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REPORT

MANAGING OFFSHORE WIND IN THE FACE OF UNCERTAINTY

KEY ADAPTIVE MANAGEMENT PRINCIPLES AND RECOMMENDATIONS

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LIST OF COMMONLY USED ACRONYMS

ACP: advanced conservation practice

BOEM: Bureau of Ocean Energy Management

BSEE: Bureau of Safety and Environmental Enforcement

COP: construction and operations plan

CZMA: Coastal Zone Management Act

DRIP: data-rich, information-poor

EPA: Environmental Protection Agency

ESA: Endangered Species Act

MSA: Magnuson-Stevens Act

NASEM: National Academies of Sciences, Engineering, and Medicine

NMFS: National Marine Fisheries Service

NOAA: National Oceanic and Atmospheric Administration

NEPA: National Environmental Policy Act

OSW: offshore wind

OCSLA: Outer Continental Shelf Lands Act

PEIS: programmatic environmental impact statement

RWSC: Regional Wildlife Science Collaborative

SAP: site assessment plan

TAC: technical advisory committee

USFWS: U.S. Fish and Wildlife Service

EXECUTIVE SUMMARY

The development of offshore wind energy is playing a key role in the transition away from harmful fossil fuels to a clean energy economy. Offshore wind could provide more than three times the electricity required to power the United States, giving the country an opportunity to fight climate change, reduce local and regional air and water pollution, and grow a new industry that supports thousands of high-quality careers. While the need for clean energy is urgent, we can and must ensure that all offshore wind in the United States is developed responsibly and in a manner that avoids, minimizes, mitigates, and monitors for adverse impacts to biodiversity and coastal and marine ecosystems.

The U.S. offshore wind industry is in its early stages. In some regions, projects that are proposed or already fully or partially operational are helping to fill data gaps through project-related monitoring and data collection, which is crucial as significant gaps exist for many species, habitats, and ecosystems likely to be affected by offshore wind development. Ocean conditions are projected to change significantly in coming decades due to the impacts of climate change. Effectively mitigating the impacts of offshore wind activities requires understanding how marine and coastal species, habitats, and ecosystems will be affected by the offshore wind industry, yet a full picture of these effects will require many more years of data collection—and the agencies managing offshore wind development must be able to adjust monitoring and management measures as more data emerge.

"Adaptive management" is crucial for meeting the dual goals of facilitating a rapid transition to renewable energy while minimizing impacts to the ocean in the face of uncertainty—and continuing to do so over time. It is an iterative process that aims to reduce scientific uncertainty and the harms of industrial development by learning from outcomes of management decisions and making necessary adjustments to future operations and development informed by the results of that learning. In its simplest form, adaptive management means learning by doing, and then revising as needed to ensure increasingly improved results.[1] Adaptive management can both inform changes in management and operation to an individual project over the project's lifetime and be used to improve the design of future wind farms.

Adaptive management is a critical component of responsible offshore wind development, as it allows projects to move forward while providing pathways for managing effects as they become known. Responsibly deploying offshore wind resources on an industrial scale will require adaptive management measures that are well tailored to effectively manage risks while avoiding undue economic burdens or unmanageable uncertainty for project developers. Offshore wind projects require high up-front capital expenditures, and developers must demonstrate to lenders, investors, and other parties with a financial interest that projects will remain operational and financially viable for decades. There will be limitations to what can be adaptively managed in an offshore wind project (e.g., there are likely non-adjustable design elements such as placement of foundations and subsea transmission cables), but data collected from projects can inform changes in management and operations of other components of an individual project and be used to improve the design of future wind farms. When designing adaptive management frameworks, regulators should consider these constraints.

Adaptive management is an essential component at every stage of offshore wind development, including site assessment, construction, operations, maintenance, and decommissioning.

This report explores how adaptive management can be implemented in offshore wind development, provides examples of its use in other sectors today, and offers clear recommendations for agencies and policymakers.

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A vessel approaches the base of a turbine on Block Island Wind Farm, located in the Atlantic Ocean off the coast of Rhode Island.

1. ADAPTIVE MANAGEMENT IS NEEDED FOR THE U.S. OFFSHORE WIND INDUSTRY

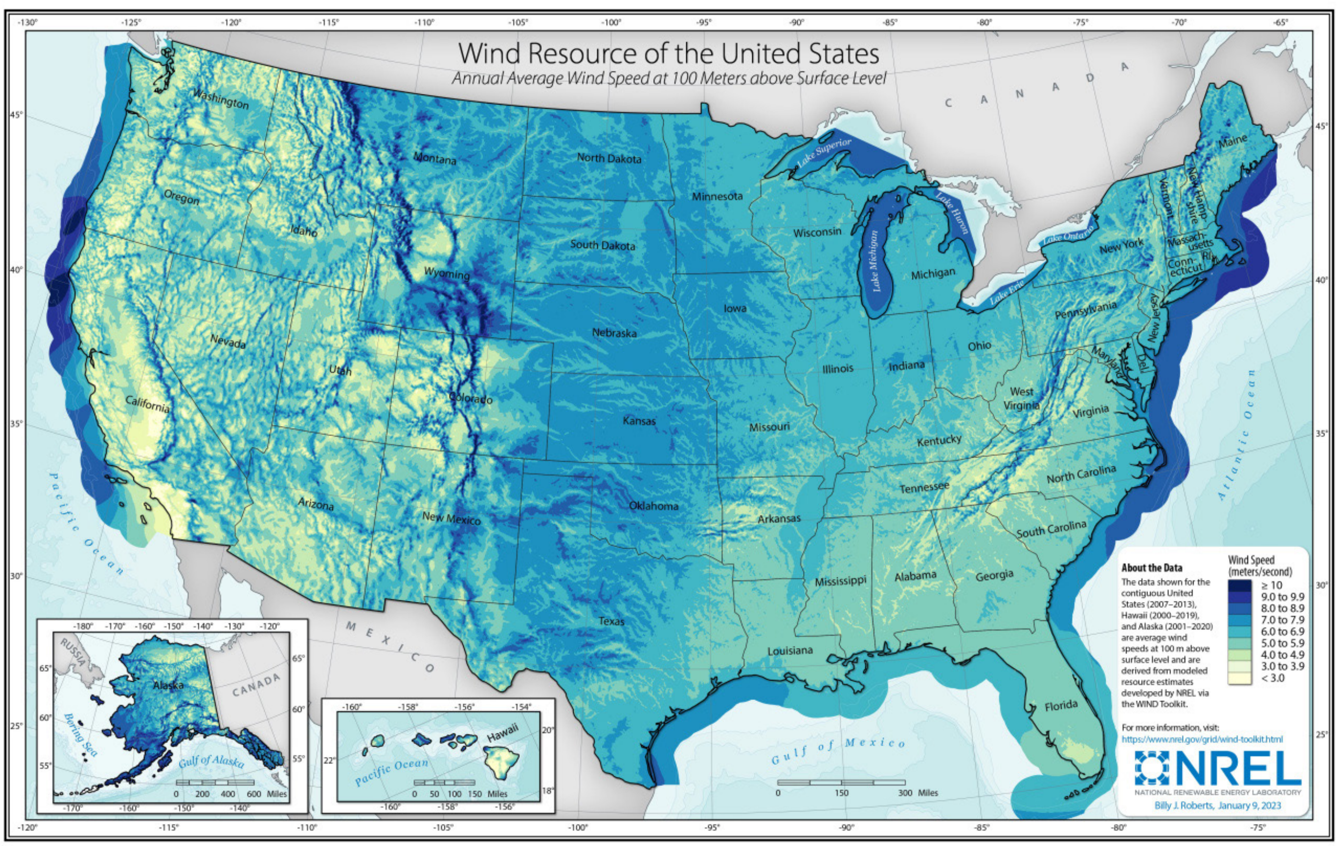
Offshore wind is an important part of the U.S. renewable energy portfolio. Wind speeds offshore are generally stronger and more consistent than onshore wind speeds, and offshore wind arrays can be built near major coastal cities, where nearly half of the U.S. population lives and energy needs are high.[2] According to the U.S. Department of Energy, U.S. offshore wind resources could meet the nation's electricity needs three times over.[3]

Offshore wind is a new industry in the United States, and currently facing political headwinds. Only a few offshore wind farms—off the coasts of Massachusetts, Rhode Island, and Virginia—are currently operational.[4] The Bureau of Ocean Energy Management (BOEM) has issued more than 30 offshore leases in federal waters in the Atlantic, Pacific, and the Gulf of Mexico.[a] Recently, the federal government entered into agreements to buy back several of these leases.[5] Six projects—four commercial and two pilot projects—are currently delivering power to the grid, with more construction ongoing.[6] By the end of 2027, there will be 6 gigawatts (GW) of offshore wind power online.[7] Other projects have received construction approvals and conducted initial surveys.[8] Twelve states have set statewide mandates or formal targets for offshore wind development totaling 115 GW to be completed by 2050.[9]

Given negative actions against offshore wind by the current administration, a freeze on new permits, agreements to buy back leases, and ongoing litigation, some projects in federal waters may not move forward in the near future.[10] The uncertainty in federal policy increases risk and cost for projects. Compounded with high initial capital expenditures and currently high supply chain costs, this uncertainty is creating a challenging investment environment for new U.S. offshore wind development.

However, states can still issue state permits and engage in planning for state components of offshore wind projects, such as port developments, and transmission lines. With

FIGURE 1: WIND RESOURCE OF THE UNITED STATES



Source: National Renewable Energy Laboratory

a Secretarial Order 3451 merged BOEM and BSEE as the new Marine Minerals Administration (MMA), although this report will still refer to the agencies as BOEM and BSEE.

the potential for offshore wind to serve as a key renewable energy resource and continued momentum at the state level, it is important to lay the groundwork now for an industry that will be sustainable in the long term.

