	Local to regional
FISHERIES MANAGEMENT	Change in quotas	Regional
	Effects on regional and shelf-wide scientific assessments leading to uncertainty in biological indices	Regional to ecosystem
	Effects on scientific advice	Regional to ecosystem

of regional science efforts. Through RODA, commercial fishing communities have opened a dialog with wind developers to address conflicts between the two industries and suggest opportunities for cooperative research. The Responsible Offshore Science Alliance (ROSA), a newly established regional science structure in the United States for which RODA was a founding member, will take a lead role in coordinating the development of a regional science framework (https://www.rosascience.org/). ROSA's overarching mission is to coordinate and deliver the best available scientific products and information necessary to address offshore development, fisheries management, and ecosystem health. By facilitating regional coordination, ROSA will foster collaboration across disciplines, work toward standardizing methodologies, and establish best practices for scientific study both within and among regions. Existing regional fisheries monitoring collaborations such as the Northeast Area Monitoring and Assessment Program (NEAMAP, 2003), a cooperative state and federal program that facilitates data collection and sharing, are excellent examples of integrating fishing industry platforms and fishers' expertise and can provide models to advance offshore wind and fisheries science.

Learning from and Building Collaborative Bridges with European Partners

Offshore wind has been generating energy for European nations for more than 20 years (Olsen and Dyer, 1993), and those nations continue to face many of the same challenges related to science-based monitoring, commercial fisheries interactions, and fisheries management that the United States is now confronting. Major research and monitoring programs have been underway at individual European wind facilities for several years (e.g., Degraer et al., 2019), and this work is increasingly making its way into the peer-reviewed literature in the forms of reports on individual research studies, research syntheses, and policy papers (e.g., Gray et al., 2016; Causon and Gill, 2018; Roach et al., 2018, Methratta and Dardick, 2019). To foster collaborations between US and European colleagues going forward, the International Council for the Exploration of the Sea (ICES) has recently convened the Working Group for Offshore Wind Development and Fisheries (WGOWDF). The central purpose of the WGOWDF is to bring the multidisciplinary expertise of its membership to bear on these issues (Box 1) in synergy with other existing ICES working groups, including one focused on Marine Benthal and Renewable Energy Developments.

Learning from Previous Experience

The Block Island Wind Farm (BIWF) is the first operational offshore wind facility in US marine waters. Commissioned in late 2016, BIWF is a 30 MW demonstration-scale project consisting of five 6 MW turbines located in state waters 6 km off the coast of Block Island, Rhode Island. The BIWF experience provided an opportunity to learn about how offshore wind interacts with both ecological and human communities. First, it illustrated the importance of early and effective industry-to-industry dialogue in the context of a comprehensive and inclusive marine spatial planning process for clarifying respective concerns and for identifying ways to minimize conflict, mitigate impacts, and generate options for mutually beneficial cooperation (McCann et al., 2013). Next, the BIWF experience demonstrated how the commercial fishing and offshore wind industries could work collaboratively to design ecological impact studies, including both a cooperative groundfish trawl survey and a ventless trap survey for American lobster (*Homarus americanus*) (Lipsky et al., 2016). In addition, the BIWF experience provided an opportunity for the first studies of offshore wind effects in a US ecosystem, including studies of the acoustic

BOX 1. TERMS OF REFERENCE FOR THE ICES WORKING GROUP ON OFFSHORE WIND DEVELOPMENT AND FISHERIES (WGOWDF)

1. Review and report on fishing industry interactions with offshore wind development and document lessons learned including effects on the distribution of fishing operations.

2. Develop and report on methodologies to assess the impact of offshore wind development on fishery resources. These assessments should include observational and model-based approaches and consider hindcast and forecast data and models.

3. Consider and report on effects of habitat alteration by offshore wind development on fisheries. This consideration should include anticipated changes to the benthic habitats, potential for invasive species, vertical and horizontal movement of water, sediment suspension, and water column changes.

