



NJ Climate Change Alliance

Ecological Monitoring and Mitigation Policies and Practices at Offshore Wind Installations in the United States and Europe

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ABSTRACT

Offshore wind energy is poised to expand dramatically along the eastern United States. However, the promise of sustainable energy also brings potential impacts on marine ecosystems from new turbines and transmission infrastructure. This whitepaper informs government officials, scientists, and stakeholders in New Jersey about the current policies and monitoring methods other jurisdictions use to monitor potential ecological impacts from offshore wind installations. We reviewed policy documents in the eastern U.S. and Europe, reviewed the scientific literature, and conducted stakeholder interviews in Spring 2020. We found:

1. Short-term (3-5 year) project-specific efforts dominate coordinated regional and project life duration ecological monitoring efforts at offshore wind farms in North America and Europe.
2. Eastern U.S. states use permitting processes, coastal zone management authorities, and sometimes require ecological monitoring/mitigation plans as part of the energy procurement process. However, publicly available federal and state-level supporting documents only vaguely describe ecological impact monitoring plans, technologies, and duration; and are unclear in differentiating required activities from recommended guidelines for monitoring.
3. A rich scientific literature forms an existing knowledge base of ecological monitoring at offshore wind installations. However, the scientific literature points to challenges in evaluating ecological impacts as monitoring technologies rapidly develop and scientists learn more about the confounding factors of climate change and the natural variability of ecological systems.
4. Interview participants described a patchwork approach to ecological monitoring developing in the U.S., with developers committing resources to various research groups and taxa with few unified regional strategies. Such a path may lead to inconsistent requirements and coordination among states, inadequate spatial and temporal scale of monitoring, and a lack of mechanisms for developers to fund coordinated, regional approaches.
5. Interview participants expressed optimism that emerging regional ecological monitoring entities (e.g., the Responsible Offshore Science Alliance or a Regional Wildlife Science Entity) could help coordinate processes for collecting and managing data to address concerns at a regional level. Successful collaborative efforts to develop baseline regional data-sharing, at a minimum, can increase the chances that scientists will be better able to assess cumulative environmental impacts of offshore wind installations in the future.

Ultimately, our review reveals that the exact nature of ecological impact monitoring at offshore wind installations in North America is still developing. State agencies and offshore wind stakeholders have the opportunity to address regional and collaborative monitoring challenges to increase the likelihood of advancing ecological monitoring investments and practices for future development.

EXECUTIVE SUMMARY

Offshore wind energy is expanding rapidly along the U.S. Atlantic continental shelf. State and federal agencies are working with scientists and stakeholders to collectively determine how best to monitor and mitigate any potential ecological impacts associated with the installation of turbines, cables, and other associated infrastructure. This review is intended to collectively inform New Jersey coastal resource managers, scientists, and stakeholders about practices for ecological monitoring and mitigation of offshore wind energy systems by summarizing current policy (Part I) and methodological approaches (Part II) to ecological monitoring thus far at European and Eastern U.S. offshore wind installations.

Part I: Ecological Monitoring Policy

We reviewed policy documents related to ecological monitoring and mitigation at offshore wind energy installations from four states in the Northeast U.S., as well as three leading European wind energy producers (the United Kingdom, Germany, and Denmark). Policy documents included developer site assessment plans (SAP), developer construction and operations plans (COP), Bureau of Ocean Energy Management (BOEM) led environmental impact statements (EIS), and state energy procurement documents and guidelines. We also interviewed 12 individuals representing 9 organizations in the U.S. that include state agencies and not-for-profit organizations with expertise related to offshore wind energy. Key findings included:

- The environmental review process in the U.S. is led by BOEM with input by various federal and state agencies. Planned ecological monitoring and mitigation activities at each installation are specified in a developer's SAP and COP. While BOEM publishes methodological guidelines for ecological monitoring, the distinction between required and recommended practices is often unclear. Draft SAPs, COPs, and other documents available to date for U.S. offshore wind energy installations are vague (or partially redacted) with respect to specific commitments of monitoring and mitigation activities that will be carried out. Instead, they are more like commitments to work with agencies, scientists, and stakeholders adaptively to address concerns during the federal National Environmental Policy Act (NEPA) environmental review process. To address unclear commitments in monitoring, interview participants encouraged a more explicit framework that clearly and consistently prescribed best-practice monitoring approaches when available, but allowed for a processes to integrate improvements in practice methods over time. Lack of consistent monitoring expectations could hamper efforts to assess variation in impacts across projects, while overly prescriptive requirements could be rendered inadequate by the time of project construction.
- In addition to the federal environmental review process, New York, Massachusetts, and Connecticut addressed potential ecological impacts of offshore wind energy projects by requiring plans for how ecological monitoring and mitigation activities would be carried out as part of the bidding/procurement process. However, rather than setting forth detailed plans for monitoring and mitigation, these documents often committed to disclosing the details at later steps in the regulatory process. In New York and Connecticut, for example, the plans (known as 'Mitigation Plans') are viewed as evolving documents which are refined and solidified through consultation with the states as the environmental review process unfolds. Several Mitigation Plans and bid documents also included commitments of funding to outside groups conducting marine science research.

Interview participants felt that ecological monitoring requirements generated as part of the procurement process allowed for flexibility, but also required shared authorities and negotiations among agencies.

- In some states, other regulatory mechanisms were also used to ensure that desired ecological monitoring practices were followed, including water quality certificates (Rhode Island), cable landing permits (New York), and Coastal Zone Management Act authorities (Rhode Island, Massachusetts).
- Europe has been studying ecological impacts at offshore wind installations for over two decades. Five European countries – Belgium, Denmark, Germany, Netherlands, and the U.K. – possess large (> 200 MW) offshore wind installations and each has different requirements for ecological monitoring and mitigation. Germany has the strictest standards with developers required to conduct two years pre- and 3 to 5 years post-construction monitoring for most potential impacts. National funding (including at least one joint project between two countries) has resulted in extensive monitoring at four installations (Alpha Ventus [Germany], Horns Rev [Denmark], Nysted [Denmark], and Egmond aan Zee [Netherlands]) for durations of up to 7 years post-construction. Otherwise, shorter-term, developer-funded ecological impact monitoring is the norm among European countries.
- Interview participants noted that a patchwork approach to ecological monitoring appears to be developing in the U.S., with developers committing resources to various research groups and taxa in different states, but with no unified regional strategy. Participants felt monitoring efforts related to individual projects, absent collaboration that includes baseline regional coordination and data-sharing at a minimum, could not address the assessment of cumulative environmental impacts of all wind installations in a region (i.e., impacts beyond those of individual projects). Participants highlighted policies that commit to shared processes and funding strategies that encourage data sharing and regional assessment. However, there are currently no models for governing regional science entities, such as the Responsible Offshore Science Alliance (ROSA), the emerging Regional Wildlife Science Entity (RWSE). New York’s Environmental Technical Working Group was cited by several participants as a helpful collaboration platform. Participants were optimistic that these entities would be successful, but concerned about maintaining progress through the implementation of programs.

Part II: Ecological Monitoring Practice

We conducted a literature review of ecological monitoring and mitigation at offshore wind installations around the world to recognize better how scientific understanding about ecological impact monitoring and mitigation practices are developing. We classified the resulting literature (over 300 peer-reviewed articles and reports published through May 2020) based on taxa, location, study type (empirical, synthesis, model), and field methods used. The purpose of the review was to better understand the prevalence and utility of various methodological approaches rather than to summarize results or outcomes of these approaches. We found:

1. Globally, birds were the best-studied group with over 125 references. Fish, invertebrates, and marine mammals were close behind with 90-100 references each. Bats and sea turtles had considerably fewer studies with 27 and 10, respectively.

2. Compared with the development of offshore wind and the associated research progress in Europe, studies are accumulating at a similar pace in North America. Fish and invertebrates appear to be less well-studied in North America.
3. Studies of the ecological impacts of offshore wind farms have focused on two broad areas: direct mortality and displacement due to habitat degradation.
 - a. Direct injury or mortality has been a primary focus for birds and bats (collisions), as well as for sea turtles and marine mammals (noise).
 - b. Displacement from offshore wind installations has also been studied for all species, but especially for fish and invertebrates, for which community-level shifts seem to be of greater interest.
4. Monitoring methods varied widely across taxa. A broad theme is the existence of many rapidly-developing technologies that will ultimately improve our ability to monitor for these potential impacts at offshore wind installations. Rapidly advancing technologies are especially relevant in the realms of measuring bird and bat collisions, as well as large-scale monitoring of marine fauna using aerial digital imaging, eDNA, and autonomous acoustic technologies.
5. Interview participants identified a need to prioritize monitoring approaches to detect biologically meaningful changes with adequate statistical power, that can be completed within an appropriate time frame to make decisions. Where the monitoring community cannot answer questions related to ecological changes within the short impact assessment timelines of individual projects, participants suggested long-term investments in regional studies as a way to prepare today for a decades-long investment in offshore renewable energy.
6. Interview participants expressed concerns that policymakers' expectations in the ability to definitively conclude whether or not ecological changes are directly related to offshore wind or establish causality may be unrealistic given potentially confounding factors such as climate change as well as natural variability. However, long-term and regional studies would again be best suited to disentangling this natural variation and providing evidence of causality.
7. Interview participants encouraged mechanisms to share regional monitoring data, including coordinated data collection efforts and common methodological standards to enable comparison. Participants saw potential benefits for coordinated data to allow a better understanding of project-specific as well as cumulative impacts from offshore wind energy development, and in evaluating the efficacy of different technologies and methods across projects.

At this early stage of offshore wind energy development in North America, it is an opportune time to take stock of the European experience and compare varied approaches among U.S. states. This assessment can serve as a starting point for those interested in New Jersey's offshore wind sector to consider an ecological monitoring and mitigation program capable of balancing stakeholders' interests in sustainable offshore wind energy and ecological impacts. This review gathers disparate information on policy and monitoring into one place to inform that effort.

PREFACE

This effort was conducted on behalf of the New Jersey Climate Change Alliance in order to inform offshore wind planning efforts in New Jersey with consideration of ocean and coastal ecological impacts of offshore wind. The New Jersey Climate Change Alliance is a network of diverse organizations that share the goal of advancing science-informed climate change strategies at the state and local levels in New Jersey, both with regard to adapting to changing climate conditions and addressing the emissions that cause climate change. Alliance participants include representatives of public, private and non-governmental New Jersey organizations from sectors including transportation, emergency managements, business, energy, engineering, farming, insurance, environment, health, community planning, environmental Justice, natural resource management, and others. The Alliance does not work to influence political outcomes or specific pieces of legislation; rather, the work of the Alliance serves to integrate science with evidence and diverse points of view through the voices of Alliance participants for the purpose of informing short and long-term climate change strategies and outlining policy options for New Jersey.

In particular, this project was intended to better understand the extent to which state agencies in New Jersey may have opportunities to monitor and address potential coastal and ocean ecological impacts of offshore wind. While the authors recognize that there is considerable effort underway in the Northeast and Mid-Atlantic to develop consistent regional (multi-state) monitoring efforts, the particular focus of this effort was to inform upcoming decision-making specific to New Jersey.

This project was supported by The Energy Foundation. While individual participants of the Alliance do not necessarily agree with each and every insight outlined in this product, the Alliance Steering Committee concurs that the content of this report/product presents critically important issues facing New Jersey. The views expressed do not necessarily represent the official positions of participants of the New Jersey Climate Change Alliance nor The Energy Foundation. Rutgers University serves as the facilitator of the Alliance and recommendations in the report do not represent the position of the University.

INTRODUCTION

Offshore wind energy production is expanding rapidly in the U.S., and expected increases from its present level of seven turbines (42 MW off Rhode Island and Virginia) range up to several thousand turbines in only 15 years (e.g., ~20,000 MW forecast by 2035; Musial et al. 2019). The ecological effects of such an expansion have been relatively well-studied in Europe, which increased from ~10 MW to over 12,600 MW (~3,600 turbines) over the period 2000–2016 (NorthSEE n.d.). However, our understanding of the potential impacts on North American marine ecosystems is still developing. In Europe, multiple ecological impacts have been documented (in at least some contexts) and are currently a focus of ecological monitoring efforts. These impacts range from the air space surrounding turbines to the seafloor (Figure 1) and include:

- mortality or injury to birds/bats and marine animals and from turbine blades and pile-driving noise, respectively;
- potential displacement of pelagic organisms (e.g., whales, fish) and seabirds from project areas if the wind energy installation creates unsuitable habitat (MMO 2014, English et al. 2017); and
- alteration of sea bottom habitats resulting in changes to fish and invertebrate communities (e.g., the ‘artificial reef’ and ‘steppingstone’ effects, and electromagnetic fields).