Careful environmental assessment, planning, monitoring, and mitigation is an important part of the current offshore wind development process, and is necessary to understand and minimize the risks offshore wind development poses to the marine environment. “Adaptive management” frameworks—by providing mechanisms for collecting data and adjusting management measures when necessary—can help achieve these goals, especially in the face of uncertainty or unknowns. The current early stage of offshore wind development makes it possible to conduct this foundational work and ensure a sustainable industry into the future.[11] This includes setting baseline standards for data collection, regularly incorporating that data into management practices, and developing systems for mitigating impacts as more information about effects becomes known. There must also be mechanisms for adjusting monitoring and management measures over time, to ensure that crucial data are collected and developer and agency resources are prudently used to advance commercial-scale deployment of an important renewable resource.[b]

While much has been learned in recent decades, significant gaps remain in our understanding of interactions with and impacts of offshore wind energy development on U.S. wildlife and ocean ecosystems. Scientific research, monitoring, and offshore wind projects around the world have helped to shed some light on these impacts, including marine mammal entanglement, bird and bat collisions with turbines, hearing loss and acoustic disturbance of marine wildlife, displacement from existing foraging areas and migratory habitats, and changes to local wind and oceanographic patterns such as upwelling (see Appendix for more detail on potential impacts and taxa likely to be affected). However, impacts are expected to extend beyond wind farms themselves to include transit corridors, cable routes, ports, and transmission points, and to span both short-term construction activities and decades-long operations.[12] In addition, the layering of multiple individual impacts has the potential to result in cumulative impacts at the population or ecosystem level.[13] Finally, development will likely occur in ecosystems for which there is inadequate baseline ecological data, hindering the offshore wind industry’s ability to effectively avoid and mitigate impacts to the marine environment at the outset of a project (see text box “Data Gaps Related to Marine Mammal Entanglement” below for an example).[14] It is clear that more data are needed.

A gull flying near turbines at the Tahkoluoto offshore wind farm in Finland.

b The Natural Resources Defense Council (NRDC) supports both the deployment of renewable energy resources and the responsible and sustainable development of these resources. Tools and practices for financing offshore wind development are beyond the scope of this report, but more information can be found on our website at: https://www.nrdc.org/issues/renewable-energy#progress.

At the same time, we must keep in mind that conditions are always changing, making regular data collection a necessity. As the climate continues to change, many marine species' distributions, prey availability, and oceanographic conditions will likely shift.[15] It is reasonable to expect that ocean conditions within and around an offshore wind farm will change considerably over the 20- to 30-year life-span of the project. While it may be difficult to fully and accurately attribute species and ecosystem effects to the offshore wind industry, given the dynamic nature of the ocean environment, it is nevertheless important to track impacts and have adaptable management systems in place to address them.

Further, one type of offshore wind system to be used in U.S. waters—floating offshore wind platforms—poses unique challenges. Approximately two-thirds of the United States' offshore wind energy potential is located in waters deeper than 60 meters and will require the use of floating offshore wind platforms, as opposed to the fixed-bottom platforms currently used along most of the Eastern Seaboard.[16] However, floating offshore wind systems are a novel technology that has not been implemented at scale anywhere in the world and has never been deployed in U.S. waters.[17]

Monitoring data from existing small-scale projects elsewhere in the world have limited applicability due to infrequent surveying for entanglements (e.g., once every one or two years) and differences in marine wildlife populations from those found in U.S. waters. Thus, the impacts of floating offshore wind technology in the United States may not be fully known until operations are underway.

With these various uncertainties, it will be important to monitor and understand changes in the seascape and iteratively manage offshore wind projects to reduce impacts in the face of those changes. Monitoring regimes should be carefully designed to collect the data most relevant for management and should be adjusted (e.g., monitoring frequency may increase or decrease) to ensure continued efficacy and cost effectiveness. Regional monitoring to determine seascape changes requires some level of continuity, after pre-construction baseline data are collected and site-level impacts are addressed, and further project-level monitoring could focus on a select number of indicators determined to be most informative in evaluating changes in the project area. For some indicators, regional monitoring may yield the most relevant data. Keeping these principles in mind will help ensure that developer and agency resources are used wisely.

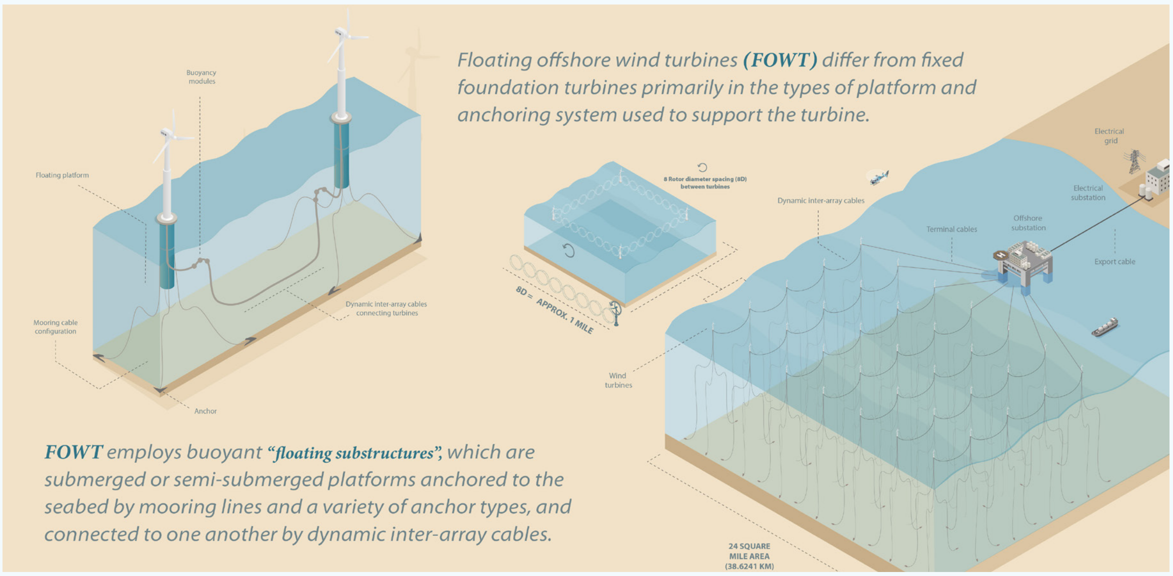
FIGURE 2: SUBSTRUCTURE TYPE NEEDED FOR OFFSHORE WIND PLATFORMS IN U.S. WATERS

Source: Phillip Beiter/NREL. (Note that NREL was recently renamed to the National Laboratory of the Rockies, or NLR)

DATA GAPS RELATED TO MARINE MAMMAL ENTANGLEMENT RISK

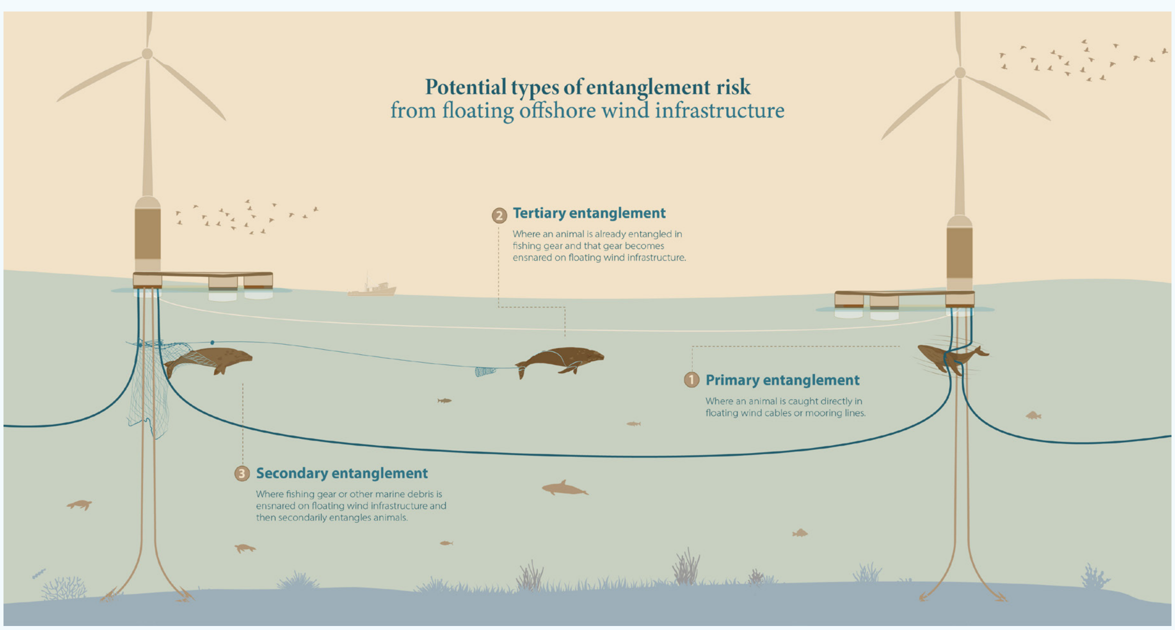
Floating offshore wind relies on extensive networks of lines and cables to secure the floating platforms to the seabed and to transmit energy from the turbines to shore. This sizable underwater footprint poses a risk of entanglement for marine wildlife, including marine mammals, sea turtles, sharks, fish, and diving sea birds.[18] Research suggests that secondary entanglement—in which marine debris such as fishing line becomes ensnared around mooring lines, mid-water cables, or other infrastructure and subsequently entangles marine wildlife—may represent the greatest risk from floating offshore wind development for a broad range of species.[19]

FIGURE 3: SCHEMATIC OF A COMMERCIAL-SCALE FLOATING OFFSHORE WIND ENERGY DEVELOPMENT, INCLUDING UNDERWATER MOORING AND CABLE SYSTEM



Source: Maxwell et al. 2022

FIGURE 4: DEPICTION OF POTENTIAL TYPES OF ENTANGLEMENT RISK



Graphic by PACT Media

However, there is little information from existing offshore wind projects about the types of marine debris that may become entangled at different depths, the configuration of the entanglement, or species' vulnerability at different depths and from different types of marine debris and platform designs. An adaptive approach to monitoring in which the first years of a project's lifetime are characterized by more frequent and comprehensive monitoring would help gather critical data to improve our understanding of entanglement risk and allow subsequent adjustment of management measures.[20] This information could also then help improve the design, operations, monitoring, and mitigation measures for existing and subsequent projects in the United States, thereby allowing operators to learn from and improve the industry's practices over time. For example, a better understanding of the depth at which different species of marine mammals are most at risk of entanglement can help to improve wind farm design, allowing developers to configure moorings to reduce risk. (See Appendix for a similar example of data gaps related to bird and bat collision risk and the possibility of adaptive management frameworks to improve knowledge and outcomes.)