4. Review ICES expertise and identify gaps and opportunities relative to renewable energy and marine ecosystems and sustainability.

environment during pile driving (Amaral et al., 2019), sediment suspension and deposition during cable laying (Elliott et al., 2017), and establishment of the post-construction benthic community (LaFrance Bartley et al. 2019), as well as effects on the flatfish community during construction (Wilber et al. 2018). Lastly and perhaps most importantly, with few unambiguous findings from these studies, the BIWF experience demonstrates the ongoing challenges in attaining a clear understanding of ecological effects. This is due in part to low statistical power and high uncertainty in individual studies. But the larger issue illuminated by these research efforts is the high degree of complexity in the interactions between wind development and environment and just how critical rigorous study designs are for understanding them.

The United States also has a long history with other offshore industries, such as the oil and gas industry, which can be further explored. For example, the fishery liaison/fishery representative framework that was developed in the UK (FLOWW, 2014) and adopted in the US offshore wind energy sector had some of its earliest roots in the Joint Oil and Fisheries Liaison Office (JOFLO) established for the oil and gas industry offshore southern California. With regard to environmental effects, analogs concerning the artificial reef effect post-construction and the effects of decommissioning structures can be brought to bear on understanding potential life-cycle effects from offshore wind (Birchenough and Degraer, 2020).

Need for Innovation

Successfully surmounting the challenges brought by offshore wind development will require innovation across several arenas, including monitoring technology, experimental design, and cooperative research. The difficulty of sampling with traditional trawl or dredging gear is driving innovation in new monitoring methods that include using environmental DNA (eDNA), both aerial and underwater autonomous vehicles, remotely operated vehicles (ROVs), digital aerial photography, automated sensors, stereo camera technology, artificial intelligence, and machine learning (Thomsen et al., 2012; Kresimir et al., 2016). Innovative experimental designs such as the before-after-gradient (BAG) method are being explored. BAG can offer many advantages over the traditional before-after-control-impact (BACI) design by explicitly incorporating spatial heterogeneity and improving the ability of a study to detect changes from baseline (Methratta, 2020). Innovation in cooperative research is spurring discussions on the use of appropriate gear and on how, when, and where to sample. It is also catalyzing collaboration among vessel operators to improve real-time data collection and to create new uses of owner-collected data. If approached deliberatively, future opportunities may exist for gear modification, vessel or marine radar improvements, or improvement of port infrastructures.

Integrated Ecosystem Assessment as an Organizing Approach

Ecosystem-based management provides a framework for balancing the ecological and human dimensions of offshore wind through consideration of how ecosystem components, including humans, interact with management sectors across the entire ecosystem (Levin and Lubchenco, 2008). As an operational approach to ecosystem-based management, Integrated Ecosystem Assessment is a multi-step process that permits the evaluation of cross-sector trade-offs (Samhouri, et al., 2014; Figure 3). Approaches to including wind facility development into an Integrated Ecosystem Assessment framework in the United States would benefit from examining previous efforts at wind facilities elsewhere to link functional diversity with ecosystem services (Causon and Gill, 2018), to identify ecosystem indicators (Raoux et al., 2019), and to develop ecosystem simulation models (e.g., Pezy et al., 2018).