In addition to the impacts of individual projects, recent interest has also focused on possibility of cumulative impacts; these are the sum total of impacts from all offshore wind development in a region and could potentially take the form of regional wildlife population declines or other changes to the continental shelf ecosystem.

Eastern states are leading the way in developing offshore wind in the U.S., with the vast majority of near-term growth in the country expected to occur on the Atlantic Continental Shelf (Musial et al. 2019). Eastern states, along with federal agencies, are pioneering efforts to understand the resulting local and regional ecological impacts. Such efforts ensure public trust and stakeholder support for the expansion of a much-needed low-carbon energy source (Bidwell 2017). Species of particular concern in this region include several listed under the Endangered Species Act, namely the North Atlantic right whale (*Eubalaena glacialis*), multiple sea turtles, Atlantic sturgeon (*Acipenser oxyrinchus*), red knot (*Calidris canutus rufa*), and northern long-eared bat (*Myotis septentrionalis*). Many other species of migratory birds, resident seabirds, and commercially important fish and invertebrates inhabit or transit through this region. The Bureau of Ocean Energy Management (BOEM) leads the assessment of environmental impacts, but state policies also apply and can vary from state to state (Campo et al. 2020).

In this document, we aim to: 1) highlight the role of states within the offshore wind energy regulatory process in the U.S. as it relates to ecological monitoring; 2) summarize the regulatory systems for ecological monitoring in select European countries for context; and 3) summarize the body of scientific literature to examine how different jurisdictions conduct ecological monitoring at offshore wind installations. We supplement this effort by conducting and summarizing content from 9 interviews with stakeholders (government and NGO) from throughout the Northeast and the Mid-Atlantic United States. The intent is to provide those interested in the development of New Jersey’s nascent offshore wind energy sector with a solid foundation of information regarding policy and methodological approaches from which to proceed. The first section ("Part I: Ecological Monitoring and Mitigation

Policies") focuses on regulatory policies and processes in each state and country considered. The second section ("Part II: Ecological Monitoring and Mitigation Practices") focuses on specific ecological impact monitoring and mitigation approaches, and how and why they are implemented at offshore wind projects worldwide.

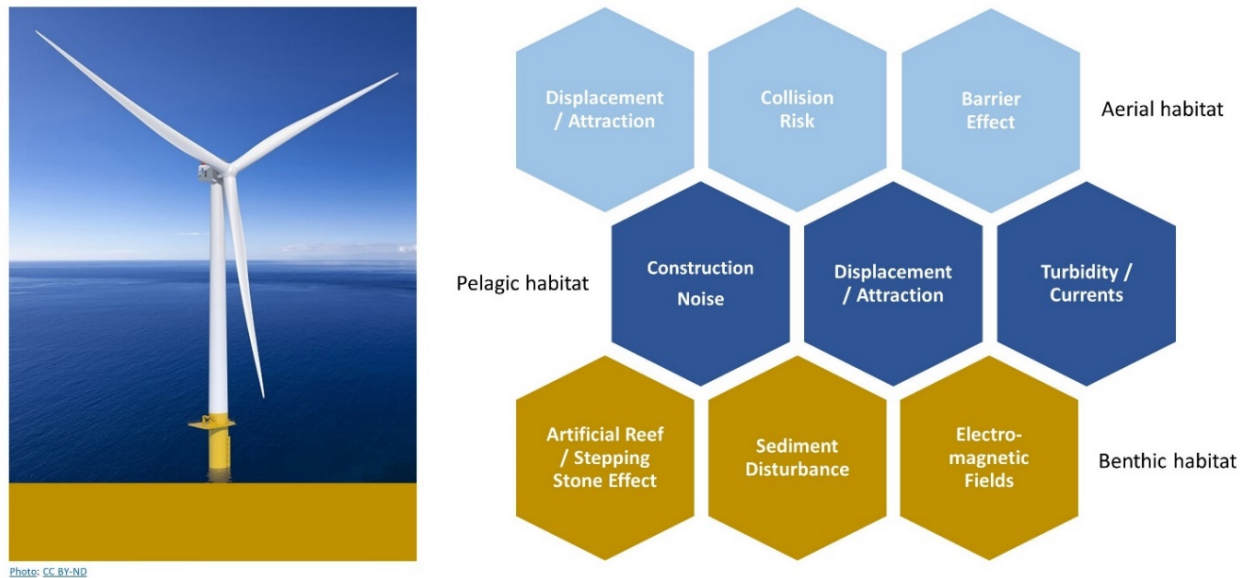


Figure 1. Some potential impacts of offshore wind installations to marine ecosystems by vertical habitat zone: aerial, pelagic, and benthic.

PART I: ECOLOGICAL MONITORING AND MITIGATION POLICIES

Currently, in the U.S., the process for establishing an offshore wind energy installation in federal waters (i.e., waters > 3 nautical miles from shore), and for deciding which ecological monitoring activities will occur there, culminates with an approved Environmental Impact Statement (EIS) prepared in accordance with the National Environmental Policy Act (NEPA). The broader process (including the NEPA review) is led by BOEM, in coordination with multiple state and federal agencies, and can be divided into four primary stages (AWEA 2020):

- 1) **Planning and Analysis**, in which BOEM leads the process of identifying an area as suitable for wind energy production and completing an Environmental Assessment (EA) to determine if an EIS is warranted;
- 2) **Leasing**, in which BOEM publishes a sale notice, holds an auction, and issues the lease;
- 3) **Site Assessment**, in which the developer prepares a Site Assessment Plan (SAP) detailing the baseline geological and ecological conditions at the site; and
- 4) **Construction and Operation**, in which the developer, in consultation with BOEM and many other agencies, prepares a Construction and Operations Plan (COP) that specifies (among other things) plans for ecological monitoring and mitigation activities. When BOEM approves the COP, it then prepares an EIS comparing various alternatives to the COP and their predicted impacts, and solicits public comments. BOEM then issues a Record of Decision detailing the preferred

alternative of the COP including plans for required ecological monitoring and mitigation activities to be completed at the wind installation.

The developer-prepared SAP must include baseline ecological information obtained during a biological survey including bottom mapping and population surveys for fish, marine mammals, sea turtles, and sea birds. (Code of Federal Regulations 30, 585.610). While the COP should include planned environmental monitoring and mitigation activities to be performed during the construction and post-construction phases (CFR 30, 585.626), there is no prescribed list of activities that must be performed at each installation. Instead, monitoring and mitigation activities are determined on a lease-by-lease basis in consultation with BOEM guidelines and multiple other agencies.

For example, “if there is reason to believe” that endangered species or their critical habitat may be affected, then BOEM consults with US Fish and Wildlife Service (USFWS) and relevant state agencies, which make a judgment as to “whether, and under what conditions, [they] may proceed” (CFR 30, 585.801). In such cases, developers are required to submit plans to BOEM to monitor incidental take and adverse effects on critical habitat. If marine mammals are potentially impacted, authorization from the USFWS or National Oceanic and Atmospheric Administration must be obtained and the developer must comply with requirements of these agencies for mitigating harm to these species (CFR 30, 585.801). If Essential Fish Habitat (defined under Magnuson-Stevens Fishery Conservation and Management Act) may be impacted, BOEM is required to consult with the National Marine Fisheries Service and the developer may be required to conduct additional surveys (CFR 30, 585.803).

When monitoring activities are required at offshore wind installations, a series of guidelines published by BOEM recommend specific monitoring methods and durations for various species groups (BOEM 2017, 2019a-c). Generally, the timeframe recommended by BOEM for impact monitoring is two to three years pre- and post-construction, although no timeframes are provided for marine mammals and sea turtles. While it seems that COPs should (per the regulations) specify exactly which monitoring and mitigation activities will be performed and for how long, the two draft COPs released thus far (for the South Fork [New York] and Vineyard Wind 1 [Massachusetts] installations) include only vague commitments with regards to monitoring. For example, the South Fork COP states that plans will be “developed in coordination with the relevant agencies prior to construction” (draft COP for South Fork Wind Farm, p. 4-436). As the finalized EIS requires a public comment period and the consideration of alternative versions of the COP (AWEA 2020), it is possible that the ultimate COP draft will provide more specific information.

During the BOEM process, usually before the COP is drafted, states begin the process of purchasing the power that will be produced and to oversee the transmission planning process for bringing the power onshore. During these stages, states have various forms of leverage to ensure that their concerns are met throughout the life cycle of the wind energy development. These range from review of the COP by state agencies, to Federal Consistency reviews allowed under Coastal Zone Management Act authority, to various purchasing and permitting processes (Campo and Iwicki 2020). States issue formal requests for proposals (RFPs) from wind energy companies to provide power (the 'procurement process'), approve long-term energy supply contracts ('power purchase agreements'), and approve permits for plans for routing and bringing electric power cables onshore.

Under the Coastal Zone Management Act, states have the authority to approve or deny a project based on consistency with the state's federally-approved coastal zone management plan. This generally relates to compatibility with existing uses of the marine environment, including the use of natural resources (e.g., fishing). An approved CZMA consistency certification is a required component of each EIS. As a single project can supply power to multiple states, these approvals often involve numerous agencies across states, and many include additional stipulations regarding which ecological monitoring and mitigation activities will occur at a project. In effect, they provide states with regulatory authority to ensure that the wind energy they purchase, though produced in federal waters, is as environmentally friendly as possible. Structures and policies differ among eastern states, and also among European countries. Below we summarize the general process for jurisdictions in the Northeast U.S., areas adjacent to New York and New Jersey in the Mid-Atlantic U.S., and Europe, as well as the progression of approvals for individual projects, to provide insight into different pathways by which states can approach ecological monitoring and mitigation at offshore wind installations.

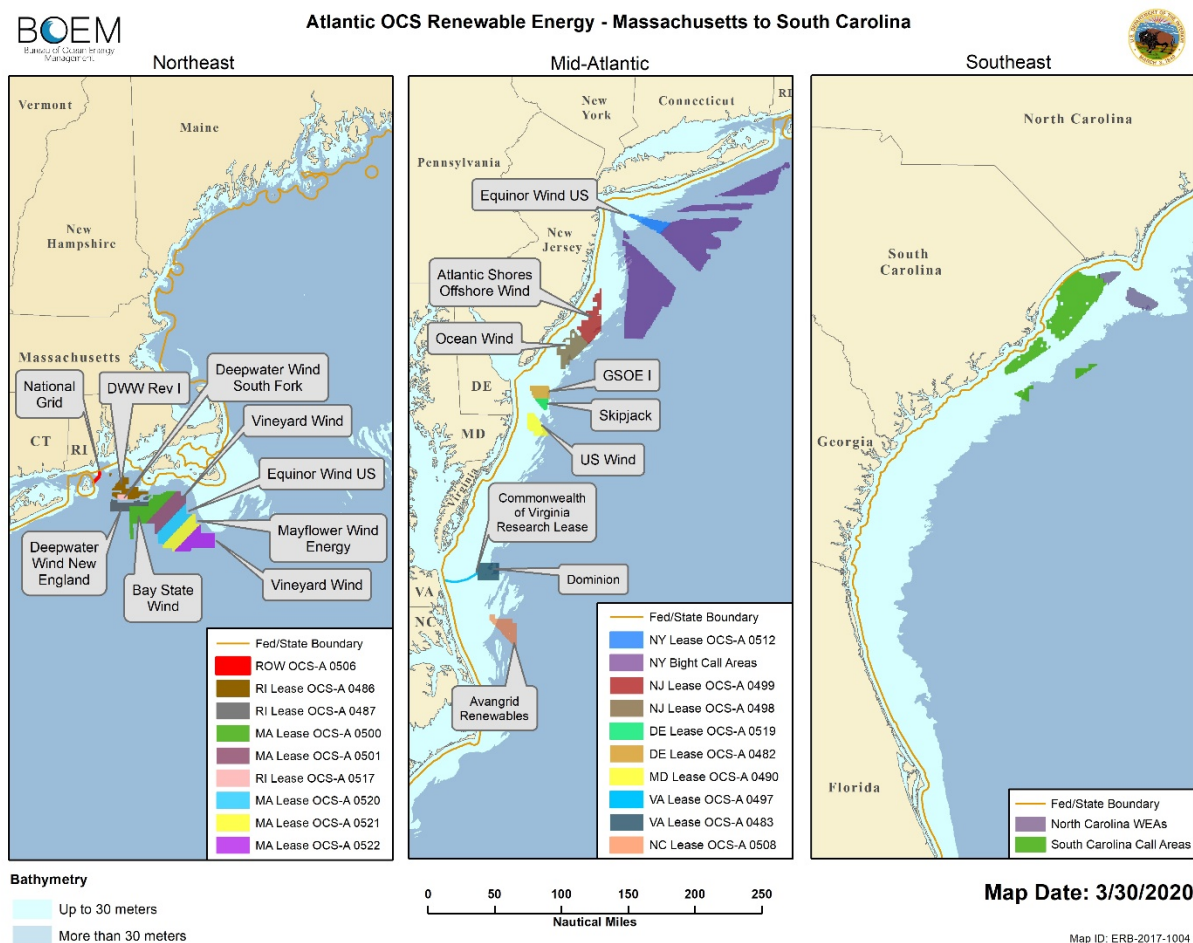


Figure 2. Map of planned or existing wind energy developments in the eastern U.S. Empire Wind is the blue triangle off New York City in the center map labeled "Equinor Wind U.S.". All other wind projects discussed in this policy review (Part I) cluster south of Cape Cod and east of Long Island. Source: Bureau of Ocean and Energy Management (BOEM).