Adaptive management is a management approach that integrates new information—such as monitoring data or updated scientific information—and advancements in technology to improve operations, fine-tune management measures, and reduce adverse impacts of offshore wind energy projects on a continual basis. It is an iterative process that aims to reduce scientific uncertainty and the harms of industrial development by analyzing the outcomes of management decisions and making necessary adjustments to future operations informed by those results.[21]

Adaptive management is an essential component at every stage of offshore wind development, including site assessment, construction, operations, maintenance, and decommissioning. It is key to responsible offshore wind development, as it enables addressing uncertainty and minimizing or avoiding impacts to the marine environment.

This report provides an overview of adaptive management, examples of effective adaptive management mechanisms used in ocean-based and renewable energy sectors today, and recommendations to inform the implementation of adaptive management for the development of offshore wind energy in the United States.

Dolphins swimming with wind turbines in the background.

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KEY PRINCIPLES OF ADAPTIVE MANAGEMENT

Six key principles should be part of any adaptive management framework and are outlined below.[22]

1. **Principle 1 (P1): Clearly defined management objectives**
Clear and agreed-upon objectives for management serve as guiding principles for decision making and enable the measurement of progress. Objectives should be SMART (specific, measurable, achievable, relevant, and time-bound) and prioritized on the basis of ecological importance.

2. **Principle 2 (P2): Clearly defined performance metrics and decision triggers**
Performance metrics are needed for understanding progress toward management objectives. These are ideally quantitative, science-based, and regularly revised in accordance with the best available scientific evidence. A decision trigger is a specific event or threshold of change that prompts a management response or action.[23]

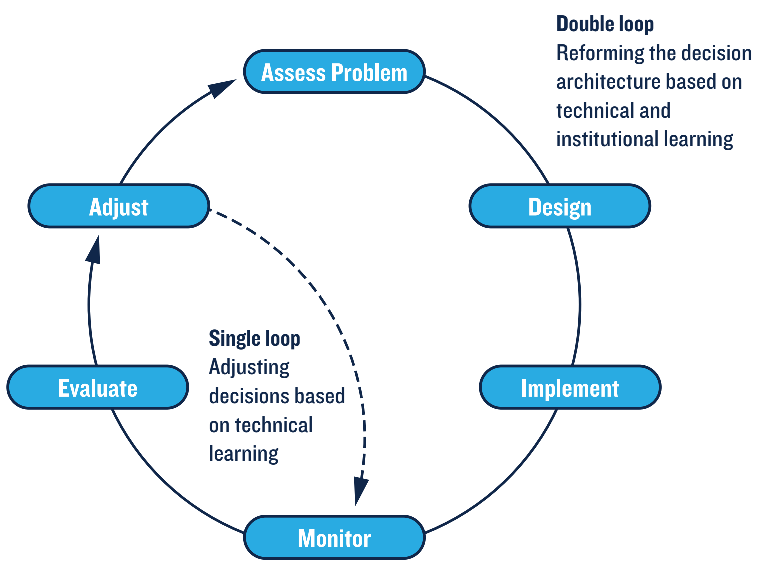
3. **Principle 3 (P3): Alternative management measures**
Alternative management measures provide a range of actions to implement when a threshold or trigger is reached. Adaptive management plans can be prescriptive, identifying a preapproved set of alternative management actions for each decision trigger before a project is underway, or flexible, setting forth a process by which to identify alternative management measures when triggers are reached.[24]

4. **Principle 4 (P4): Monitoring to inform management decisions and reduce uncertainty**
Monitoring protocols are designed to produce data and metrics relevant to management objectives and are conducted with a clear, hypothesis-driven framework for analyzing, interpreting, and acting upon the results. Data collection is conducted via appropriate sampling mechanisms and at scales sufficient to determine whether decision triggers are being reached.

5. **Principle 5 (P5): Public engagement**
Successful adaptive management requires robust public engagement and consultation with interested parties to share information, gather input, understand different perspectives, and proactively address disagreements.[25]

6. **Principle 6 (P6): Learning at the project and programmatic levels**
Over the course of a project, insights gained from monitoring data and scientific research are used to inform future management actions, which are then monitored and assessed to inform further actions; this is known as "single-loop learning."[26] Lessons learned across multiple projects are used to improve and inform development and future management decisions at the programmatic or institutional level; this is known as "double-loop learning" (see Figure 5).[27]

FIGURE 5: SINGLE LOOP AND DOUBLE LOOP LEARNING



Source: Adapted from Williams & Brown 2018: https://link.springer.com/article/10.1007/s00267-018-1107-5.

2. EXISTING U.S. STATUTORY AND REGULATORY FRAMEWORKS FOR OFFSHORE WIND

In the United States, there is no single statutory or regulatory framework covering offshore wind development. Instead, a variety of federal and state statutes govern different aspects of offshore wind development, and many agencies oversee it.[28] While major agency decisions—such as selling offshore wind leases or approving construction plans or permits—have always been accompanied by environmental review and have often required adaptive management measures, the practical effect of the existing regulatory structure is that there is no single agency or entity overseeing the effects of offshore wind development on ecosystems or species. Further, some species, habitats, and potential adverse effects are not explicitly covered by any statutory scheme.

It is important to understand what is currently in place before discussing what an effective adaptive management framework for the offshore wind industry would look like (see section 3). The current structure and potential for regulatory gaps heighten the need for a robust, comprehensive adaptive management system.

LEASING, CONSTRUCTION, AND OPERATIONS OF OFFSHORE WIND-RELATED INFRASTRUCTURE

BOEM administers the leasing of federal waters for offshore wind development and also approves developers' site assessments and construction and operations plans under the Outer Continental Shelf Lands Act (OCSLA).[29] However, many other state and federal agencies are involved at various stages. Adaptive management is often recommended but very rarely required by statute.

Prior to selling wind leases and approving construction and operations plans, BOEM has in the past conducted environmental review pursuant to the National Environmental Policy Act (NEPA).[30] It has also required developers to comply with avoidance, monitoring, minimization, and mitigation measures in their leases and construction and operations plan approvals to reduce adverse environmental effects.[31] With the current freeze on federal permitting of offshore wind projects, it is unclear whether BOEM will continue to do so for future approvals. In states with strong Coastal Zone Management Act (CZMA) implementation policies, state coastal agencies also have the opportunity to review BOEM's approvals to ensure consistency with state coastal policies. These states also can require that approvals include management measures to minimize impacts on state coastal zones.[32]

OCSLA—the statute regulating offshore wind leasing and operations—does not currently provide clear direction for the adaptive management of offshore renewable energy projects.[33] While OCSLA's implementing regulations require developers to submit monitoring and mitigation data gathered from site assessment and construction and operations activities to regulatory agencies annually and recommend new mitigation or monitoring measures where prior measures are "not effective," no guidance exists for determining said efficacy.[34] Similarly, while NEPA requires environmental review at different stages of project development, adaptive management is not explicitly required by NEPA. Rather, U.S. agencies in the past have viewed adaptive management as a discretionary approach that may be used in conjunction with the NEPA process.[35] For example, BOEM provides best management practices for construction and operations plans that recommend lessees develop a project-level monitoring program that includes adaptive management strategies for construction, operation, and decommissioning, but this approach is not required.

Lessees also need approvals from a variety of other agencies and jurisdictions. For instance, to construct and operate offshore wind platforms, anchoring systems, and other infrastructure like transmission lines, approvals are needed from the Bureau of Safety and Environmental Enforcement and the Army Corps of Engineers. Other agencies, like the National Oceanic and Atmospheric Administration (NOAA), U.S. Fish and Wildlife Service, and U.S. Environmental Protection Agency, need to be consulted on matters under their regulatory purview, such as management of endangered species and waterway discharges.[36] If transmission lines or other infrastructure are installed in a national marine sanctuary, the NOAA Office of National Marine Sanctuaries needs to grant approvals.[37] Any infrastructure in state waters or on state lands needs approvals from responsible state coastal agencies and port and harbor districts.[38] In all these instances, the lead agency has the power to require mitigating conditions. However, again, there is no consistent statutory direction regarding adaptive management.

MANAGEMENT OF PROTECTED SPECIES

Where offshore wind projects may affect threatened or endangered species, federal agencies must consult with the agencies charged with overseeing protected species to ensure that wind projects will not jeopardize species or their habitats.[39] Federal agencies must also consult with the National Marine Fisheries Service where offshore

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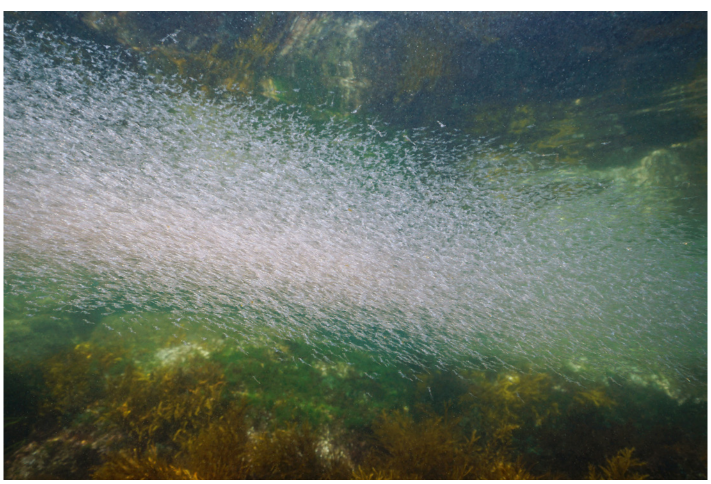
A humpback whale breaching the waters of Channel Islands National Marine Sanctuary, California.

wind activities might have adverse impacts on essential fish habitat.[40] Consulting agencies can impose measures on offshore wind operations to prevent or reduce harm to species protected by these provisions of law.[41] Project operators must also comply with species protection laws like the federal Endangered Species Act, Marine Mammal Protection Act, Migratory Bird Treaty Act, and state endangered species acts, and they can face civil and/or criminal penalties if they unlawfully harass, injure, kill, or otherwise "take" protected species.[42] These statutes typically establish processes by which the federal wildlife agencies may authorize take, provided that certain substantive and procedural requirements are met, including for mitigation.[43]

While these regulations provide for mitigation of adverse effects on protected species, and in some instances also provide for monitoring and reporting of the effects on species, they still fall short of a full adaptive management framework—applying only to protected species and, for many mitigation measures, only on a project-by-project basis.