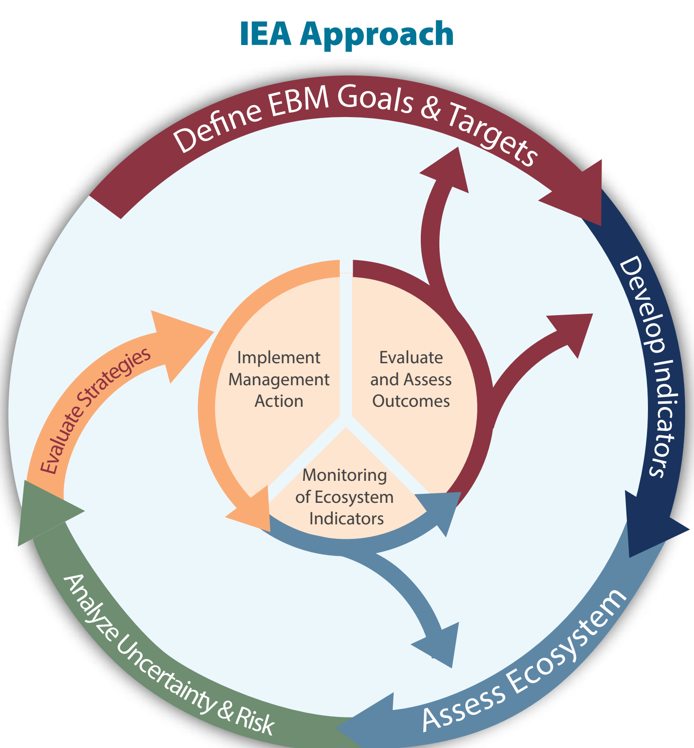

FIGURE 3. The NOAA Integrated Ecosystem Assessment (IEA) approach, a multi-step process that permits evaluation of cross-sector trade-offs. EBM = Ecosystem Based Management. *From NOAA IEA Program,* https://www.integratedecosystemassessment.noaa.gov/national/IEA-approach, *Samhouri et al., (2014)*

CONCLUSIONS AND RECOMMENDATIONS

Renewable energy and sustainable seafood are both integral elements of a sustainable ocean economy and will certainly both be needed to support the future of society. The spatial overlap between these two industries in the offshore zone creates not only many challenges but also many opportunities. Achieving coexistence will involve an all-of-the-above approach that incorporates a combination of collaboration, regional approaches, and innovation. To that end, we make the following recommendations:

1. Continue to advance cross-sectoral collaborations.
2. Co-design methods and approaches with the fishing community in coordination with wind energy developers to address specific areas of conflict, collect enhanced spatially referenced fisheries data, and create a common framework for mitigating adverse impacts to fishing communities.
3. Develop regional approaches to advance the best possible science that utilize standardized methods and an accepted set of best practices for designing impact studies.
4. Adapt existing fisheries resource surveys to wind development in order to continue to deliver the highest quality scientific advice.
5. Develop means to integrate local-scale monitoring with regional and shelf-wide scientific assessments.
6. Continue to innovate in the arenas of cooperative research, monitoring technology, and experimental design.
7. Continue building opportunities to learn through domestic and international collaborations that develop operational information products and methods.
8. Advance an Integrated Ecosystem Assessment framework that includes offshore wind in the evaluation of trade-offs and cumulative impacts.

REFERENCES

Amaral, J.L., A.S. Frankel, A.A. Khan, Y.-T. Lin, J.H. Miller, A.E. Newhall, G.R. Potty, and K.J. Vigness-Raposa. 2019. *Underwater Acoustic Monitoring Data Analyses for the Block Island Wind Farm, Rhode Island*. BOEM 2019-029, 110 pp., https://espis.boem.gov/final reports/BOEM_2019-029.pdf.

Beiter, P., and W. Musial. 2016. *Terminology Guideline for Classifying Offshore Wind Energy Resources*. NREL/TP-6A20-65431, NREL, Golden, CO, https://www.nrel.gov/docs/fy16osti/65431.pdf.

Birchenough, S.N.R., and S. Degraer. 2020. Science in support of ecologically sound decommissioning strategies for offshore man-made structures: Taking stock of current knowledge and considering future challenges. *ICES Journal of Marine Science* 77:1,075–1,078, https://doi.org/10.1093/icesjms/fsaa039.

BOEM (Bureau of Ocean Energy Management). 2019. *National Environmental Policy Act Documentation for Impact-Producing Factors in the Offshore Wind Cumulative Impacts Scenario on the North Atlantic Continental Shelf*. US Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs, Sterling, VA, OCS Study 2019-036, 213 pp.