Massachusetts (USA)

Massachusetts is a leader in offshore wind energy production as its 800 MW Vineyard Wind 1 project will likely be among the first large offshore wind installations to supply power to the U.S. (possibly in 2023). Massachusetts' process for procuring offshore wind energy begins with an RFP administered by the Department of Energy Resources (DOER) and the Commonwealth's distribution companies (Bill H.4568, Section 83C). The RFP states that developers must demonstrate that all proposed projects mitigate environmental impacts "where possible" and requires a detailed description of how they will accomplish mitigation efforts. It also considers, among other economic incentives, investment in "... environmental research facilities to support offshore wind industry". After a winning bid is selected, a long-term power purchase agreement must be negotiated and approved by the Massachusetts Department of Public Utilities (MA DPU) subject to an additional review of economic considerations and planned mitigation of environmental impacts (Bill H.4568). Review of the COP is required by the Massachusetts Office of Coastal Zone Management, which issue a consistency certification with regards to the state's coastal zone management plan (e.g., compatibility with existing maritime industries and natural resource priorities) prior to the EIS when the certification is typically required. Furthermore, the Massachusetts Environmental Policy Act requires a Final Environmental Impact Report certificate, the Clean Water Act (Section 401) requires a Water Quality Certification, and Massachusetts Department of Environmental Protection (MassDEP) requires a Waterways (Chapter 91) license for shoreline alterations. Potential environmental impacts due to cable landings must also be reviewed and approved by the Energy Facilities Siting Board as well as applicable local governments and commissions.

The winning bidder for Massachusetts' first RFP in 2018 (Vineyard Wind LLC) proposed the Vineyard Wind 1 project (800 MW, 84-turbines) located in federal waters south of Nantucket (lease area OCS-A 0501 in Figure 2). MA DPU approved the applicant's long-term power purchase agreement. A letter from MA DOER recommended approval of the application and recognized Vineyard Wind LLC's voluntary commitment of \$15 million for an economic development fund, including \$3 million for an "Innovations for Marine Mammals Protection Fund" (also known as the "Whales and Wind Fund"). DPU also acknowledged a cooperative agreement between the developer and environmental non-profit groups pledging to take steps to avoid harm to endangered North Atlantic right whales (e.g., altering the seasonal and daily timing of pile-driving). The project's COP (Appendix III-D) includes a commitment to monitor populations of benthic fish and other organisms for 5 years post-construction, an unusually long duration compared with BOEM recommendations and European studies (typically ~2-3 years; BOEM 2019a). Vineyard Wind is proposing a minimal post-construction bird monitoring program based on their determination that levels of exposure and impact to migratory birds and seabirds will be "insignificant" or "unlikely" (Vineyard Wind 1 COP, Volume III, Section 6, p. 6-75). Planned post-construction bird monitoring activities include using a "standardized protocol" to document any dead or injured birds encountered, although specific details of the protocol are not disclosed. MassDEP, the Energy Facilities Siting Board, the Cape Cod Commission, and the town of Barnstable (site of the cable landing) in 2018–2019 (MA OCZM 2020) submitted all required approvals for the project. The consistency certification from the Office of Coastal Zone Management proved controversial. It resulted in Vineyard Wind, LLC creating a \$17 million fund to aid fishers in both Rhode Island and Massachusetts (Kuffner 2019). The

National Marine Fisheries Service (NMFS) declined to endorse the draft Environmental Impact Statement (EIS), citing concerns regarding navigation and fisheries access (Davidson 2020). In response to these and other concerns, a comprehensive study was undertaken by the U.S. Department of Interior assessing the cumulative impacts to various resources and industries (e.g., fisheries) of all offshore wind installations proposed between New York and Massachusetts (MA OCZM 2020). BOEM released the report in June 2020 as a draft supplement to the draft EIS. It found potentially “major effects” on commercial fishing and shipping (Harrington 2020a). A public comment period will follow that will inform potential alternatives, and ultimately a final EIS will be released. The results of the Vineyard Wind 1 EIS process will likely have broad implications for other installations planned for the same region (the Rhode Island – Massachusetts Wind Energy Area, RI-MA WEA) and elsewhere in the U.S. Vineyard Wind 1 was initially scheduled to come online in 2021, but this has now been pushed back to at least 2023.

In Massachusetts’ second RFP for offshore wind power in 2019 (Section 83C II), MA DOER and the Commonwealth’s electric companies chose the Mayflower Wind project (804 MW) by developer Mayflower Wind LLC (a joint venture of Shell and EDP Renewables). Mayflower Wind filed for MA DPU approval of its long-term power purchase agreement in early 2020. The application is still under review, and MA DOER again issued a letter urging the DPU to approve the agreement based on its review of the initial bid. The application and the DOER letter cite the developer’s voluntary commitment to creating a \$77.5 million Offshore Wind Development Fund to be administered by the Massachusetts Clean Energy Center (masscec.com), including \$10 million for marine science and fisheries research (Exhibit A of the proposal). A completed SAP, but not a COP, has been submitted to BOEM so far. Ecological monitoring activities conducted as part of the SAP are unknown as the section is redacted as “Privileged and Confidential” in the version available on the BOEM website.

Rhode Island (USA)

Rhode Island’s process for obtaining offshore wind energy stands out among Northeastern states in several respects. From 2016-2020, Block Island Wind Farm was the nation’s first and only operational offshore wind installation (Virginia now has two turbines). At 5 turbines (30 MW), Block Island is much smaller than other planned projects in North America, and it is still the only project located in state waters. A subsequent and larger project was also unusual in that its procurement relied on adopting a portion of an RFP issued by neighboring Massachusetts (possibly to sidestep the legislative hurdles of creating its own RFP process). Otherwise, Rhode Island’s process is similar to other states. State agencies work closely with BOEM during the NEPA process (RI DEM 2020), issue permits related to transmission infrastructure, and must approve consistency with other maritime uses via the Rhode Island Coastal Resources Management Program (CRMP). Additionally, the Public Utility Commission (PUC) must approve a final power purchase agreement. The PUC does not explicitly require information related to environmental impacts for the application to PUC (Rhode Island General Law 39-26.1-8). In practice, requirements related to ecological monitoring at offshore wind installations in Rhode Island have been implemented via water quality permits (Block Island Wind Farm; RI DEM 2020) and CRMP approval (Kuffner 2019), rather than as part of the procurement or the power purchasing processes.

Block Island Wind Farm (labeled as “National Grid” in Figure 2), built by developer Deepwater Wind LLC (now Ørsted), began operation in 2016. As the nation’s first offshore wind installation, it was

intended as a pilot project for subsequent larger installations in federal waters, and received considerable federal funding as a result (e.g., the BOEM-funded 'RODEO' program). Researchers conducted intensive environmental monitoring of the site with the University of Rhode Island, Woods Hole Oceanographic Institute, and others. In addition to BOEM-funded ecological monitoring, the Rhode Island Department of Environmental Management (RI DEM) required the Block Island Wind Farm developer to fund collection and analysis of fish (trawl) and lobster population data in a before-after control impact (BACI) design as a condition for a required Water Quality Certificate (RI DEM 2020). It is unclear if other ecological monitoring or mitigation activities, before or after construction, were required of the developer for this project.

The competitive solicitation process for Rhode Island's second source of offshore wind power (Revolution Wind Farm, 400 MW, ~40-50 turbines; labeled "DWW Rev 1" in Figure 2) was unusual in that Massachusetts led the process (Rhode Island adopted 400 MW, while Massachusetts adopted 800 MW; Kuffner 2018). In practice, it allowed Rhode Island to take advantage of Massachusetts' RFP requirements that the developer detail planned ecological monitoring and mitigation activities. It also means that Rhode Island was not able to use this RFP solicitation process to impose its own requirements. The Rhode Island PUC then approved a long-term power purchase agreement for Revolution Wind Farm with the developer Deepwater Wind LLC (now Ørsted) in 2019. In their proposal to PUC, Deepwater commits an unknown (redacted) sum in seed funding for a UMASS Marine Fisheries Institute and Blue Economies Initiative. They also cite their environmental responsibility at the Block Island Wind Farm, as well as an agreement with NGOs to comply with best practices for North Atlantic right whale conservation. The developer offered economic investments in the form of \$40 million in port improvements (Ørsted, Revolution Wind Fact Sheet). The developer is required to have an approved consistency certification by the Rhode Island Coastal Resources Management Council, stating that the project would not adversely affect fisheries or other maritime industries in the state. This process has become a venue for objections from commercial fisheries groups in Rhode Island and Massachusetts (Kuffner 2019). The supplement to the Vineyard Wind 1 EIS which found potentially "major" cumulative impacts on fishing and navigation is likely to influence final approvals and ecological monitoring requirements at Revolution Wind (Davidson 2020, Harrington 2020a). The SAP has been released on the BOEM website, but Appendices which may contain information on ecological monitoring activities were not included. The COP is not yet public.

Connecticut (USA)

In Connecticut, the Department of Energy and Environmental Protection conducts the RFP process for purchasing offshore wind energy (DEEP; Public Act 19-71 of 2019). DEEP then reviews proposals in consultation with the Attorney General's Office, the Office of Consumer Counsel, the Public Utilities Regulatory Authority (PURA), and the state's electric distribution companies. Once selected, developers must then submit an environmental and fisheries 'Mitigation Plan' detailing how the developer will monitor and mitigate potential ecological impacts of the project. The plan is then reviewed and (if adequate) approved by DEEP. However, the Mitigation Plan represents an evolving document, subject to change throughout the BOEM-led process of developing the final COP in collaboration with various federal and state agencies (reNews 2020). In addition to DEEP's approval of the Mitigation Plan, the

developers require PURA's approval for a long-term power purchase agreement with the state's electric distribution companies.

In 2018, DEEP selected the Revolution Wind Farm by developer Ørsted to supply 304 MW to Connecticut, an amount added to the 400 MW the same installation will deliver to Rhode Island. PURA approved a long-term power purchase agreement in December 2018 (Ørsted 2018). Specific ecological monitoring or mitigation activities proposed at Revolution Wind Farm are unknown as the winning bid and COP are not yet public. However, the winning bid included \$15 million in local economic development commitments, which could include some support for ecological monitoring or mitigation activities.

Before Connecticut's second (2019) RFP for wind energy, DEEP created a Commission on Environmental Standards to decide what ecological monitoring and mitigation information should be included in the Mitigation Plans (CT DEEP 2019). In the second RFP, DEEP selected the Park City Wind project by developer Vineyard Wind LLC (lease area OCS-A 0501 in Figure 2) to supply 804 MW of offshore wind energy to the state. The Mitigation Plan, submitted in April 2020, was viewed favorably in part due to the 1 x 1 nautical mile turbine spacing (allowing transit of fishing vessels), as well as commitments to environmental monitoring (CT DEEP 2019). In the Mitigation Plan, the developer describes collecting one year of boat-based transect seabird surveys and commits continued financial support of the New England Aquarium's ongoing aerial surveys for marine mammals. Otherwise, the developer cites sufficient existing baseline data and participation in a "Regional Science Entity" (a consortium of government agencies, developers, and NGOs, which the plan says is in the early stages of formation) as justification for not providing more concrete plans for post-construction monitoring. No specific mitigation measures are present for noise effects. The developer will address collision impacts to birds and bats by reducing lighting on structures (flashing red lights) to the extent allowed by the FAA, including (if approved) the use of an Aircraft Detection Lighting System that only turns on when airplanes are near. The developer may define further ecological monitoring details when the COP is released. Agencies and the developer anticipate the project will come online in 2025.