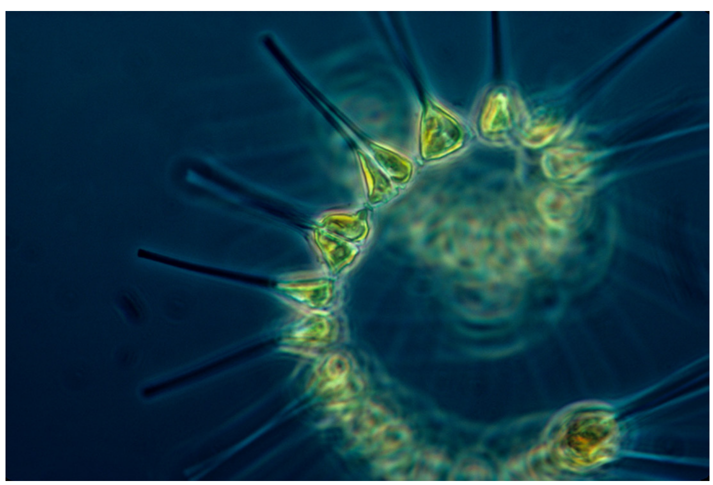
UNREGULATED OR UNDERREGULATED AREAS

Current management regimes do not cover all the species or habitats that could be impacted by offshore wind development, nor all types of effects. For example, although impacts may be reviewed during the project development process, important forage species like plankton and small pelagic fish are immensely important to oceanic food webs and are not comprehensively managed by existing statutes. Similarly, surface currents and subsurface upwelling processes supply essential nutrients to species throughout the water column but are not regularly monitored or managed under any existing statutory system. Additionally, certain types of benthic habitat may support important ecosystem services, like providing shelter and nursery areas to species, but are not explicitly protected under the Magnuson–Stevens Act's essential fish habitat provisions or any other statutory framework.[44]



© Shutterstock

Krill swarming in the eastern Atlantic Ocean.



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A microscopic image of phytoplankton.

3. SPECIFIC ADAPTIVE MANAGEMENT MEASURES FOR OFFSHORE WIND DEVELOPMENT

Using adaptive management to guide offshore wind development will ensure that the industry grows in a sustainable manner.

This section details various measures and approaches for adaptive management of the offshore wind energy sector, as well as recommendations for regulators as they begin to consider and develop an adaptive management framework for the U.S. offshore wind industry. It is broken into four parts: (1) measures relevant to all phases of offshore wind development; (2) measures to be taken when setting up an adaptive management framework; (3) measures to be implemented during the leasing and permitting phases; and (4) measures to be implemented during the construction and operations phases.

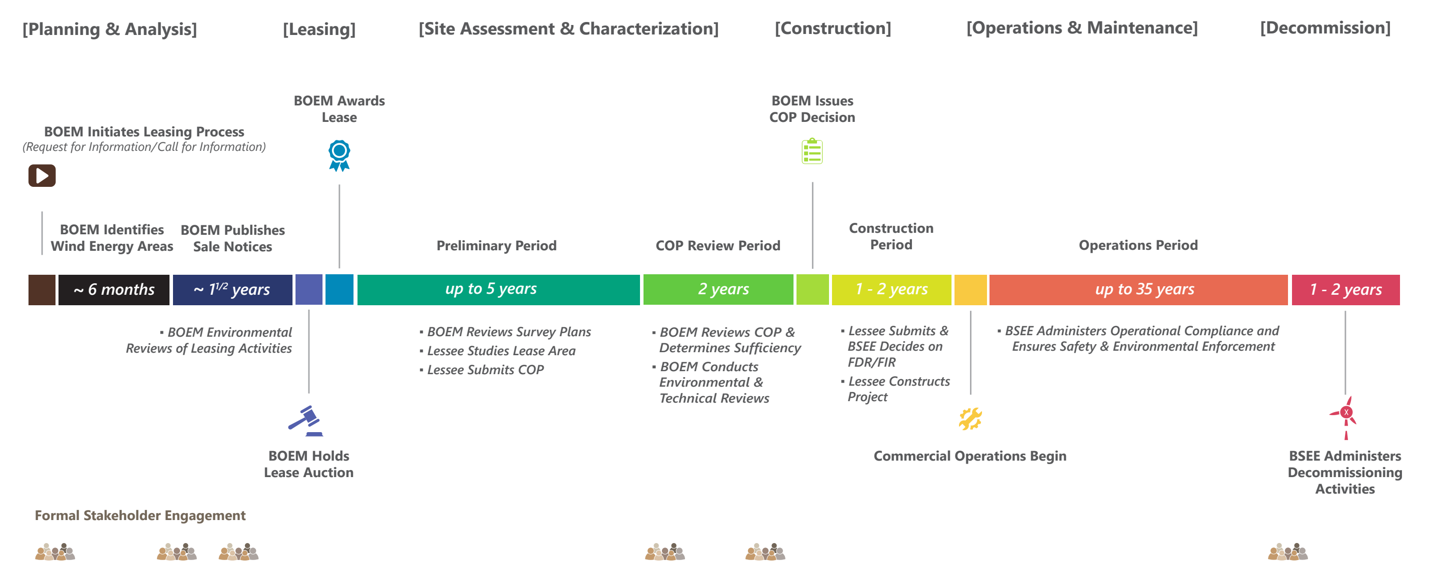
3.1 ADAPTIVE MANAGEMENT MEASURES RELEVANT TO ALL PHASES OF OFFSHORE WIND DEVELOPMENT

3.1.1 REGIONAL IMPLEMENTATION SHOULD BE INFORMED BY A NATIONAL FRAMEWORK

Given the scale and complexity of ecosystems—with many marine species that migrate vast distances and/or inhabit regions on a seasonal basis, and interrelated processes like wind and current systems driving marine productivity—data collection at a single wind farm would be insufficient to answer questions about the impacts of offshore wind at the broad spatial and temporal scales needed.[45] Ecosystem-wide learning and adaptive management requires large-scale, region-specific data collection, similar to that employed by the U.S. fisheries management system, where regional councils use broad federal science and stakeholder input to manage a region's fisheries and adaptively set catch limits each year (see Appendix). Larger-scale data collection and analysis also allow for double-loop **learning [P6]**, whereby data are collected from individual projects using standardized metrics and protocols and analyzed at programmatic levels to improve management and inform the development of future wind energy projects across an entire region.[46]

Double-loop learning has greater overall benefits compared with project-level (or single-loop) learning in terms of protecting wildlife, improving future decision making, and supporting the further development of the offshore wind industry.[47] In addition, significant biological and oceanographic differences exist between U.S. ocean regions that may necessitate ecosystem-appropriate **monitoring protocols [P4]**, **decision triggers [P2]**, and **mitigation measures [P3]**. For these reasons, region-scale implementation of adaptive management—as opposed to nationwide, or solely at the individual project scale—is likely most appropriate for the U.S. offshore wind sector. Regional implementation also aligns with the programmatic approach BOEM has taken in the past with the California leases and in the New York Bight by recommending issues to evaluate

FIGURE 6: LEASING AND PERMITTING PROCESS FOR U.S. OFFSHORE WIND ENERGY PROJECTS



Source: U.S. Bureau of Ocean Energy Management and potential mitigation measures in a programmatic environmental impact statement (PEIS) (see also section 3.3.1).[48]

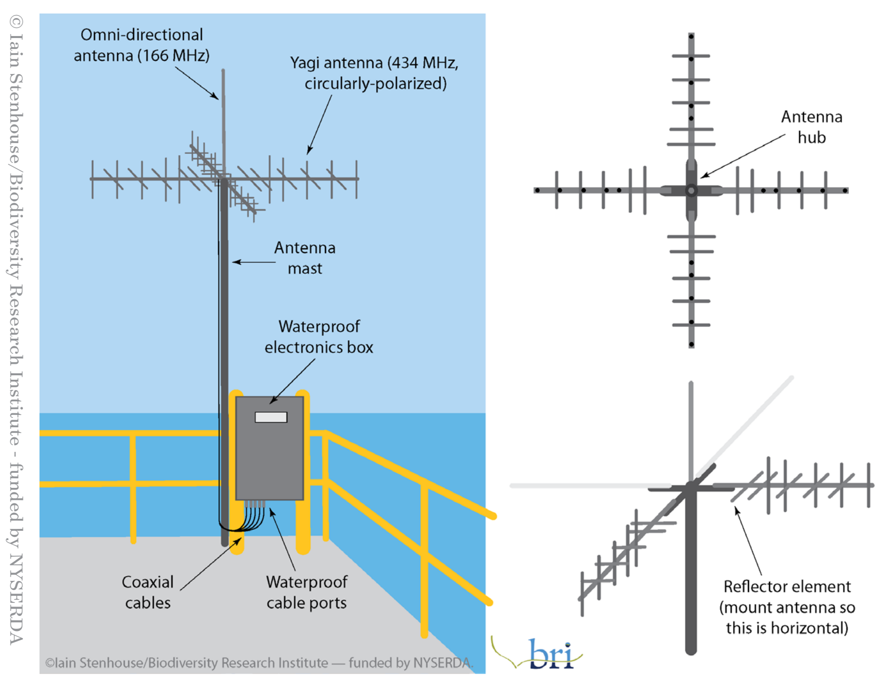
While adaptive management is best implemented at the regional scale, an overarching, nationally consistent set of adaptive management guidance, criteria, and standards—packaged together in a national adaptive management framework—should be developed to promote clarity and consistency in the way adaptive management is applied across the U.S. offshore wind sector, thereby reducing uncertainty and regulatory burden for developers. Currently, adaptive management practices are developed on a project-by-project basis for some taxa (such as birds and bats), but no overarching federal guidelines or criteria exist for all projects.[49]

Some states, however, have successfully implemented statewide adaptive management frameworks. For example, Oregon's Territorial Sea Plan—the plan for regulating the state's coastal and marine habitats, sets out a framework of policies that should guide renewable energy development, including siting guidance, resource protection standards, detailed data collection requirements, and adaptive management components necessary for inclusion in the operations plans of all renewable energy projects proposed and developed in Oregon state waters.[50] Such guidance helps to increase clarity for developers and ensure that monitoring and adaptive management at the project level are implemented consistently across state waters.