BOEM. 2020. Vineyard Wind 1 *Offshore Wind Energy Project Supplement to the Draft Environmental Impact Statement*. Office of Renewable Energy Programs, Sterling, VA, BOEM 2020-025, 420 pp.

Causon, P.D., and A.B. Gill. 2018. Linking ecosystem services with epibenthic biodiversity change following installation of offshore wind farms. *Environmental Science and Policy* 89:340–347, https://doi.org/10.1016/j.envsci.2018.08.013.

Degraer, S., R. Brabant, B. Rumes, and L. Vigin, eds. 2019. *Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea. Marking a Decade of Monitoring, Research, and Innovation*. Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, Brussels, 134 pp.

Despres-Patanjo, L.I., T.R. Azaovitz, and C.J. Byrne. 1988. Twenty-five years of fish surveys in the Northwest Atlantic: The NMFS Northeast Fisheries Center's bottom trawl survey program. *Marine Fisheries Review* 50:69–71.

DOE (Department of Energy). 2019. *2018 Offshore Wind Technologies Market Report*. Oak Ridge, TN, 92 pp., https://www.energy.gov/sites/prod/files/2019/09/f66/2018 Offshore Wind Technologies Market Report.pdf.

Elliot, J.B., K. Smith, D.R. Gallien, and A.A. Khan. 2017. *Observing Cable Laying and Particle Settlement During the Construction of the Block Island Wind Farm*. BOEM 2017-027, 226 pp., https://espis.boem.gov/final reports/5596.pdf.

Floeter, J., J.E.E. van Beusekom, D. Auch, U. Callies, J. Carpenter, T. Dudeck, S. Eberle, A. Eckhardt, D. Gloe, K. Hänselmann, and others. 2017. Pelagic effects of offshore wind farm foundations in the stratified North Sea. *Progress in Oceanography* 156:154–173, https://doi.org/10.1016/j.pocean.2017.07.003.

FLOWW (Fishing Liaison with Offshore Wind and Wet Renewables Group). 2014. *FLOWW Best Practice Guidance for Offshore Renewables Developments: Recommendations for Fisheries Liaison*. 74 pp., https://www.sff.co.uk/wp-content/uploads/2016/01/FLOWW-Best-Practice-Guidance-for-Offshore-Renewables-Developments-Jan-2014.pdf.

Fugate, G. 2019. Coastal Zone Management Act Federal Consistency Concurrence Letter for the Vineyard Wind Project. Rhode Island Coastal Resources Management Commission, http://www.crmc.ri.gov/windenergy/vineyardwind/VW_FedConConcur_20190228.pdf.

Gill, A.B., M. Bartlett, and F. Thomsen. 2012. Potential interactions between diadromous fishes of UK conservation importance and the electromagnetic fields and subsea noise from marine renewable energy developments. *Journal of Fish Biology* 81:664–695, https://doi.org/10.1111/j.1095-8649.2012.03374.x.

Gray, M., P.-L. Stromberg, and D. Rodmell. 2016. *Changes to Fishing Practices Around the UK as a Result of the Development of Offshore Windfarms – Phase 1 (Revised)*. The Crown Estate, 121 pp.

Hooper, T., C. Hattam, and M. Austen. 2017. Recreational use of offshore wind farms: Experiences and opinions of sea anglers in the UK. *Marine Policy* 78:55–60, https://doi.org/10.1016/j.marpol.2017.01.013.

Jones, I.T., J.A. Stanley, and T. Aran Mooney. 2020. Impulsive pile driving noise elicits alarm responses in squid (*Doryteuthis paeleii*). *Marine Pollution Bulletin* 150:110792, https://doi.org/10.1016/j.marpolbul.2019.110792.

Knowlton, A.R., and S.D. Kraus. 2001. Mortality and serious injury of northern right whales (*Eubalaena glacialis*) in the western North Atlantic Ocean. *Journal of Cetacean Research and Management* (Special Issue) 2:193–208, https://doi.org/10.47536/jcrm.vi.288.