New York (USA)

New York currently has plans to receive power from at least three offshore wind installations, all located in federal waters and in various stages of the BOEM process. Beginning in 2018 (the state's 'Phase 1' solicitation for ~1700 MW of offshore energy), the state required two 'Mitigation Plans' as part of its bidding process for Offshore Wind Renewable Energy Certificate (OREC) and power purchase agreements (PPA): one addressing fisheries impacts and one for other environmental impacts (NYSERDA 2019). New York's State Energy Research and Development Authority (NYSERDA) leads the OREC process under the approval of N.Y. Public Service Commission (PSC), and with input from the Long Island and New York Power Authorities (LIPA and NYPA; Case 18-E-0071, PSC order, July 12, 2018). NYSERDA developed the Mitigation Plans' requirements in consultation with relevant stakeholders (NYSERDA 2019). The Mitigation Plan documents are expected to evolve over the course of the NEPA approval process, subject to change "due to various factors, including, but not limited to, the State Agency Consultation and Technical Working Group Participation..., and through interactions with BOEM" as the SAP and COP are finalized (NYSERDA 2019, p. 81). NYSERDA announces any amendments to the plans in

quarterly public statements. In addition to NYSERDA approval of Mitigation Plans, the N.Y. Coastal Zone Management Program (CZMP) must approve a 'consistency certification' demonstrating no adverse impacts to other users of the state's marine resources (e.g., commercial fisheries) and that the project generally complies with the state's federally-approved coastal zone management plan. Finally, the N.Y. Public Service Commission must approve the route and landing plan for the power cable as laid out in the final COP (Article VII, New York Public Service Law).

New York's first offshore wind power project, South Fork Wind Farm located east of Montauk (130 MW, ~15 turbines), is scheduled to come online in 2022. This project preceded the current (as of 2018) system of NYSERDA-led review and OREC system, with a 2015 procurement process and 2017 power purchase agreement (PPA) led by LIPA. The final PPA makes no mention of ecological monitoring or mitigation and presumably was not required to as the project preceded the requirement for detailed Mitigation Plans. The project (labeled "Deepwater Wind South Fork" in Figure 2) is located in the Rhode Island and Massachusetts Wind Energy Area (RI-MA WEA) for which BOEM completed a comprehensive Environmental Assessment (EA) in 2013 (BOEM 2013). As such, the final SAP (2016) and draft COP for South Fork Wind Farm both rely heavily on the EA as well as on prior ecological baseline survey efforts that were carried out as part of the Rhode Island Ocean Special Area Management Plan, the New York Ocean Plan, and the Massachusetts Ocean Plan. Based on our review of the COP, the only original data collection efforts by Ørsted, or consultants for the project, were acoustic bat detectors placed aboard a ship July – November 2017 (Draft COP pg. 4-270) and 161 benthic fish and invertebrate samples collected in November 2017 using high-resolution photo sampling (draft COP, Appendix N). No mention of post-construction monitoring is made in the draft COP beyond a commitment to "collaborative science with the commercial and recreational fishing industries pre-, during, and post-construction" (draft COP, p. ES-12). Similarly, the COP states "environmental monitoring of various resources will take place and will include, at a minimum, coordination and data sharing with regional monitoring efforts. Monitoring plans will be developed in coordination with the relevant agencies prior to construction" (draft COP, p. 4-436). In response to concerns about fisheries access, Ørsted recently amended its COP to include wider turbine spacing (1 x 1 nautical miles) to facilitate commercial fishing boat transit and committed ~\$2 million for local infrastructure and a fisheries fund (Harrington 2020b, Murphy 2020). The navigation issue will likely persist as BOEM's recently completed 'cumulative impacts' assessment of the entire RI-MA WEA cluster found potentially "major impacts" to navigation (Davidson 2020, Harrington 2020a). The report on cumulative impacts was published as a supplement to the Vineyard Wind 1 EIS, but the outcome will likely affect the ultimate configuration of the South Fork project as well. Additionally, the South Fork project is currently delayed, awaiting approval of the cable landing plan by the N.Y. Public Service Commission (Murphy 2020). The delay is due to local opposition to the power cable landing location in eastern Long Island and opposition of commercial fishing groups. Proposed ecological mitigation measures included in the draft COP include placing limitations on pile-driving (i.e., ceasing January 1 – April 30 and whenever cetaceans or sea turtles are present), deeply burying cables (4-6 feet), and using bird-friendly lighting.

The next project, scheduled to come online in 2024, is Sunrise Wind Farm (880 MW, ~110 turbines), also east of Montauk and built by the same developer, Ørsted. This project received NYSERDA approval for OREC purchase and sale in 2019. It was viewed favorably during review in part because the RI-MA WEA has a well-characterized environment, and the developer offered \$21 million in local

economic investment (NYSERDA 2019, <https://sunrisewindny.com/>). Proposed ecological monitoring activities and timelines are relatively vague in the mitigation plans, stating they "will develop study topics and methodologies through an iterative process... to collect sufficient baseline data prior to offshore construction, and will continue throughout construction and operation of the project..." (NYSERDA 2019, p. F-28). Presumably, the definition of "sufficient" will ultimately be determined by NYSEDA, BOEM, and the relevant state and federal agencies reviewing the final COP and EIS. Specific monitoring activities identified include: 1) boat-based seabird surveys conducted in 2017; and 2) continuing benthic habitat surveys "as part of the regulatory process" (NYSERDA 2019, p. E-8), which according to BOEM guidelines, involves 2-years of quarterly sampling, pre- and post-construction (BOEM 2019c). Mitigation measures proposed include monitoring and adjusting operations for cetaceans during construction, and the use of large turbines with high minimum blade height (30 m) to minimize bird collisions. The 2017 SAP for the lease area does not list any specific monitoring activities, and the project has yet to release a public COP.

The Empire Wind project off New York City (816 MW, 60-80 turbines) by developer Equinor Wind US LLC is scheduled to become operational in 2027. Equinor's proposal was viewed favorably by NYSEDA due in large part to the company's extensive commitment to ecological impact monitoring and mitigation (Hokanson 2019). For example, the company's expertise in gravity-based foundations would eliminate much of the need for noisy pile-driving that can harm endangered right whales and sturgeon (NYSERDA 2019). Developer-funded survey efforts included oceanographic and meteorological measurements, benthic sediment and macrofaunal sampling (video and grab samples), three years of monthly digital [aerial surveys](#) for seabirds, marine mammals, and sea turtles, and placement of a bat detector on board a research vessel (NYSERDA 2019). Monitoring of nocturnal migrant birds (e.g., using radar) does not seem to have been included, despite the site's location in a migratory flyway (the New York Bight within the Atlantic Flyway). Mitigation efforts offered included the use of gravity-based foundations to eliminate pile-driving noise; relatively high minimum blade heights (85 ft) to reduce seabird collision risk; and deeply-buried armored electric cables to reduce potential electromagnetic field effects. BOEM approved the project's SAP in 2018; the draft COP is not yet public.

Mid-Atlantic States (USA)

In the sections above, we focused on New England states and New York as they are generally farther along in the process. However, there are also significant plans for offshore wind energy development in the Mid-Atlantic states, including some of the largest projects under consideration. Here we briefly summarize the progress of offshore wind energy development in New Jersey, Delaware, Maryland, and Virginia including any details regarding ecological monitoring and mitigation where available.

New Jersey. In 2019, an executive order by Governor Murphy (#92) set the ambitious target of 7.5 GW of offshore wind energy for New Jersey by 2035. In the same year, the New Jersey Board of Public Utilities announced Ørsted as the winner of an RFP to develop the 1.1 GW Ocean Wind Project off Atlantic City. In their 444-page application for Offshore Wind Renewable Energy Credits, Ørsted states they will conduct additional ecological monitoring to supplement the state's exhaustive baseline surveys. However, the details of these activities as well as mitigation measures appear to be redacted from the report (e.g., pages 15-7 to 15-16). Redaction of such information from public documents is

common in the industry (e.g., in the Mayflower Wind SAP and Deepwater RFP documents discussed above) to protect proprietary information. According to an NJ Department of Environmental Protection website the proposal contained “detailed environmental protection and mitigation plans” (NJDEP n.d.). Similar RFPs are expected from New Jersey approximately every 2-3 years until 2035.

Delaware. One wind energy installation (Skipjack, ~120 MW; lease OCS-A 0519 in Figure 2) is planned to make cable landfall in Delaware, although it will provide electricity for Maryland. The project caused controversy as the cable landfall is planned for public land (Fenwick State Park; Tabeling 2020). In exchange, the developer Ørsted committed \$18 million to Delaware Department of Natural Resources and Environmental Control for park and shoreline improvements. Delays in approvals have pushed back an expected project commissioning date from 2022 to at least 2023.

Maryland. In addition to the Skipjack project, Maryland is planning to receive power from the planned Marwin installation (248 MW; lease OCS-A 0490 in Figure 2) by developer US Wind, a subsidiary of the Italian company Renexia. Both Marwin and Skipjack have been a source of persistent controversy during public hearings by Maryland Public Service Commission due their visibility from shore (Prensky 2020). Those objections, plus uncertainty surrounding the regulatory process surrounding Massachusetts’ Vineyard Wind 1 project, has led to delays. Marwin is now projected to be commissioned in 2024 at the earliest.

Virginia. The second operational offshore wind energy installation in the U.S. was recently installed in federal waters off Virginia: two turbines (12 MW) built 27 miles off Virginia Beach by Dominion Energy in June 2020 on a lease site owned by the Virginia Department of Mines Minerals and Energy (Dominion Energy 2020). The project resulted from a government-funded scoping study, the Virginia Offshore Wind Technology Assessment Project (VOWTAP), and is intended as a pilot to facilitate expansion into a much larger offshore wind project by Dominion (up to 2 GW). Dominion plans to have a COP for the expansion completed by 2022 and for it to be operational by 2024 (Dominion Energy 2020). Governor Ralph Northam recently signed laws mandating over 5 GW of offshore wind energy for the state by 2034 (Schneider 2020).

United Kingdom

The United Kingdom (U.K.) currently leads the world in offshore wind energy with over 8 GW spread across 30+ wind installations, the first beginning operation in 2000. In the U.K., offshore wind projects require a license under the Food and Environmental Protection Act (FEPA, Part II), issued by different agencies depending on jurisdiction (England, Wales, Scotland, or Northern Ireland; CEFAS 2010). The process is analogous to the U.S. NEPA process in that it requires developers to conduct a thorough review of potential environmental impacts, mitigation measures, and provisions for monitoring to verify that significant impacts do not occur. The developer funds monitoring and mitigation efforts, but some licenses (e.g., for 5 of 19 wind installations reviewed in MMO 2014) state that separate research conducted and funded by the U.K. government may substitute for developer-funded investigations where appropriate. The duration of ecological monitoring required in the U.K. varies from 1-3 years pre-construction and 1-3 years post-construction, with a few exceptions (MMO 2014). There have been two comprehensive reviews of ecological monitoring practices encompassing 19 of the U.K.’s offshore wind

installations (CEFAS 2010 and associated reports; and MMO 2014), which we summarize here by taxa and habitat zone.

Benthic ecology and fish. Developers undertook required quantitative sampling of sediment- and surface-dwelling invertebrate abundance (including the colonization of underwater structures) at all 19 U.K. wind installations reviewed (Walker et al. 2009a, MMO 2014). The most common methods were grab samples, 2-m beam trawls, and photo/video sampling. FEPA licensure required fish monitoring for 17 of 18 wind installations with information available (MMO 2014). The primary methods were 2-m beam trawl (10-30 min per sample) and a variety of commercial fishing techniques summarized as catch-per-unit-effort (CPUE). Sample size requirements of the FEPA licenses are vague, but, in practice, professionals conducted ~20-40 grab sample stations and 7-28 trawl stations per project site, plus less-intensive sampling at 1-4 reference ('control') sites (Walker et al. 2009a, 2009b). Reviews of fish monitoring at offshore wind farms in the U.K. note that a lack of standardization and short duration of monitoring limit the ability to generalize regarding impacts (Walker et al. 2009b, MMO 2014).