A national framework should include standards, criteria, and guidance for developers—supplemented by region-specific protocols (e.g., regional **monitoring priorities [P4]**, **decision triggers [P2]**, and/or **mitigation measures [P3]**) where technical, biological, and oceanographic differences necessitate them—to ensure that individual projects' adaptive management plans are coordinated and consistent. A framework should also promote the collection and analysis of region-wide data to facilitate double-loop **learning [P6]**, incorporating lessons learned from early wind farms into programmatic planning and future offshore wind development. A draft national framework should go out to public comment for **broad community and interested party input [P5]** before finalization (see section 3.1.4). The following sections detail key elements for inclusion in a potential national adaptive management framework.

3.1.2 REGIONAL SCIENCE COLLABORATIVES SHOULD INFORM THE DEVELOPMENT OF REGIONAL MONITORING PROGRAMS AND STANDARDS

Effective adaptive management relies on, and should ideally help to inform, strong scientific **research and monitoring programs [P4]**. Regional offshore wind science collaboratives can enable region-wide coordination of scientific research and monitoring priorities, house data and synthesize information about the effects of offshore wind, and set standards for monitoring protocols, including data standards to ensure that monitoring data are comparable across projects. As nonregulatory bodies, these entities should operate independently of state and federal agencies; include representatives from different sectors including industry, state and federal governments, tribal governments, and the scientific and NGO community; and draw on the expertise of scientists to develop guidelines.[51] One such science collaborative is already doing this work—the Regional Wildlife Science Collaborative (RWSC), which serves as a coordination hub for offshore wind research. Its objectives include increasing collaboration, limiting redundancy, informing research priorities, suggesting common data standards, and increasing data sharing and transparency across the Eastern states.[52] State and federal agencies should continue to support the establishment of regional science collaboratives for all U.S. regions developing offshore wind.



Example of monitoring array on offshore wind platform.

Because monitoring and adaptive management are so closely related, **monitoring [P4]** priorities should ideally inform adaptive management frameworks and vice versa, including **metrics and decision triggers [P3]** (see section 3.2.1). Regulatory agencies should coordinate closely with regional science collaboratives already established (e.g., RWSC), and those in the process of being established, to ensure that a national adaptive management framework aligns with, and is informed by, regional monitoring priorities, protocols, and data standards identified by such entities.

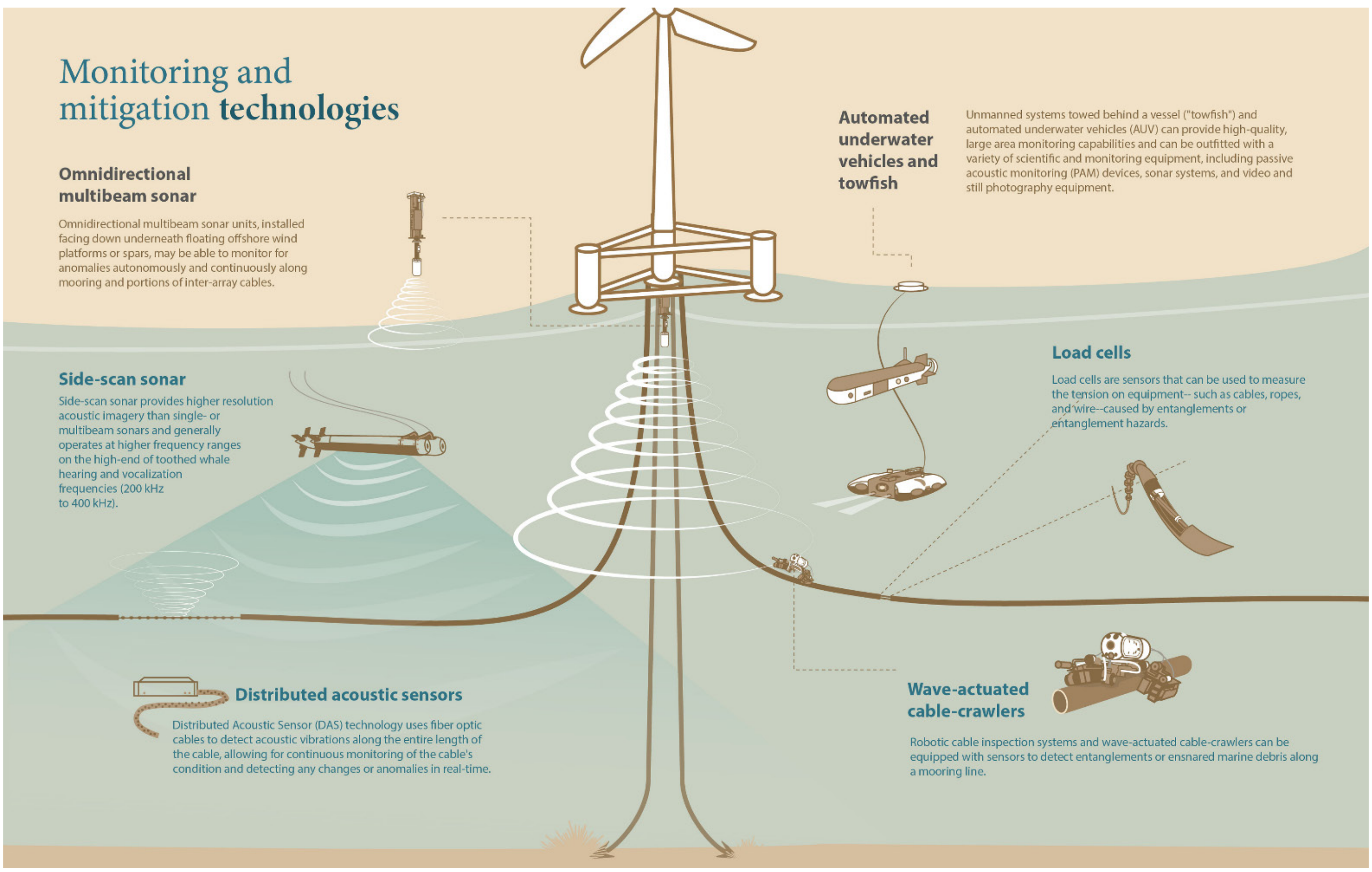
3.1.3 STANDARDIZED, MANAGEMENT-DRIVEN MONITORING SHOULD BE CONDUCTED THROUGH ALL STAGES OF A PROJECT

Accurate baseline data and robust, continuous **monitoring [P4]** are the cornerstones of effective adaptive management.[53] However, it is neither practical nor feasible to continuously monitor all components of an ecosystem, and monitoring data that are not tied to specific management questions have limited value in a management context.[54] Identifying a subset of monitoring priorities can ensure that monitoring remains cost effective, while also informing management decisions. Monitoring priorities should include indicators that represent key components in an ecosystem and specific impacts; assist with tracking changes to baseline conditions and species impacts; allow change to be identified and measured; correspond to management triggers that are similarly scaled; and be clearly linked to management objectives.[55]

In addition, while specific monitoring needs may vary across different phases of a project, a standardized approach throughout all phases is critical to improve models, which are often used to analyze or forecast impacts, and to effectively inform management decisions.[56] At the project level, this means aligning pre- and post-construction monitoring so results can be interpreted in relation to one another and can feed into shared, coherent modeling and analyses. At the regional or programmatic level, this means standardization of monitoring across projects—including methods and protocols used, metrics and indicators measured, and data formats and reporting protocols—to enable learning and comparisons across projects as well as region-wide studies to improve our understanding of ecosystem-scale dynamics and cumulative impacts. Regional science entities and regulatory agencies should work together to develop and require consistent monitoring protocols and data standards to be used across all phases of offshore wind projects (see sections 3.1.1 and 3.1.2).

The deployment of regional monitoring systems can also promote efficient, consistent, and standardized data collection across projects. For example, on the U.S. East

FIGURE 7: EXISTING MONITORING AND MITIGATION TECHNOLOGIES AVAILABLE FOR INTEGRATION INTO FLOATING OFFSHORE WIND SYSTEMS



Graphic by PACT Media

Coast, a region-wide passive acoustic monitoring (PAM) system has been proposed to monitor wind energy areas; if implemented, it would be a powerful tool for detecting the presence of marine species, mitigating risk, and identifying potential offshore wind impacts.[57] Many offshore wind projects on the East Coast are already conducting long term PAM monitoring within their lease areas as per regulatory requirements, and the data being collected will be used to monitor marine mammals within these areas and understand any potential impacts on marine mammals at the site level. The West Coast already has a number of acoustic monitoring systems in use, including in the Morro Bay Wind Energy Area, and there have been discussions about setting up a system in the Humboldt Wind Energy Area.[58] Efforts to establish or expand PAM systems in other regions should begin as early as possible, as NOAA and BOEM have recommended three to five years of data collection before wind farm construction, data collection during construction, and three to five years of data collection during wind farm operation to effectively capture variations in marine species' movement patterns.[59] As offshore wind development grows, PAM and other regional monitoring systems will become increasingly valuable for informed decision making.