Kresimir, W., L. Nathan, C. Meng-Che, H. Jenq-Neng, and T. Rick. 2016. Automated measurements of fish within a trawl using stereo images from a camera-trawl device (CamTrawl). *Methods in Oceanography* 17:138–152, https://doi.org/10.1016/j.mio.2016.09.008.

LaFrance Bartley, M., P. English, J.W. King, and A.A. Khan. 2019. *Benthic Monitoring During Wind Turbine Installation and Operation at the Block Island Wind Farm, Rhode Island – Year 2*. BOEM 2019-019, 318 pp., https://espis.boem.gov/final reports/BOEM_2019-019.pdf.

Levin, S.A., and J. Lubchenco. 2008. Resilience, robustness, and marine ecosystem-based management. *Bioscience* 58:27–32, https://doi.org/10.1641/B580107.

Lipsky, A., S. Moura, A. Kenney, and R. Bellavance. 2016. *Addressing Interactions Between Fisheries and Offshore Wind Development: The Block Island Wind Farm*. SeaPlan, Boston, 16 pp., https://www.openchannels.org/literature/13558.

Livermore, J. 2017. *Spatiotemporal and Economic Analysis of Vessel Monitoring System Data Within Wind Energy Areas in the Greater North Atlantic*. Rhode Island Department of Environmental Management Division of Marine Fisheries, 349 pp., http://www.dem.ri.gov/programs/bnatres/fishwild/pdf/RIDEM_VMS_Report_2017.pdf.

McCann, J., S. Schumann, G. Fugate, S. Kennedy, and C. Young. 2013. *The Rhode Island Ocean Special Area Management Plan: Managing Ocean Resources Through Coastal and Marine Spatial Planning*. University of Rhode Island Coastal Resources Center/Rhode Island Sea Grant College Program, Narragansett, RI, 68 pp.

McClatchie, S., J. Duffy-Anderson, J.C. Field, R. Goericke, D. Griffith, D.S. Hanisko, J.A. Hare, J. Lyczkowski-Shultz, W.T. Peterson, W. Watson, and others. 2014. Long time series in US fisheries oceanography. *Oceanography* 27(4):48–67, https://doi.org/10.5670/oceanog.2014.86.

Methratta, E.T., and W.R. Dardick. 2019. Meta-analysis of finfish abundance at offshore wind farms. *Reviews in Fisheries Science & Aquaculture* 27:242–260, https://doi.org/10.1080/23308249.2019.1584601.

Methratta, E.T. 2020. Monitoring fisheries resources at offshore wind farms: BACI vs. BAG designs. *ICES Journal of Marine Science* 77:890–900, https://doi.org/10.1093/icesjms/fsaa026.