Marine mammals. The only systematic marine mammal observations explicitly required under a FEPA license in the U.K. were 4 years of annual Harbor Seal (*Phoca vitulina*) monitoring required at Scroby Sands, a known breeding location for the species (two years pre- and two post-construction; Philpot 2009, MMO 2014). At other projects, monitoring requirements were either absent (8 projects) or vaguely worded (11 projects mainly approved in 2007 and later; MMO 2014). In the latter case, licenses included language indicating possible marine mammal monitoring requirements for 3-20+ years post-construction to be determined in consultation with Natural England and others and reviewed periodically. The MMO (2014) review found no documentation of such monitoring actually occurring as a result of FEPA license conditions. However, at one site (Robin Rigg in Scottish waters), marine mammal monitoring was carried out as part of a different regulatory pathway (Section 36 of the Electricity Act) and involved the creation of a designated monitoring organization and a longer-than-usual duration of the study (at least 10 years total; Vallejo et al. 2017).

Birds. Seabird abundance was monitored for multiple species for 2-3 years pre- and 2-3 years post-construction at all offshore wind installations reviewed by MMO (2014) except two. At Scroby Sands, the focus was on a single species (Little Tern), while at Robin Rigg, a longer duration of monitoring was conducted (5 years pre- and post-construction; Budgey and Ormston 2009, MMO 2014, Vallejo et al. 2017). The primary purpose of these surveys was to quantify habitat displacement. The primary method was boat-based or aerial line-transect surveys conducted in a Before-After Control-Impact (BACI) design following Camphuysen et al. (2004). MMO (2014) suggests increasing potential for recently-developed digital aerial photography-based survey methods as well. Marine radar measurements of abundance and flight heights (coupled with visual observations to provide species identities) were also conducted at a minimum of three projects to inform collision risk and wind installation avoidance (the 'barrier effect'; Budgey and Ormston 2009, MMO 2014). Collision risk, when assessed, was based on statistical models of abundance and flight height (Band 2012), and not by direct observation with collision detection systems (i.e., systems capable of sensing and tallying collisions as they occur; MMO 2014).

Germany

Germany's first offshore wind installation (Alpha Ventus, 60 MW) came online in 2010, followed by > 20 more installations in the next decade totaling over 6 GW of energy. The regulatory process is overseen by Federal Maritime and Hydrographic Agency (BSH), which ultimately signs off on Environmental Impact Assessments (EIA) prepared and funded by the developer (Portman et al. 2009). All EIAs for projects > 20 turbines must follow a set of clearly-defined ecological monitoring protocols (Nolte 2008, BSH 2013). These standards were refined during a research program conducted at Alpha Ventus from 2007-2012 by a public-private organization (Portman et al. 2009, BSH 2014). The organization (the Offshore Wind Energy Foundation, offshore-stiftung.de/en/) owned the lease for the Alpha Ventus wind installation and conducted all required monitoring under BSH standards, plus additional, more-detailed research into ecological impacts funded by the German government (MMO 2014; see rave-offshore.de/en/ecology.html). BSH standards for developer-funded monitoring of subsequent projects dictate two years of baseline study, construction monitoring, and 3-5 years of post-construction monitoring, and a required study of a reference (i.e., control) area in addition to the project area. Below, we briefly review the specific protocols required for each taxa. However, exemptions from the standards can be granted if demonstrated to be unnecessary (BSH 2013), and we are therefore not certain what proportion of wind installations were required to implement each monitoring measure.

Benthic ecology and fish. Five video transects per year are required during baseline only. In all phases, a minimum of one 2-m beam trawl and one grab sample station per nautical mile (or 20 stations minimum) are required per year. Scrape samples also must be collected in the operations phase to assess colonization of underwater structures. An additional 20-30 trawl stations (7-m or Otter type) are required per year to sample fish.

Birds, bats, and marine mammals. Ship-based surveys (12 per year) and/or digital aerial photo surveys (8-10 surveys per year) are required during all phases to survey resident birds and marine mammals. In addition, migratory birds are monitored using a combination of radar and flight-call recordings (supplemented by visual observations) during at least 900 hours spread across the spring and fall migratory periods (using methods of Hüppop et al. 2002), and a high-definition camera system is deployed to determine the species mix of birds found in the rotor-swept area. In the Baltic Sea, bat detectors also must be deployed. To monitor porpoises, 1-2 passive acoustic whale and dolphin detectors (C-PODS) are deployed per project and kept in continuous operation to monitor use of the site pre- and post-construction.

Denmark

Denmark built the world's first offshore wind installations in the 1990s and the country currently generates ~1.5 GW of offshore wind power from 15 project sites. The Danish Energy Agency coordinates the permitting process, which consists of a preliminary investigation permit, an establishment permit, and an operations permit. An Environmental Impact Assessment is completed either by the state-owned transmission company (Energinet; for government-initiated projects) or by the developer (for 'open door' developer-initiated projects); in both cases the developer covers the costs (DEA 2017). This is followed by an 8+ week public comment period and the granting of an establishment and 25-year operations permit (Anker and Jørgensen 2015). Similar to Germany, two early projects (Horns Rev I and

Nysted, totaling 326 MW) were the subject of intensive, government-funded ecological research from 2000-2006 (English et al. 2017). A follow-up study from 2009-2012, co-funded by Germany due to their proximity and common interest in potential ecological effects, focused on longer-term impacts to populations along with targeted questions related to noise impacts (MMO 2014).

Benthic ecology and fish. Benthic invertebrates and fish in Denmark have been monitored using versions of grab samples, photo surveys, dredges or trawls, and catch-per-unit-effort fishing approaches. Grab sample densities ranged from 0.1-0.7 stations km⁻² at an early project to 0.9 stations km² more recently, while fish sampling density was 0.2 stations km² during both projects (Leonard et al. 2006, Energinet.dk 2010). We were unable to determine the duration of monitoring for recent projects, but the well-studied Horns Rev I project involved a typical 2-3 years pre- and post-construction, with an unusually long-term follow-up seven years post-construction due to a government-funded research program (Leonard et al. 2006, Maar et al. 2009, van Deurs et al. 2012, Stenberg et al. 2015).

Marine mammals and birds. Some form of BACI monitoring of marine mammals appears common for Danish offshore wind projects (e.g., three of four projects reviewed by MMO 2014). Methods used to assess potential impacts include modelling based on large-scale existing data sets, supplemented by local passive acoustic ('click detector') monitoring for Harbor Porpoise and aerial surveys for seals at haul-out sites on land where they rest (e.g., Energinet.dk 2010). The duration of monitoring was two years before and after construction at one recent site (commissioned in 2009) and used two T-POD porpoise detectors inside and two outside the wind installation (Tougaard and Carstensen 2011). Bird usage of offshore wind installations is studied using historical data sets, boat-based and aerial transect surveys, and coupled radar/visual surveys (Energinet.dk 2010). Typical durations of monitoring are unknown, but a recent project completed at least two years of pre-construction aerial and radar monitoring, followed by a more targeted three-year post-construction study using radar to investigate risks to migrating raptors (Energinet.dk 2010, Jensen et al. 2016).

Stakeholder Interviews

Our interviews with stakeholders from the Northeast U.S. shed additional light on the policy considerations surrounding ecological monitoring at offshore wind installations. We interviewed 12 individuals representing 9 organizations that include state agencies and not-for-profit organizations. There were three themes that interviewed participants discussed related to the processes with which monitoring is integrated into offshore wind projects:

1. Strengths and limitations of existing authorities and incentives;
2. Mechanisms to encourage data sharing and investment in regional data; and
3. Models of governance and funding to support regional ecological monitoring and cumulative impacts assessment.

Interview participants discussed both coastal zone management authorities (i.e., federal consistency reviews) and procurement decisions as mechanisms for encouraging ecological monitoring and mitigation at offshore wind installations. Several interview participants noted that procurement authorities may have greater flexibility in asking for ecological monitoring. This is because stipulations included as part of RFPs do not necessarily require legal justification, unlike permit enforcement or the application of CZM authorities. However, procurement process flexibility may clash with the potential

for competing agendas among state agencies working through the procurement process. In particular, participants observed tensions between the need for speed and efficiency in development processes and the capability to rigorously evaluate and learn from environmental impacts. Interview participants also stressed that different ecological monitoring plans required under the various state procurement processes also mean that developers are competing and strategizing over what entities will participate in the monitoring, which can further fragment data and monitoring protocols.

Interview participants also noted that a patchwork approach to ecological monitoring has developed, with developers committing resources to various research groups and taxa in different states, but with no unified regional strategy. Participants viewed coordinated efforts supported or led by the states as the best chance for ensuring a well-funded and regionally-consistent monitoring program. The emergence of regional coordinating or advising bodies for ecological monitoring was also welcome, with a notable example being a nascent umbrella organization known as the 'Regional Wildlife Science Entity'. However, participants stated that the success of such entities was still dependent on coordination and collaboration of states as well as the various other existing and emerging groups concerned with coordinated regional and international ecological monitoring practices (e.g., ROSA, ICES working group, MARACOOS). Also, participants highlighted previous and recent attempts by states to coordinate regional monitoring efforts (e.g., joint ecological surveys by Rhode Island and Massachusetts, and a monthly coordinating conference call by eastern states). Several cited regional entities as the most efficient way to leverage increasingly large leases (from a few million to over \$100 million) into ecological monitoring and mitigation support for development. In other words, the same money scattered into many fragmented entities may not go as far to answering key questions regarding ecological impacts and the utility of mitigation efforts. Other potential funding strategies suggested by interviewees included fixed contributions by developers (e.g., per MW) into regional entities or coordinated programmatic monitoring by states as a means of providing reliable funding for ecological monitoring while offering developers a predictable expense.

While these coordination efforts are important, many organizations (e.g., ROSA) are in their early stages of development. Some participants perceive ongoing tensions between participation in ecological monitoring efforts with the overall economic development and sustainability goals set forth by states. Some interview participants reflected on this tension as a conflict within the environmental community between a desire for renewable energy and apprehension regarding cumulative environmental impacts. Some also expressed a concern that there would always be a tension between the cooperation of the developers to share some data and competing interests to hold other data proprietary. These tensions make regional data sharing and science entities fragile unless state, NGO, and developer partners define precise governance mechanisms and data-sharing agreements from the outset.

PART II: ECOLOGICAL MONITORING AND MITIGATION PRACTICES

Offshore wind energy production has occurred for only three decades in Europe and less than five years in North America. As such, questions remain regarding the relative importance of the various potential ecological impacts (see Figure 1) and how best to monitor for and mitigate them. In addition, with improving ecological monitoring and mitigation technologies comes an increased number of options available to researchers and policymakers, resulting in a shifting patchwork of ecological monitoring standards worldwide. Here we review the literature to shed light on ecological monitoring and mitigation practices at offshore wind installations. We focus on methodology and study design and do not attempt to summarize the scientific consensus regarding the relative severity of each impact. However, we present a list of references for longer-duration studies and meta-analyses related to such impact assessments in Appendix A.

We conducted a systematic review of the ecological monitoring and mitigation literature for six taxa groups at offshore wind installations: invertebrates, fish, marine mammals, sea turtles, birds, and bats. This review involved 1) performing a series of searches on Web of Science and Google Scholar (see Appendix B); 2) retaining only peer-reviewed articles, book chapters, or reports related to ecological monitoring/mitigation and offshore wind (i.e., those that specifically mention offshore wind impacts as a motivating factor in the abstract, keywords, or introduction); and 3) adding to this list of references by crosschecking against the searchable renewable energy literature database maintained by the Pacific Northwest National Laboratory (tethys.pnnl.gov). For birds, we stopped adding from the Tethys database once we reached 126 references, which was judged to be a representative sample (by extrapolation, we estimate a total of ~150-200 bird references may exist). We then placed all references into non-exclusive categories by taxa, location, study type (empirical, synthesis, conceptual framework, or quantitative model), and field methods used. Studies were classified as empirical if the collection of original data was a focus of the study. We categorized review articles as pertaining to a taxa only if they devoted a substantial section to it (≥ 1 full paragraph).