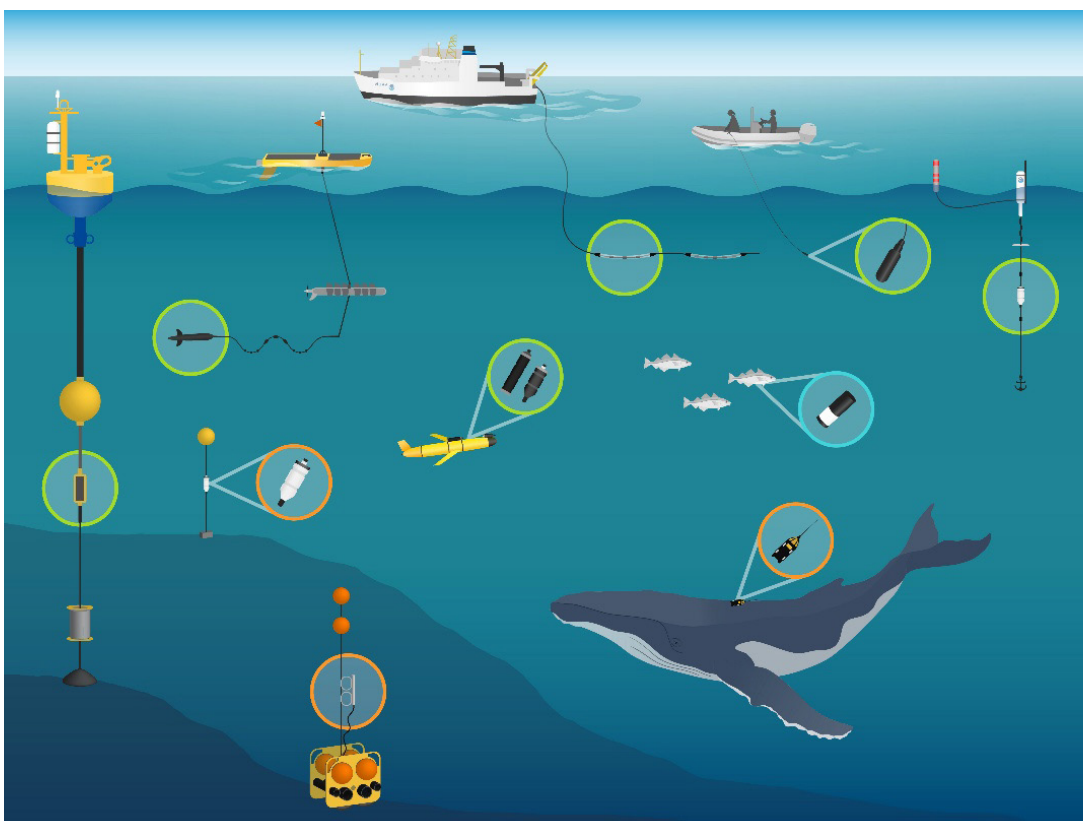
Finally, monitoring data collected through project-level and regional-scale monitoring systems should be reported to regulatory agencies and regional science entities at regular intervals and should be made publicly available on a timely basis. Delaying the release of monitoring data precludes adaptive management and prevents meaningful mitigation. Frequent reporting is necessary to promptly alert agencies, lessees, and the public to impacts and to enable avoidance, minimization, and mitigation of adverse impacts throughout all phases of development, operations, and decommissioning.[60] Such data should be housed using shared, standardized data reporting formats. We further recommend incorporation of the detailed recommendations for data transparency and equitable data sharing developed by RWSC as well as those developed by Ocean Conservancy.[61]

3.1.4 DEVELOPMENT OF ADAPTIVE MANAGEMENT FRAMEWORKS SHOULD EMPLOY A TRANSPARENT AND INCLUSIVE PUBLIC ENGAGEMENT PROCESS

Responsible offshore wind development **meaningfully engages state and local governments, the public, and interested parties from the outset [P6]**.[62] Transparent public discussion can foster a better understanding of adaptive management, increase engagement in the process, and communicate that regulatory agencies are being responsive to impacts and proactive in environmental protection.[63] Regulatory agencies should employ a transparent and inclusive engagement process that allows meaningful participation in the development of adaptive management frameworks. Such a process would make data and rationale publicly available and would solicit public input before major decisions are made. Public outreach is already a requirement of NEPA and of state-level statutes such as the California Environmental Quality Act (CEQA) and the

FIGURE 8: ACOUSTIC MONITORING TECHNOLOGIES

Scientists study marine animals using a variety of technologies to record underwater sounds, including archival passive acoustic recordings (orange), real-time passive acoustic data collection (green), and active acoustics (blue).



Source: NOAA Fisheries

California Coastal Act.[64] By leveraging these processes and actively sharing information on scientific questions, potential effects, monitoring, and mitigation actions, regulatory agencies can immediately begin gathering input to inform the development and application of adaptive management in the planning and operations stages of offshore wind projects.

3.1.5 ADAPTIVE MANAGEMENT PLANS SHOULD INCORPORATE TRIBAL INPUT, KNOWLEDGE, AND CONCERNS

Responsible offshore wind development must include **robust consultation with all Native American Tribes and communities [P6] affected by projects, not just federally recognized Tribes.**[65] As part of its lease conditions, BOEM already requires lessees to develop a Native American Tribes Communications Plan (NATCP), which gives Tribes with cultural and historical ties to the lease area an early and active role in providing input on potential project impacts. This early engagement helps to identify and address concerns before decisions are made, promoting a more inclusive and responsive decision-making process. Some states may also require consultation and outreach as part of their permitting process. Developers should be required to incorporate Tribal input, knowledge, and concerns into a project's adaptive management plan to ensure that plans are responsive to new information and changing circumstances as well as the needs and priorities of Native American communities.

3.2 PLANNING OR SETUP PHASE: DEVELOPMENT OF KEY COMPONENTS OF REGIONAL AND PROJECT-LEVEL ADAPTIVE MANAGEMENT PLANS

3.2.1 SUITABLE, SCIENCE-BASED DECISION TRIGGERS SHOULD BE IDENTIFIED BY INDEPENDENT SCIENTIFIC ENTITIES

Identifying unacceptable levels of change that trigger shifts in management if they are reached—often called **"decision triggers" [P2]**—is a critical component of effective adaptive management. Failure to properly set triggers associated with management objectives can result in what the policy literature characterizes as a "data-rich, information-poor" (DRIP) condition, where there is an abundance of data but regulators are unable to assign meaning to the data with confidence.[66] However, identifying what makes a good trigger is challenging and remains a significant knowledge gap for the offshore wind energy sector.[67] Triggers are typically bellwethers, set at a point where impacts are not yet severe or irreversible, so that impact avoidance remains possible. Choosing the right **metrics [P2]** is critical. For example, using a metric like "population abundance" on its own may well be inappropriate, particularly if abundance trends are difficult or take years to assess or if it is hard to attribute them specifically to offshore wind impacts. Rather, assessments of maximum mortality events, population variability, and/or changes in habitat quality using proxy indicators (e.g., prey abundance and distribution, ambient noise) would be better suited to serve as useful triggers.

There may be other effects, such as oceanographic impacts or benthic habitat disturbance, for which determining the threshold for a decision trigger is quite difficult. Quantitative modeling can help to determine where actionable thresholds should be set by predicting ranges of consequences that correspond to different resource conditions.[68]

Identifying suitable, science-based **decision triggers [P2]** requires scientific knowledge, time, and resources and coordinated efforts by marine and wildlife scientists and knowledge holders.[69] Because this requires significant ecological understanding and modeling expertise, the development of decision triggers is best done by scientists or scientific entities with deep knowledge of the system, guided by input from regulators on requirements for environmental review and permitting. In addition, because the thresholds at which triggers are set will influence **mitigation measures [P3]** and **monitoring [P4]** protocols needed for a project—and therefore the cost of a project over time—they should be developed by scientists or scientific entities that are as independent of the regulatory process as possible and free from political or business influence. Soliciting input from Tribes, fishers, conservation groups and other interested parties may also be warranted where there are multiple competing objectives or where the identification of triggers must incorporate both scientific expertise and value judgments about the management of the ecosystem. An independent study identifying appropriate national and/or regional decision triggers for key taxa should be conducted by an entity, such as the National Academies of Sciences, Engineering, and Medicine (NASEM) or a regional collaborative, that will provide independent, objective, and nonpartisan advice with high standards of scientific and technical quality. Agencies regulating offshore wind, in consultation with said entity, should then require developers to integrate chosen decision triggers into monitoring and adaptive management plans, with guidance and criteria outlined in the national adaptive management framework (see section 3.1.1).

3.2.2 SUITABLE ALTERNATIVE MANAGEMENT MEASURES SHOULD BE IDENTIFIED FOR USE WHEN DECISION TRIGGERS ARE REACHED

Predetermined **alternative management measures [P3]** provide a range of actions to be taken or considered at each decision point or when a decision trigger is reached.[70] The optimal approach will depend on a number of factors, including the availability of baseline data and robust monitoring systems, the existence of effective management measures, and conservation and regulatory goals.

For example, in the onshore wind context, the Shiloh IV Wind Project's adaptive management plan uses a stepwise approach to mitigate eagle fatalities, specifying predetermined advanced conservation practices (ACPs) to implement at different mortality thresholds (see Appendix). In addition to predetermined ACPs, the Shiloh IV Wind Project plan allows managers to use other, equivalent ACPs developed on the basis of new information, techniques, or science over time, identified in consultation with a technical advisory committee of U.S. Fish and Wildlife (USFWS) staff. Whereas the Shiloh IV Wind Project approach fosters flexibility and responsiveness to changing conditions and information, an approach that identifies a discrete menu of alternative management measures at the outset of a project may offer greater financial and regulatory certainty to developers.[71] In that vein, a number of state and federal fisheries are managed using harvest control rules, which are predefined procedures for setting catch limits based on the current or projected state of a fishery.[72] For instance, California's Spiny Lobster Fisheries Management Plan details eight regulatory options for managers to use if threshold reference points are triggered after a stock assessment (see Appendix). This is accompanied by a "control rule matrix" outlining different scenarios with recommended management responses for each trigger, helping managers to select the most appropriate strategy while allowing flexibility within scientifically grounded, predefined measures.