NEAMAP (Northeast Area Monitoring and Assessment Program). 2003. *Development of a Cooperative State/Federal Fisheries Independent Sampling Program*. 12 pp.
NMFS (National Marine Fisheries Service). 2018. *Fisheries Economics of the United States, 2016*. US Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-187a, 243 pp.
NMFS. 2020. *Addendum to Fisheries Economics of the United States, 2016*. US Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-187a, 243 pp.
Nye, J.A., J.S. Link, J.A. Hare, and W.J. Overholtz. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. *Marine Ecology Progress Series* 393:111–129, https://doi.org/10.3354/meps08220.
Olsen, F., and K. Dyre. 1993. Vindeby off-shore wind farm—Construction and operation. *Wind Engineering* 17:120–128.
Pezy, J.-P., A. Raoux, and J.-C. Dauvin. 2018. An ecosystem approach for studying the impact of offshore wind farms: A French case study. *ICES Journal of Marine Science* 77:1,238–1,246, https://doi.org/10.1093/icesjms/fsy125.
Popper, A.N., and A.D. Hawkins. 2019. An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. *Journal of Fish Biology* 94(5):692–713, https://doi.org/10.1111/jfb.13948.
Raoux, A., G. Lassalle, J.-P. Pezy, S. Tecchio, G. Safi, B. Ernande, C. Maze, F. Le Loc'h, J. Lequesne, V. Girardin, and others. 2019. Measuring sensitivity of two OSPAR indicators for a coastal food web model under offshore wind farm construction. *Ecological Indicators* 96:728–738, https://doi.org/10.1016/j.ecolind.2018.07.014.
Roach, M., M. Cohen, R. Forster, A.S. Revill, and M. Johnson. 2018. The effects of temporary exclusion of activity due to wind farm construction on a lobster (*Homarus gammarus*) fishery suggests a potential management approach. *ICES Journal of Marine Science* 75:1,416–1,426, https://doi.org/10.1093/icesjms/fsy006.
Statoil. 2015. *Hywind Scotland Pilot Park Environmental Statement*. Stavanger, Norway, 462 pp.
Samhouri, S.F., A.J. Haupt, P.S. Levin, J.S. Link, and R. Shuford. 2014. Lessons learned from developing integrated ecosystem assessments to inform marine ecosystem-based management in the USA. *ICES Journal of Marine Science* 71:1,205–1,215, https://doi.org/10.1093/icesjms/fst141.
Smythe, T., H. Smith, A. Moore, D. Bidwell, and J. McCann. 2018. *Methodology for Analyzing the Effects of Block Island Wind Farm (BIWF) on Rhode Island Recreation and Tourism Activities*. US Department of the Interior, Bureau of Ocean Energy Management, OCS Study BOEM 2018-068, Sterling, VA, 84 pp.
Stelzenmueller, V., M. Coll, A.D. Mazaris, S. Giakoumi, S. Katsanevakis, M.E. Portman, R. Degen, P. Mackelworth, A. Gimpel, P.G. Albano, and others. 2018. A risk-based approach to cumulative effects assessments for marine management. *Science of the Total Environment* 612:1,132–1,140, https://doi.org/10.1016/j.scitotenv.2017.08.289.
Stenberg, C., J.G. Støttrup, M. van Deurs, C.W. Berg, G.E. Dinesen, H. Mosegaard, T.M. Grome, and S.B. Leonhard. 2015. Long-term effects of an offshore wind farm in the North Sea on fish communities. *Marine Ecology Progress Series* 528:257–265, https://doi.org/10.3354/meps11261.
Thomsen, P.F., J. Kielgast, L.L. Iversen, P.R. Moller, M. Rasmussen, and E. Willerslev. 2012. Detection of a diverse marine fish fauna using environmental DNA from seawater samples. *PLoS ONE* 7:e41732, https://doi.org/10.1371/journal.pone.0041732.
Wilber, D.H., D.A. Carey, and M. Griffin. 2018. Flatfish habitat use near North America's first offshore wind farm. *Journal of Sea Research* 139:24–32, https://doi.org/10.1016/j.seares.2018.06.004.
Willsteed, E.A., S. Jude, A.B. Gill, and S.N.R. Birchenough. 2018. Obligations and aspirations: A critical review of offshore wind farm cumulative impact assessments. *Renewable and Sustainable Energy Reviews* 82:2,332–2,345, https://doi.org/10.1016/j.rser.2017.08.079.

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AUTHORS

Elizabeth T. Methratta (elizabeth.methratta@noaa.gov) is Fishery Biologist, IBSS Corporation, in support of NOAA Fisheries, Woods Hole, MA, USA. **Anne Hawkins** is Executive Director, Responsible Offshore Development Alliance, Washington, DC, USA. **Brian R. Hooker** is Lead Biologist, US Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs, Sterling, VA, USA. **Andrew Lipsky** is Lead for Fisheries and Offshore Wind, and **Jonathan A. Hare** is Science and Research Director, both at NOAA Fisheries, Woods Hole, MA, USA.

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