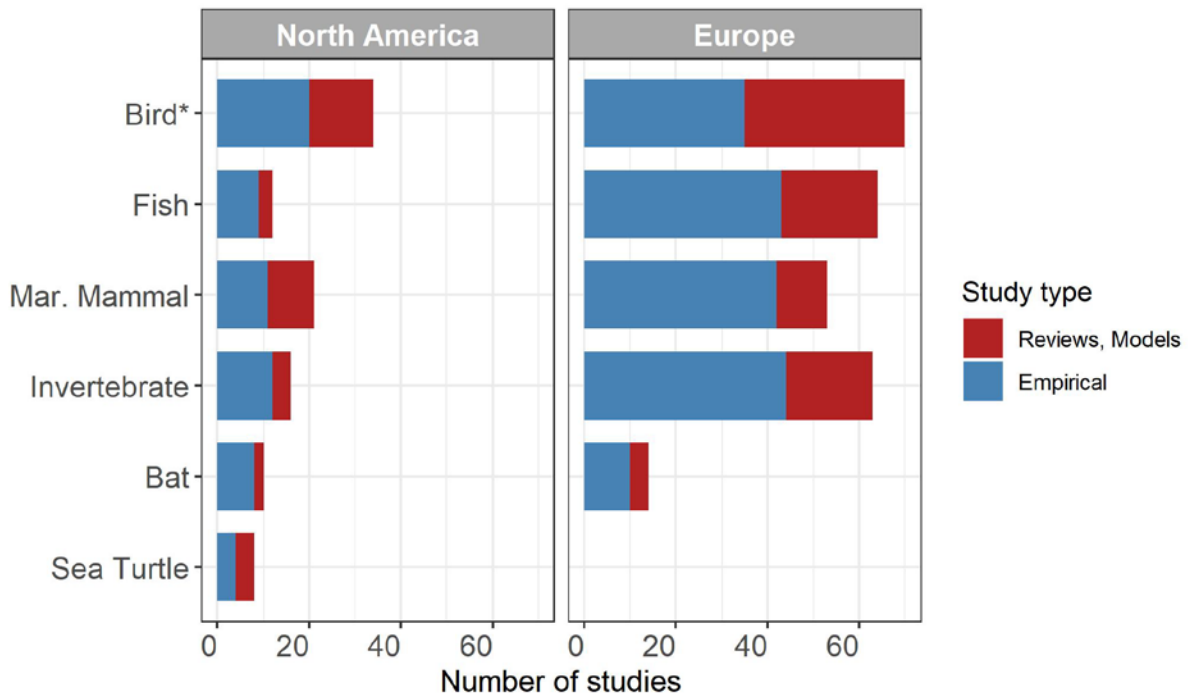


Figure 3. Number of references we reviewed related to ecological impacts of offshore wind, by taxa and study type. *For birds, our sample consisted of only 126 of the possibly ~150-200 total bird references (see text). Mar. Mammal = Marine Mammal.

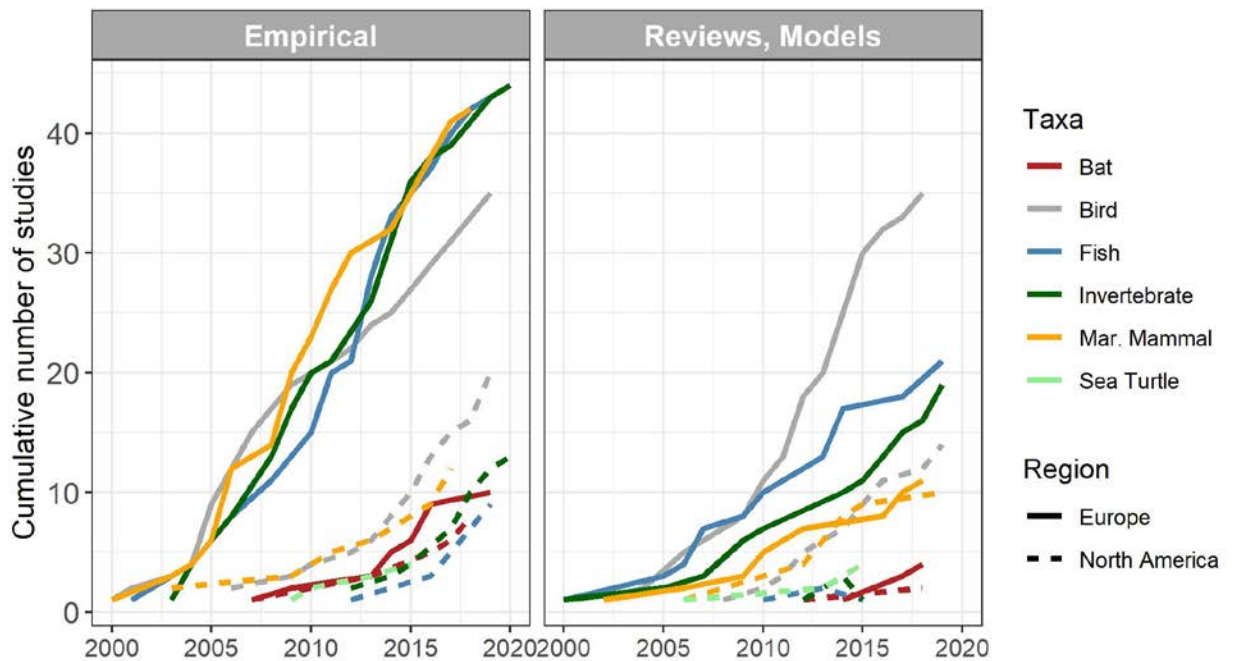


Figure 4. The accumulation of published literature over time in Europe and North America related to ecological impacts of offshore wind. Mar. Mammal = Marine Mammal.

The final literature matrices contained 126 references on birds (46% empirical, of which 34% were from North America; Figures 3 and 4), 96 on fish (63% empirical, 15% North American), 95 on marine mammals (60% empirical, 19% North American), 91 on invertebrates (65% empirical, 20% North American), 27 on bats (72% empirical, 38% North American), and 10 on sea turtles (40% empirical, 100% North American; Figures 3 and 4). Figure 3 shows this breakdown of references by taxa, study type, and geography graphically, excluding those references with no location or located outside of Europe or North America. Few bat studies, but a relatively even distribution of bird, fish, marine mammal, and invertebrate studies is apparent in Europe (~50-70 studies each; note, however, that bird references are incomplete as discussed above). In comparison to Europe, North America shows greater relative representation of bird and bat studies and less representation of fish and invertebrate studies. Figure 4 shows the accumulation of published studies over time, by publication year. In Europe, this pattern seems to confirm the relatively similar pace of study accumulation among birds, fish, marine mammals, and invertebrates in terms of empirical studies. However, birds outpace the other taxa in syntheses and modeling studies, potentially due to a proliferation of modeling efforts related to collision risk estimation. In North America, an expected lag of about 15 years is apparent relative to European studies, along with a strong representation of bird studies in the literature. The pace of study accumulation, in general, seems to be relatively similar in North America and Europe, although it may be too early to tell this with certainty.

In the sections that follow, we summarize this body of literature, paying special attention to empirical studies of ecological impacts within three main habitat zones (Figure 1): aerial, pelagic (i.e., the water column), and benthic (i.e., the sea floor). We highlight specific field methods used, how widespread they are, and how they help to shed light on the primary ecological impact categories. Additional methods not yet in common usage are also discussed. To inform potential options from a regulatory perspective, we cite example studies that use each method from European and U.S. wind installations.

Aerial habitats: birds and bats

The potential impacts of offshore wind installations to bird populations are primarily from 1) displacement from otherwise suitable ocean habitats; 2) direct mortality from collision with turbine blades; and 3) the 'barrier effect' in which transitory individuals will not fly through wind installations, adding energetically costly detours to their movements (Band 2012). Most research regarding bats is concerned solely with collisions as they only migrate through the offshore environment (Table 1).

Table 1. Aerial habitats: summary of monitoring and mitigation methods for ecological impacts. Commonness refers to their usage at offshore wind installations in North America and Europe. Methods marked with an asterisk (*) are mitigation measures; the rest are monitoring methods.

Ecological impact	Method	Description	How commonly used?
Displacement / Attraction	Visual transect surveys	Ship- or aerial-based visual (distance sampling) surveys covering large areas (> 100 km ²)	Common
	Photo transect surveys	Digital aerial photography transects often with automated species identification	Less common (increasing)
Collision Mortality	Radar (+ visual, camera, audio recording, or bat detectors)	Radar maps 3D tracks of organisms as they transit the wind installation. Coupled with other methods to determine species identity	Common
	Collision Risk Models	Estimate risk by species based on abundance and flight height	Common
	Tracking Individual Animals (Telemetry)	Using transmitters to track 2D or 3D paths of organisms as they transit the wind installation	Less common
	Collision Detection Systems (based on radar, cameras, vibration)	Networks of multiple sensors that tally collisions with blades, and in some cases record species identity	Rare (increasing)
	Thermal Video	New but promising due to ability for nighttime measurements with automated species I.D.	Rare
	LiDAR	Drone-based methods of measuring flight heights recently trialed	Rare
	Curtailment*	Stopping turbine blades during times of high bat or bird abundance (usually low wind speeds during migration)	Rare
	Altered Lighting*	Shifting to lower intensity, shorter-wavelength, blinking or flashing lights	Rare
Barrier Effects	Radar or telemetry (see above)	Track whether birds transit through or around the wind installation.	Common

Various measures of bird abundance, usually at large spatial scales (areas >100 km²), are used to assess habitat displacement or attraction at offshore wind installations, often with a BACI design. The most common method is aerial or ship-based visual transect surveys, with counts corrected for imperfect detection using a 'distance sampling' statistical approach (MMO 2014, BOEM 2017). Such methods were used to measure large-scale bird abundance in 24 of 58 empirical avian studies we reviewed (15 aerial, 12 boat) and are consistent with methods used by the continental-shelf-wide AMAPPS monitoring program in the U.S. (Atlantic Marine Assessment Program for Protected Species). Digital aerial photography transects, frequently coupled with computer-assisted species identification, are a more recent variant on these surveys, but appear to be increasing in frequency (Buckland et al. 2012). This photography-based method was employed in only two empirical studies we reviewed (Normandeau Associates 2013, Williams et al. 2015), but it is recommended in recent federal U.S. and U.K. reviews (MMO 2014, BOEM 2017) and is now the default practice in Germany (BSH 2013). Both the ship-based and aerial count methodologies discussed above are typically used to measure habitat displacement at the level of the individual wind installation. However, the resulting population consequences (i.e., cumulative impacts) of such displacement have also been investigated using this data, generally by using spatial modelling approaches to extrapolate measured impacts across a wider area (e.g., the North Sea; Busch et al. 2013).

The risk of avian and bat collisions with turbines is typically assessed using 'collision risk models' based on two sources of data (local abundance and flight height distributions) to estimate the number of individuals transiting the rotor-swept portion of the wind installation. This number paired with an estimate of the probability of being struck by a blade while inside the wind installation yields an expected number of annual collisions (Band 2012; see Masden and Cook 2016 and Kleyheeg-Hartman et al. 2018 for recent reviews of different modelling approaches). Abundance within and immediately around the wind installation is commonly assessed using marine radar based on a stationary platform, or less commonly a ship, located near the wind installation. This method has the advantage of not only recording paths of individuals as they move around or through the wind installation, but also recording their altitudes. Species identity is not recorded, however. Therefore, radar methods are typically supplemented by visual observers or automated photography by day, and acoustic recording of flight calls by night (Williams et al. 2015). Acoustic bat detectors can also be employed to estimate the proportion of individuals detected that are bats (Ahlén et al. 2009). In Germany, standard protocols for radar assessments are prescribed and follow methods of Hüppop et al. (2002, BSH 2013).