Possible **alternative management measures [P3]** for offshore wind adaptive management plans include adjustments to wind farm design of existing or future projects (see section 3.4.2), changes to operations (e.g., deployment of deterrents, changes to lighting arrays, curtailment; see section 3.4.3), changes to **monitoring frequency or coverage [P4]**, including the scaling back of monitoring, and the introduction of additional monitoring methods or technologies. Models can help to facilitate comparisons between costs and outcomes of different management actions and play a vital role in exploring and identifying appropriate alternative management measures for the offshore wind sector.[73] With the guidance of independent scientific experts or entities such as NASEM, regulatory agencies should identify acceptable alternative management measures to be implemented when decision triggers are reached. Guidance and criteria should be provided to developers, ideally as part of a national adaptive management framework. Alternative management measures themselves should also be periodically reviewed, and as more information is gathered and new technologies or management measures become available (see sections 3.3, 3.4), monitoring frequencies may increase or decrease. In some contexts, such as with national marine sanctuary management plans or vehicle fuel economy standards, the statutes establishing those programs may require periodic reevaluation and revision.[74] Currently there is no similar requirement in the statutes governing offshore wind development.

3.3 LEASING AND PERMITTING PHASES

3.3.1 ROBUST ENVIRONMENTAL REVIEW SHOULD BE CONDUCTED THROUGHOUT THE LEASING AND PERMITTING PROCESS

A staged approach to offshore wind development, in which adverse impacts on marine wildlife are minimized by using the findings from one phase of project development to inform or adjust the implementation and management of subsequent phases, can itself be a form of adaptive management and

A juvenile golden eagle flying near wind turbines.

support single-loop **learning [P6]**. This can come in the form of staged consenting—an approach more commonly used in other countries or at the U.S. state level—or staged environmental review and permitting, which is more common at the federal level in the United States, such as the processes required under NEPA (see section 2) and other statutes.

Staged consenting is an approach in which a project initially begins at a smaller scale (e.g., pilot-scale rather than commercial) and is granted approvals for subsequent phases of development only following environmental review and confirmation that development will not have unduly negative effects.[75] For example, Scotland's MeyGen tidal energy project was initially granted consent for a limited phase, with subsequent phases that would be approved only after comprehensive monitoring to evaluate the behavior of mobile species and validate collision risk models, and after thorough environmental review to confirm that impacts from the prior phase had not exceeded acceptable thresholds.[76] In the United States, this approach has been taken in some state waters. For instance, the State of Maine Research Lease will allow the state and stakeholders to conduct research, test, evaluate impacts, and learn from a small-scale offshore wind turbine array to inform the future of the industry in the region.[77] In Oregon, the state's Territorial Sea Plan allows regulatory agencies to permit a project as a phased development if potential impacts are unknown at the time of application due to a lack of data, allowing further data collection prior to subsequent build-out of the project.[78] However, while it is a useful approach, federal agencies have not required pilot-scale projects before approving commercial-scale projects.

The United States has at times taken a staged approach to offshore wind environmental review at the federal level under the environmental review process required under NEPA through the use of PEIS. A PEIS evaluates the available scientific knowledge and data and potential cumulative and regional impacts of development of multiple proposed projects at a regional scale and identifies avoidance, minimization, and mitigation measures that can be incorporated by individual projects in the region. A robust PEIS analysis could create greater efficiencies for subsequent project review and highlights for project developers the value of incorporating lower-impact design and operations elements into construction and operations plans (COPs). BOEM has already prepared PEISs for two regions undergoing offshore wind development, California and the New York Bight.[79] These documents provided overviews of potential environmental effects of a single representative offshore wind project and outlined potential avoidance, minimization, and mitigation measures but stopped short of requiring binding mitigation measures.

At the project level, robust environmental review for the full scope of a project at every stage of development is crucial for responsible offshore wind development. Regulatory agencies should continue to conduct robust programmatic and project-specific environmental assessments throughout the leasing and permitting process, **applying lessons learned [P6]** from each stage to future stages of development.

3.3.2 ADAPTIVE MANAGEMENT SHOULD BE BUILT INTO PERMIT REQUIREMENTS

The inclusion of conditions that protect the environment in approvals is critical for the responsible development of offshore wind energy. For example, approval of COPs should be contingent upon the inclusion of project-specific adaptive management plan(s) (see section 3.4) that are informed by site assessment findings, adhere to the guidance and criteria set forth by a national adaptive management framework (see section 3.1.1), and, where appropriate, are informed by project financing constraints.

Further, activities related to site assessment and preconstruction surveys are themselves associated with a variety of impacts to marine wildlife and ecosystems. For example, acoustic impacts from geophysical site assessment surveys are of particular concern for marine mammals and should be actively and adaptively managed throughout the site assessment phase, as was required on the U.S. east coast. Regulatory agencies should require lessees to demonstrate how underwater noise will be avoided, minimized, and mitigated to the fullest extent feasible in site assessment plans (SAPs), including setting sound thresholds that should not be exceeded to protect marine life, selecting technologies to achieve the lowest practicable sound levels for key affected species (see below), and the use of real-time observing systems (e.g., protected species observers on vessels, passive acoustic monitoring systems) to trigger shutdowns when marine mammals and other sensitive wildlife are present.[80] As more is learned about the patterns, distribution, and impacts on wildlife during site assessment activities, as well as the efficacy of various mitigation measures, this information can inform the project's COP and future projects' SAPs.

3.3.3 PERMITS SHOULD INCLUDE REQUIREMENTS FOR THE USE OF BEST AVAILABLE TECHNOLOGY

As the U.S. offshore wind industry matures, new methods and technologies may become available that enhance wind farms' ability to **monitor [P4]**, detect, and prevent impacts to marine wildlife. For instance, collision detection technology capable of identification at the species level is essential for monitoring impacts to birds and bats. However, potential technologies are still being studied and tested, and none are widely available at commercial scale for the offshore environment.[81] Once developed and commercially available, this technology should be integrated into offshore wind farms' ongoing monitoring and operations to the maximum extent practicable. Regulatory agencies should require developers to adhere to best available technology standards and ensure that developers are periodically required to update that technology to ensure that offshore wind farms are best able to monitor, reduce impacts, and facilitate adaptive management throughout the lifetime of a project (some U.S. offshore wind projects' permits already require such measures). Some types of technology will be easier than others to integrate into an already constructed wind farm.

For instance, technologies that can be added on to the overall infrastructure (e.g., monitoring systems that can be deployed via a buoy or attached to existing platforms, cables, or other infrastructure) may be more feasible in the short term than those requiring integration into the turbines themselves.

3.4 ADAPTIVE MANAGEMENT MEASURES RELEVANT TO THE CONSTRUCTION AND OPERATIONS PHASE

3.4.1 PROJECT-SPECIFIC ADAPTIVE MANAGEMENT PLANS SHOULD BE INFORMED BY NATIONAL AND REGIONAL GUIDANCE

BOEM's COP Best Management Practices recommend that lessees develop a project-level monitoring program that includes adaptive management strategies for construction, operation, and decommissioning phases and aims to mitigate potential adverse impacts.[82] However, as described in section 2, there is no clear regulatory framework outlining what types of strategies to include or how to include them. A national adaptive management framework should provide guidance and criteria for developers compiling adaptive management strategies in an individual project COP, including **decision triggers [P2]** and appropriate **alternative management measures [P3]** to implement in the event a decision trigger is reached (e.g., changes to turbine design for existing or future projects, times of operation, or maintenance schedule). These adaptive management strategies could be contained in one overarching adaptive management plan within a project's COP, or separate, taxa-specific plans, such as bird and bat management plans and marine mammal management plans.

One useful example is the Welsh government's guidance for project-level adaptive management, which details the required elements that developers should include in an adaptive environmental management plan.[83] The requisite components include a description of maximum potential impact; management measures to avoid, reduce, or mitigate impacts, including fail-safes such as curtailment; a monitoring plan to support the deployment of those measures; actionable triggers for determining when to deploy those measures; reporting mechanisms; and provisions for reviewing the plan periodically as more data are gathered. The regulating body notes that the plan may require amendment if new data show that changes are needed to achieve its management goals—promoting double-loop learning.

3.4.2 NEW OR IMPROVED DESIGN MEASURES SHOULD BE IMPLEMENTED WHERE FEASIBLE

Incorporating risk reduction **measures [P3]** into wind energy project design at the outset can help to maximize the avoidance and prevention of impacts to the environment as well as enhance **monitoring [P4]**. For example, design-related **measures [P3]** recommended to reduce risks to birds and bats from onshore wind farms include minimizing roosting areas on structures, painting turbine blades with black stripes or alternating colors to avoid motion smear, installing acoustic and visual deterrents, and ensuring that lighting of structures employs only strobed or blinking lights, ideally with all lights flashing synchronously.[84] More study is needed to identify the most effective design measures to prevent bird and bat collision risks posed by offshore wind farms, but they could include: minimizing lighting on a facility, directing lights to point downwards, and avoiding broad-spectrum lights.[85] Design strategies to reduce marine mammal entanglement risk for floating offshore wind platforms include minimizing slack lines, using large-diameter cables, and burying inter-array cables when possible.[86]

Given the early stage of the U.S. offshore wind industry, uncertainties still exist around optimal wind farm design to reduce risks in the offshore environment. As projects become operational and **monitoring data [P4]** help build

An offshore turbine under construction at the South Fork Wind Project off of New York.

our understanding around design and risk reduction, **new or improved design measures [P3]** should be implemented where feasible. Adaptive management plans should detail **when [P2]** and **how [P3]** to adjust project design, where possible, when existing mitigation measures prove insufficient in reducing marine wildlife impacts or mortality. For non-adjustable design elements (e.g., placement of fixed-support turbines, moorings for floating turbines, and subsea transmission cables), programmatic or "double-loop" **learning [P6]** from early wind farms can improve future wind farm designs, ensuring that adaptive management drives continual improvement.