Other methods used to collect abundance and flight altitude data for use in collision risk models include telemetry (tracking individual animals using various transponders or dataloggers attached to their bodies), thermal infrared video, and drone-mounted LiDAR (light detection and ranging), although the latter two are still relatively early in development. Telemetry informs collision risk by tracking individual animals to identifying how likely they are to travel through a wind installation area (Burger et al. 2012, Loring 2016). In some forms (e.g., with satellite tags), this includes not only geographic coordinates (horizontal position) but also flight altitude (vertical position) to more accurately gauge risk (Ross-Smith et al. 2016). Thirteen of 58 empirical avian studies we reviewed used animal tracking methods, including satellite tags for larger species (8 studies), and, for smaller species, VHF nanotags dependent on the MOTUS (motus.org) receiver network (3 studies) or light-level geolocators (1 study; Burger et al. 2012). The lack of ability to track flight altitude for smaller species that cannot support

larger satellite tracking devices and the level of effort required per individual bird (i.e., for trapping, tagging, and data processing) are both drawbacks of relying solely on a telemetry-based approach. Thermal video and LiDAR methods are not in widespread use, but show promise. Thermal video, like radar, allows quantification of local abundance at night when visual surveys are difficult. However, unlike most radar systems, trials by the Pacific Northwest National Laboratory show it has potential for automated species identification based on flight paths (Cullinan et al. 2015). Limitations of the technique include a sensitivity to humidity and a limited field of view (Cullinan et al. 2015). Drone-based LiDAR measurements are similarly early in development, but trials in the U.K. show it may be an efficient way to collect flight height data on birds and bats to inform collision risk models (Cook et al. 2018).

Commercial collision detection systems are a much more direct way of measuring collisions at offshore wind installations, but they are still rarely used in practice in an offshore environment, partially due to high cost and an early stage of development (reviewed, including information on costs, in Collier et al. 2011, 2012, Dirksen 2017). These systems are generally composed of multiple sensors (vibration, imaging, and/or radar) networked to each other and to a central processor which classifies signals as collisions (or not) and logs data. They are represented by a range of different commercial models (e.g., I.D. Stat, VARS, WT-Bird, DT Bird, MERLIN, MUSE, TADS, ATOM). When working properly, they have the ability to tally collisions with turbines, and in several models, allow identification to species based on concurrent high-definition imagery. Their use may increase in the future as technologies mature and active testing at offshore wind installations progresses (Dirksen 2017).

In addition to displacement and collisions, the 'barrier effect' has also been raised as a concern in several European countries. This is when a wind installation acts as a large-scale obstacle forcing flocks or individuals to make energetically-costly detours around it. Barrier effects can be of special concern if offshore wind installations are sited in a way that bisects major migration corridors (e.g., a raptor flyway) or if they obstruct regular 'commuting' routes between breeding and foraging grounds (MMO 2014, Jensen et al. 2016). They are studied in much the same way as collision risk, by measuring local abundance and tracking movements of individual animals using radar, telemetry, or other techniques discussed above. As with habitat displacement, modelling approaches (e.g., avian energetics models) can be used to extrapolate the estimated energetic costs of barrier effects to inform potential cumulative population-level impacts (Masden et al. 2009).

A broad range of mitigation techniques have been investigated to minimize bird and bat collisions at wind installations, and 'best management practice' recommendations are currently being formulated for use at offshore wind installations (NYSERDA E-TWG 2020). Cook et al. (2011) chose ten of the more promising collision-reducing mitigation techniques to review including temporary shutdowns of turbine blades, special paints, altered lighting, laser deterrents, audio deterrents, decoy towers, and altering turbine spacing and height, among others (Cook et al. 2011). They found the most evidence for effectiveness associated with lighting schemes and temporary shutdowns. However, they found that all schemes thus far were developed at onshore wind energy installations and were largely untested in an offshore environment. Lighting of structures has been well-researched with respect to collisions on land, with the general conclusion that shorter wavelengths and shorter pulse durations are optimal for preventing collisions by nocturnal migrants (i.e., a blue strobe light is preferable to a steady red light; Cook et al. 2011). Currently available COPs for eastern North American offshore wind installations generally mention implementing mitigation steps such as fewer, lower intensity, and flashing lights

"when practicable" (Vineyard Wind COP, Vol. III, Section 6), subject to limitations imposed by the Federal Aviation Administration and the U.S. Coast Guard. Temporary shutdowns of turbine blades, either triggered by radar surveillance indicating high bird densities, or by other conditions predictive of higher densities (e.g., at night during migration), would clearly reduce the chance of collisions, but this also comes at a cost to energy production (Cook et al. 2011, Boonman 2018). We are aware of one example of such a 'curtailment' approach in practice at offshore wind installations. In the Netherlands, offshore turbines in the North Sea are shut down at night between 15 August – 1 October when wind speeds are less than 5 m/s to protect a migratory bat species (Boonman 2018).

Pelagic habitats: marine mammals, sea turtles, pelagic fish

Concerns about impacts to pelagic species such as marine mammals, sea turtles, and pelagic fish can be divided into two main categories: 1) displacement from or attraction to offshore wind installation areas due to habitat changes; and 2) direct injury or mortality from 'impulsive' pile-driving noise during construction (MMO 2014, English et al. 2017). While displacement could result from disturbance created by operational turbine noise or by changes in oceanographic processes, attraction to wind installations could be due to the increase in reef-like habitats (the 'artificial reef effect') or to the 'fish aggregating device effect' (FAD; named after the buoy-like devices used commercially to attract pelagic fish; MMO 2014). The habitat displacement/attraction effect is commonly studied by measuring abundance across the entire wind installation area in a BACI design, while noise impacts use similar data along with laboratory studies to indirectly assess impacts (BSH 2013, MMO 2014). Impacts to currents and related oceanographic processes are typically studied using sensors coupled with hydrodynamic models (Brodie et al. 2018, Barbut et al. 2019).

Table 2. Pelagic habitats: summary of monitoring and mitigation methods for ecological impacts. Commonness refers to their usage at offshore wind installations in North America and Europe. Methods marked with an asterisk (*) are mitigation measures; the rest are monitoring methods.

Ecological impact	Method	Description	How commonly used?
Displacement / Attraction	Visual transect surveys	Ship- or aerial-based visual (distance sampling) surveys for marine mammals, turtles, etc.	Common
	Acoustic Monitoring	Record whale or dolphin vocalizations to calculate indices of abundance	Common
	Photo transect surveys	Digital aerial photography (mammals, turtles, sharks, etc.) often with automated species identification	Less common (increasing)
	Tracking Individual Animals (Telemetry)	Satellite or acoustic telemetry tags used to track paths of individual animals as they transit the wind installation area	Less common
	Hydroacoustic (Sonar)	Hydroacoustic transects to monitor fish abundance	Less common
	Video Monitoring	Continuous video monitoring of specific areas (e.g., seal haul-outs)	Rare
Noise Impacts	Exposure Assessment	Variety of methods used to measure abundance during construction (see above)	Common
	Altered Timing*	Restricting pile-driving during peak abundance (e.g., whale migration)	Common
	Soft Starts*	Gradual starting pile-driving, allowing mobile organisms to leave	Common
	Alternative Foundations*	Gravity-based structure (GBS) foundations require no pile-driving	Less common
	Acoustic Deterrents*	Noise-making devices deter marine mammals from entering the wind installation during pile-driving	Less common
	Bubble Curtains*	Dampens noise by encircling the pile-driving site with bubbles	Less common
	Coffer Dam*	Creates a physical barrier around the pile-driving site	Rare

Methods to measure wind-farm-scale abundance of marine mammals (and therefore to address both the displacement/attraction and the noise exposure questions) have principally focused on 1) acoustic detectors and recorders and 2) aerial or boat-based transect surveys. Acoustic 'click' detectors (T-PODs and C-PODs), which quantify echolocation clicks of toothed whales and porpoises, are the standard acoustic technique used in most European studies where Harbor Porpoise (*Phocoena phocoena*) is the species of greatest concern (Lindeboom et al. 2011, BSH 2013, MMO 2014, Wingfield et al. 2017). However, where baleen whales such as the North Atlantic right whale are of interest, broader-frequency hydrophones are used (Hodge et al. 2015, Salisbury et al. 2016, Brookes et al. 2017). Some form of audio recording was used in 26 of the 57 empirical marine mammal studies we reviewed. Large-scale aerial or boat-based surveys (again compatible with the AMAPPS approach) were also commonly used for assessing abundance, representing 18 of the 57 empirical studies (14 aerial, 5 boat). In recent years, aerial photography coupled with automated species identification is becoming increasingly common, and has been used to jointly monitor diverse pelagic taxa including whales, dolphins, sharks, seals, and sea turtles (BSH 2013, Normandeau Associates 2013, Williams et al. 2015). Two lesser-used methods for monitoring marine mammals include using satellite tags to track movements of individuals in relation to the wind installation area (e.g., seals; Lindeboom et al. 2011), and performing continuous video monitoring of particular locations (e.g., seal haul-out areas; Edrén et al. 2010).

Sea turtles are rare in northern Europe, and therefore all three field-based studies we reviewed of sea turtles in relation to offshore wind occurred in the U.S. These studies all involved aerial surveys (two of which were photo-based) and one included boat-based surveys as well. Their purpose was to assess large-scale abundance and inform potential exposure to noise impacts and/or address the displacement/attraction question. Williams et al. (2015) noted the difficulty in distinguishing the various species of smaller (i.e., non-leatherback) sea turtles as a limitation of the aerial photography-based approach. Acoustic telemetry is another potentially useful tool for monitoring sea turtles, along with other pelagic species. This technique involves attaching sound-producing units to animals and deploying receivers throughout the environment to detect them and track their movements. Acoustic telemetry networks and data sharing platforms (e.g., Atlantic Cooperative Telemetry Network, Mid-Atlantic Acoustic Telemetry Observation System) are currently being expanded off the eastern U.S., with partial funding from BOEM (Williams and Goodale 2015). These collective data networks may also help to address questions of displacement and noise impacts as it will help to track the movements of over 70 species including sea turtles, marine mammals, and fish.

Studies of displacement or attraction to offshore wind installation areas by pelagic fish, including mackerel, herring, salmon, and others, were less common in the literature (16 of 60 empirical fish studies reviewed) compared with those related to bottom-dwelling species. The most common way to study wind-farm-scale abundance of pelagic species was via hydroacoustic (sonar) surveys (e.g., Lindeboom et al. 2011, Krägefsky 2014). Catch-per-unit-effort approaches were also used, with the specific gear type depending on the species being targeted (MMO 2014).

The most common foundation type for offshore wind turbines requires the use of pile-driving, which can injure or kill marine wildlife via intense pressure waves. This issue is usually studied indirectly by 1) measuring abundance of organisms in the area (using methods discussed above) prior to or during construction to assess potential exposure risk (Haelters et al. 2015); 2) conducting laboratory studies of behavioral or physiological responses to noise (Kastelein et al. 2018); or 3) conducting desktop studies

comparing hearing capabilities of each taxa with properties of the noise in question (ESS Group 2006). Noise mitigation methods are commonly used in Europe and North America during construction including: 1) planning construction activities to be outside of peak occurrence times; 2) deploying sentinel observers or acoustic detectors during construction to trigger cessation of construction activities when organisms are present; 3) using 'soft starts' in which noise is increased gradually allowing mobile animals to leave the area; and 4) using audio deterrents (e.g., 'seal scarers') to keep marine mammals out of the exposure area (Gordon et al. 2007, MMO 2014). The choice of seasonal timing of construction is particularly relevant for migratory species such as the North Atlantic right whale. A best-practices document was recently drafted for reducing impacts to this species, jointly signed by conservation groups (Natural Resources Defense Council and others) and offshore wind developers (Stephens et al. 2019). Active noise reduction techniques such as bubble curtains (multiple concentric circles of continuous bubbles) and coffer dams (physical noise barriers) are also used to help developers achieve noise-reduction requirements but appear to be uncommon in practice (BSH 2013, MMO 2014). The use of gravity-based structures (GBS) as foundations – large concrete conical structures buried into the sediment – is also a viable method of noise reduction as it eliminates the need for pile-driving. These foundations have been used in Denmark and Belgium and are planned for New York's Empire Wind project (MMO 2014, Coates et al. 2015, NYSEDA 2019). However, this foundation type may not be possible in all sedimentary environments (NYSEDA 2019).

Finally, while not always required as part of the licensing process, oceanographic factors such as water chemistry, temperature stratification, currents, turbidity, and others are documented or suspected impacts of large offshore wind installations, with potential impacts on fish, invertebrates, and especially species with drifting larvae (Barbut et al. 2019). Brodie et al. (2018) reviewed the potential for and utility of long-term monitoring of these factors in an offshore wind installation context.

Benthic habitats: bottom-dwelling invertebrates and fish

Benthic fauna can be broadly characterized into three groups: sessile colonists of hard substrates, organisms living within sediments, and organisms living at or near the seafloor surface. These organisms include diverse invertebrates as well as demersal (bottom-dwelling) fish. As benthic species exist in the same aquatic environment as pelagic species, and many are similarly mobile, they also share the potential for impacts from underwater noise and habitat displacement; these impacts are generally studied using the same methods discussed above (for an Atlantic sturgeon example, see Ingram et al. 2019). Impacts unique to the benthos include changes in populations or community structure due to 1) disturbance of sediments from construction activities or 'scour' around foundations; 2) increases in the amount of hard substrate available due to turbine foundations; and 3) behavioral disruptions caused by electromagnetic fields from cables (Table 3).

Table 3. Benthic habitats: summary of monitoring and mitigation methods for ecological impacts. Commonness refers to their usage at offshore wind installations in North America and Europe. Methods marked with an asterisk (*) are mitigation measures; the rest are monitoring methods.

Ecological impact	Method	Description	How commonly used?
Sediment Disturbance	Grab samples	A rectangular frame used to collect sediment and associated fauna	Common
	Trawl surveys	2-m or 4-m nets pulled along the bottom. Larger sizes sometimes used for fish	Common
	Other CPUE	Variety of net, trap, or hook-based methods to catch fish, generally presented as catch per unit effort	Common
	Photo/Video Transects	Towed camera sleds or other transect-based photo sampling	Less common
	Side-scan sonar	Maps the physical characteristics of the sea bottom using sonar	Less common
Artificial Reef / Steppingstone Effect	Scrape Sampling	Scraping organisms off of defined sections of structures and counting them	Common
	Photo/video Samples	Photos for documenting and quantifying organisms on hard substrates	Common
	Tracking Individual Animals (Telemetry)	Satellite or acoustic telemetry tags used to track paths of individual animals as they transit the wind installation area	Less common
	Hydroacoustic (Sonar)	Hydroacoustic transects to monitor fish abundance	Less common
	eDNA	Detect presence of invasive species spread due to steppingstone effect	Rare
	Alternative scour protection types*	Various infrastructure for preventing scour around turbine base; each contributes different amounts of hard substrate	Common
Electromagnetic Field Impacts	Surveys along cable route	Abundance surveys (described above)	Common
	Cable armoring, burying depth*	Thickly armored and deeply buried cables limit EMF exposure	Common

Seafloor sediments can be disturbed during the installation of turbines, the burying of cables, and by scour around foundations caused by currents. The methods most commonly used to study benthic community response to sediment disturbance include grab samples, beam trawls (2-m or 4-m), and photo/video samples. For example, of 58 empirical benthic invertebrate studies reviewed, 14 used some form of grab sampling, nine used beam trawls or dredges, and six used some form of photo transect sampling (e.g., Bartley et al. 2018, Cruz-Marrero et al. 2019). Demersal fish populations are often studied with the same methods (e.g., 2-m or 4-m beam trawls; Walsh and Guida 2017), in addition to surveys with slightly larger trawls (e.g., 7-m-wide and Otter trawls; BSH 2013), and a diversity of catch-per-unit-effort approaches with a variety of fishing gear types (MMO 2014). Side-scan sonar can also be used to characterize the physical habitat structure of the sea bottom (3 studies; LaFrance et al. 2014, Pearce et al. 2014, Bartley et al. 2018). Environmental DNA (eDNA) survey methods, while not currently in use at offshore wind installations to our knowledge, also represent a potentially useful emerging approach to monitoring fish and invertebrate presence and abundance at these sites (Thomsen et al. 2016, Stoeckle et al. 2017).

The increase in hard substrates from wind turbines can have two main impacts, 1) an 'artificial reef' effect, in which new communities form on the added hard substrates and, relatedly, 2) a 'steppingstone' effect, in which shifts in the distribution of native or non-native species, are observed (e.g., Adams et al. 2014, Airolidi et al. 2015). The latter is due to the addition of islands of hard substrates in areas where sandy substrates dominate. Methods used to assess these impacts include scrape samples (15 of 58 empirical benthic invertebrate studies), video/photo samples (12 of 58), and studying colonization of experimental substrates ('fouling panels'; 3 of 58). Genetic approaches and hydrodynamic models have been used in several studies to assess current connectivity among populations inhabiting hard substrates, as well as the likelihood of increased connectivity as wind installation 'steppingstones' continue to be installed (Adams et al. 2014, Airolidi et al. 2015, Luttikhuisen et al. 2019). Again, eDNA represents an emerging technology that has been successful at monitoring for low-density aquatic invasive species, as well as bottom-dwelling fish, elsewhere (Thomsen et al. 2016, Sepulveda et al. 2019). In terms of mitigation, the type of scour protection materials used around wind installation foundations can have significant effects on the amount of hard substrate available to serve as artificial reef or as steppingstones (reviewed in Langhamer 2012, Linely et al. 2007). Therefore, there could be tradeoffs between increasing hard substrates to benefit certain fish species versus reducing hard substrates that may serve as steppingstones for invasives.

Electromagnetic fields (EMFs) are produced by underwater cables associated with offshore wind installations and have been demonstrated to have behavioral effects on several electro-sensitive species. Several laboratory studies have been conducted on how realistic levels of EMF affect crustaceans, fish, and turtles, among others (Miller et al. 2009, Woodruff et al. 2012). In practice, European and U.S. wind installations usually assess impacts by conducting population monitoring for fish and invertebrates (as described above) along the cable route, in addition to the turbine area. In the U.K., the presence of sharks and rays during baseline surveys triggers a requirement for additional monitoring to assess the local distribution of these species due to their known EMF sensitivity (MMO 2014). Mitigation measures for EMFs usually entail armoring of cables and burying to depths of 4-6 feet (e.g., see New York and Massachusetts policy sections above).

Stakeholder Interviews

Our interviews with stakeholders in the Northeast revealed several critical monitoring and mitigation issues not fully captured by our literature review. These include:

1. Misperceptions about the data requirements and structure requirements for data sharing;
2. Prioritizing monitoring within funding and time constraints; and
3. Setting expectations for statistical significance and robustness of monitoring data.

Assuming a regional platform for sharing data, interview participants noted that sharing data does not require rigid standards that must apply in all situations to all developments. Rather, participants encouraged a thoughtful process or recurring forum that states, developers, and other stakeholders could use to coordinate their efforts. Considering how state data may differ as a matter of policy, or in response to improvements in technology, lead interview participants to highlight further need to maintain flexibility in monitoring protocols and data-sharing arrangements. They highlighted the coordination efforts of state technical working groups as a good starting point for a future regional forum or coordinating entity.

Interview participants suggested that defining the questions that need to be answered, within constraints on time and funding, are some of the most valuable discussions currently underway within regional actors and forums. In particular, interview participants suggested that the research community must work harder to understand the ties between time, methods, and the types of outcomes that one can expect under current NEPA processes. In many cases, current requirements do not generate data that allow regional researchers or future researchers to rely on the work, perpetuating the need to restudy impacts for each project. Participants also had concerns about the statistical power of most NEPA-compliant study durations to detect the effects that policymakers feel they need for defensible decisions. In addition, participants felt monitoring efforts related to individual projects, absent regional coordination and data-sharing, could not address the assessment of cumulative environmental impacts of all wind installations in a region (i.e., impacts beyond those of individual projects).

Interview participants also indicated a paradox in the current state of ecological data in the oceans. One participant noted that ocean data were generally rich, but “highly vulnerable,” citing potential adjustments and reconfigurations of the NMFS trawl survey. Other participants noted similar concerns, indicating that monitoring questions requiring time series data to identify the explicit impacts of offshore development may be difficult for researchers to untangle in a way that is statistically valid and generalizable. While more prolonged monitoring efforts may indicate that a species distribution has changed, researchers may not be able to directly associate such a change with the impacts of offshore wind development activities, as opposed to changes in physical oceanography driven by a changing climate.

CONCLUSIONS

In this review, we set out to summarize the various policies governing ecological monitoring and mitigation requirements at offshore wind installations in the eastern U.S. and in Europe. We also attempted to characterize the predominant methodologies used to address these concerns. Our findings broadly indicate that the character of ecological monitoring at U.S. offshore wind installations is still actively being determined. Coordination of ecological monitoring policy and practice among states is in

the early stages at present, and could ultimately result in a unified approach or a patchwork of monitoring requirements as has been the case in Europe. However, North America has the benefit of being able to learn from the European experience both in terms of policy and practice. Building on those lessons will ensure that wind energy on the Atlantic continental shelf and elsewhere in North America can be developed as sustainably as possible.

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Appendix A: Selected references of longer-duration empirical studies and meta-analyses assessing the magnitude of various ecological impacts of offshore wind installations.

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Degraer et al. (Eds.) (2019). *Environmental impacts of offshore wind farms in the belgian part of the north sea: marking a decade of monitoring, research and innovation*. Brussels: Royal Belgian Institute of Natural Sciences (RBINS). An edited book bringing together empirical research summarizing the state of knowledge regarding ecological impacts of Belgian wind installations. Many taxa and ecological communities are represented.

Lindeboom, H., et al. (2011). Short-term ecological effects of an offshore wind farm in the dutch coastal zone; a compilation. *Environmental Research Letters* 6:035101. A summary of before-after control impact studies for multiple taxa conducted at the Dutch wind installation Egmond aan Zee (OWEZ).

Methratta, E. T., & Dardick, W. R. (2019). Meta-analysis of finfish abundance at offshore wind farms. *Reviews in Fisheries Science & Aquaculture* 27:242-260. A meta-analysis of impacts of offshore wind installations on fish. The result was a higher abundance of finfish within vs. outside of offshore wind farms.

Popper, A. N., & Hawkins, A. (Eds.). (2016). *The effects of noise on aquatic life II* (p. 1292). New York, NY: Springer. This is an edited volume of research papers investigating noise impacts on marine wildlife. It is not specific to offshore wind installations, but several studies related to them are included.

Reubens, J. T., et al. (2014). The ecology of benthopelagic fishes at offshore wind farms: a synthesis of 4 years of research. *Hydrobiologia* 727:121-136. Synthesizes four years of behavioral fish research at offshore wind installation in Belgium to shed light on the question of the 'artificial reef' effects on fish communities. Attraction to wind turbine foundations was documented in cod and pouting during certain seasons.

Stenberg, C., et al. (2015). Long-term effects of an offshore wind farm in the north sea on fish communities. *Mar. Ecol. Prog. Ser.* 528:257-265. Studied dab, whiting, and sandeel abundance at Horns Rev 1 wind farm for 1 year pre-construction and 7 years post-construction. They found no evidence of negative effects of the wind installation on populations.

Vallejo, G. C., et al. (2017). Responses of two marine top predators to an offshore wind farm. *Ecology and Evolution* 7:8698-8708. This paper reports on ~ 5 years of pre-construction monitoring and 5 of post-construction monitoring of Guillemots (a seabird) and Harbor Porpoises at Robin Rigg offshore wind installation in Scottish waters. They found no evidence of displacement from the wind installation area.

van Deurs, M., et al. (2012). Short-and long-term effects of an offshore wind farm on three species of sandeel and their sand habitat. Mar. Ecol. Prog. Ser. 458:169-180. A longer-term (7-year) before-after control-impact (BACI) study of the effects of the Horns Rev 1 wind installation (Denmark) on sandeel populations. Results were equivocal.

WOZEP (Dutch Governmental Offshore Wind Ecological Programme). URL:

<https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/ecology/> A collection of documents summarizing the Dutch experience researching ecological impacts of wind installations.

Appendix B: Literature search methods

We searched Web of Science and Google Scholar for each combination of the terms below, exporting all references (~10000), excluded duplicates, and further excluded those not related to offshore wind installation impacts or ecological monitoring. We then sorted all references by taxa (birds, bats, fish, invertebrates, marine mammals, sea turtles) and categorized them by study type (empirical, synthesis, quantitative model, conceptual framework), location, and field methods used () We then cross-checked the resulting list of references for each taxa against the Tethys renewable energy literature database maintained by the Pacific Northwest National Laboratory (<https://tethys.pnnl.gov/>) and added any relevant references missed by our initial search. Throughout, we included peer-reviewed articles, book chapters, and reports, but excluded presentations and conference abstracts.

- "wind turbine" AND ocean
- "wind turbine" AND wildlife
- "wind turbine" AND current*
- "wind turbine" AND fish*
- "wind turbine" AND plankton
- "wind turbine" AND invasive*
- "wind turbine" AND bird*
- "wind turbine" AND bat*
- "wind turbine" AND mammal*
- "wind turbine" AND ecolog*
- "wind turbine" AND benth*
- "wind turbine" AND noise
- "wind turbine" AND environment*

... "wind energy" AND [all of those things above]