3.4.3 CURTAILMENT MAY BE APPROPRIATE TO ADAPTIVELY MANAGE IMPACTS

Curtailment is a **management measure [P3]** that involves limiting operations to reduce harm—for example, changing the angle of turbine blades at specified low wind speeds to prevent them from spinning and thus reduce impacts on bird and bat species, or limiting the operation of individual turbines or an entire wind farm during key periods, such as migration.[87] For instance, research has shown that bats are most at risk of collision with onshore turbines in late summer and early fall, on warm nights when wind speeds are relatively low. Curtailing turbine operations when wind speeds are below five meters per second has consistently proved to reduce bat collisions.[88] More study is required, but if monitoring shows that impacts to birds or bats are significant in the offshore environment, curtailment is a tool that may be appropriate to adaptively manage impacts.[89]

Currently there is a lack of data related to collision risk for birds and bats in the offshore environment (see Appendix for more detail). However, as offshore wind projects come online, as **monitoring technologies [P4]** improve, and as more **monitoring data [P4]** are collected, a greater understanding of collision risks can emerge. This can inform whether curtailment is appropriate and enhance the use of targeted curtailment for wind farm operations via adaptive management, both for individual projects and for regional programs via single- and double-loop **learning [P6]** (including potential times of day, night, or seasons when curtailment would be more effective for different species and regions), as it will be important to consider commercial needs and offtake obligations. In the meantime, smart curtailment systems like real-time, automatic detection systems using radar, video monitoring, and/or acoustic detection can be useful for reducing collisions while minimizing energy loss. It can be useful to build these systems into a project's design at the beginning of the project, or in an adaptive management plan to implement as impacts occur and/or thresholds are met. For example, the Shiloh IV Wind Project's adaptive management plan identifies the deployment of radar systems as an **alternative management measure [P3]** when eagle fatalities have occurred, to guide implementation of real-time, temporary curtailment as eagles or large raptors approach specific turbines (see Appendix).[90] While curtailment has been proved effective on land, further testing is needed to determine the efficacy of this **measure [P3]** in the offshore environment.

3.4.4 COMPENSATORY MITIGATION CAN BE COMPLEMENTARY TO ADAPTIVE MANAGEMENT WHERE IMPACTS CANNOT BE PREVENTED

Even after all avoidance and minimization methods have been implemented, there are likely to be some remaining impacts of offshore wind energy development that cannot be prevented. Compensatory mitigation, or offsetting, could therefore be a key component of a robust mitigation hierarchy for some species and can be used to achieve no net loss, or even net gain, for some affected wildlife populations and/or habitats. While compensatory mitigation is not exclusively an adaptive management tool, we include the concept here because it has a role to play in the adaptive management of offshore wind projects for some species with unavoidable impacts, though it will not be appropriate in all situations, such as those involving threatened or endangered species or highly localized species or populations with small home ranges. At the same time, it is important to ensure that compensatory mitigation does not become the default for triggered actions in an adaptive management scheme.

Compensatory measures typically involve funding or facilitating the reduction of threats to affected species in other locations or from other stressors or creating similar habitat elsewhere. For example:

- In the United States, the Shiloh IV Wind Project's adaptive management plan includes compensatory mitigation for fatalities of eagles protected by the Endangered Species Act (ESA) by retrofitting electric poles in the region to reduce the likelihood that they will cause future fatalities (see Appendix for case study).[91] The intent is to minimize the potential for eagle electrocutions and ensure that the effects of eagle fatalities caused by Shiloh IV are offset by enhancing the safety of electrical poles in the area.

Three nearshore artificial nesting structures installed by Red7Marine along the East Coast of England on behalf of Ørsted. The structures are required as a part of the Development Consent Order for the Hornsea 3 Offshore Windfarm as an ecological compensation measure for a vulnerable seabird species—the Black-legged kittiwake (*Rissa tridactyla*).

- Similarly in the United Kingdom, impacts to a protected bird species from the Norfolk Offshore Wind Zone are offset through the installation of artificial nesting structures at a nearby site, to help provide alternate bird habitats in an urban nesting area.[92]

In addition to legally mandated compensatory mitigation, offsetting measures are increasingly being taken up voluntarily by developers interested in improving conservation outcomes and relationships with and buy-in from stakeholders, demonstrating that projects are bringing about positive change at the local level and/or contributing to global nature-positive ambitions such as “biodiversity net gain”—a planning approach that ensures new developments leave biodiversity in a better state than before.[93] For example:

- A consortium of developers partnered with The Rich North Sea and installed oyster tables at Blauwwind Wind Farm to help boost struggling native oyster populations in the North Sea.[94]
- The wind developer Avangrid is taking voluntary measures to mitigate impacts to the ESA-protected rufa red knot and piping plover in preparation for required compensatory mitigation for a planned project off the U.S. East Coast.[95]

Other well-tested conservation measures for marine birds that may serve as effective offsetting measures include invasive species removal at breeding colonies, establishment of new seabird colonies through translocation and/or social attraction, and actions to reduce fisheries bycatch.[96]

3.4.5 REGIONAL CUMULATIVE EFFECT ANALYSES SHOULD BE CONDUCTED PERIODICALLY THROUGHOUT AN OFFSHORE WIND FARM’S LIFE-SPAN

Currently, regulatory agencies must complete cumulative effects analyses for proposed projects under NEPA and state equivalents like CEQA. In such an analysis, the agency assesses the environmental impact of an action when added to other past, present, and reasonably foreseeable future actions.[97] These analyses provide a broader understanding of the environmental impacts of offshore wind development, to inform better decisions and mitigation strategies at the regional scale and facilitate double-loop **learning [P6]**. However, BOEM currently considers regional cumulative effects only when approving the leasing and construction and operations phases of offshore wind development. This is insufficient, as offshore wind energy projects will be operational for approximately 30 years or more, and the effects and impacts of offshore wind energy development on habitats and species may change during the lifetime of the project or development area—especially as ocean conditions shift in the coming decades.[98] Regional cumulative effect analyses should be completed periodically throughout the operational phase as well, to evaluate the efficacy of **mitigation measures [P3]** on ecosystem-level processes and impacts, to inform whether **decision triggers [P2]** are set appropriately or need adjustment in light of changing conditions, and to better understand the cumulative impacts of offshore wind at the regional scale over time to facilitate **learning [P6]**.

CONCLUSION

Adaptive management is essential to ensuring the responsible development of the U.S. offshore wind energy sector, as it provides a flexible, science-based approach to managing uncertainty, minimizing environmental impacts, and incorporating new information as it emerges. By implementing science-based adaptive management, regulators can support a dynamic and resilient offshore wind industry that aligns with national energy, climate, and conservation goals. The recommendations outlined in this report offer a pathway for establishing an effective adaptive management framework that will help guide the sector toward long-term environmental, economic, and social sustainability.

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Dolphins swimming as a wind turbine installation vessel builds an offshore wind turbine on top of a previously installed foundation.

APPENDIX

1. SUMMARY LIST OF RECOMMENDATIONS AND OPTIONS

Here we offer a summary of this report's recommendations and options for the implementation of adaptive management for the U.S. offshore wind energy sector. All recommendations and suggestions are directed toward state and federal regulatory agencies, unless otherwise stated.

REGIONAL IMPLEMENTATION SHOULD BE INFORMED BY A NATIONAL FRAMEWORK:

- **Recommendation 1**—Develop a national framework for regional-scale adaptive management of offshore wind to promote clarity and consistency for the sector nationwide. This framework should:
  - include national and region-specific guidance and criteria for developers to implement adaptive management at the project level;
  - detail region-specific, science-based protocols (e.g., regional monitoring priorities and protocols, decision triggers, and alternative management measures) where necessary due to biological and oceanographic differences among regions;
  - identify appropriate decision triggers through independent studies led by nonpartisan scientific entities such as a regional science collaborative or NASEM;
  - facilitate double-loop learning to incorporate lessons learned and data gathered from early wind farms into future projects across a region; and
  - develop guidance and protocols with input from Native American Tribes and communities, academics, environmental and environmental justice nonprofits, and other interested parties, including through a public comment period before finalization.
- **Recommendation 2**—Continue to support the establishment of regional science collaboratives for U.S. regions developing offshore wind to establish coordinated and standardized monitoring and data protocols that are informed by, and feed into, adaptive management at the regional and project levels.
- **Recommendation 3**—Conduct periodic regional cumulative effect analyses during the operational phase of offshore wind, instead of solely at the front end of development.
- **Recommendation 4**—Conduct periodic review of adaptive management measures, decision triggers, and the national framework itself as more information is gathered and new technologies or improved management measures become available.
- **Recommendation 5**—Consider setting up regional adaptive management advisory groups with multi-stakeholder representation to advise on the implementation of adaptive management and help to facilitate double-loop learning.

STANDARDIZED, MANAGEMENT-DRIVEN MONITORING SHOULD BE CONDUCTED THROUGH ALL STAGES OF OFFSHORE WIND DEVELOPMENT:

- **Recommendation 6**—Work with regional science collaboratives to develop and implement a coordinated and standardized approach to monitoring throughout all phases of development.
- **Recommendation 7**—Select monitoring priorities that are indicators for key components in an ecosystem; allow for change to be identified and measured and clearly link to management objectives.
- **Recommendation 8**—Deploy regional monitoring systems where feasible to promote efficient, consistent, and standardized data collection across projects.
  - Begin efforts to set up regional PAM systems as early as possible.
  - Leverage public–private partnerships to fund and operationalize regional monitoring systems.
- **Recommendation 9**—Conduct research and data collection in a collaborative and transparent manner, involving recognized marine and wildlife experts, engaging relevant stakeholders, and making results publicly available.
- **Recommendation 10**—Promptly make monitoring data on entanglements, vessel strikes and fatalities, and turbine collisions publicly available, and house all monitoring data in public portals using standardized data reporting formats.

BUILD ADAPTIVE MANAGEMENT INTO LEASING AND PERMITTING REQUIREMENTS:

- **Recommendation 11**—Define conditions for the approval of SAPs and COPs that adhere to adaptive management guidance and criteria discussed herein, and address potential environmental impacts identified in the EIS. For example:
  - Require the inclusion of project-specific adaptive management plan(s) in COPs.
  - Require lessees to demonstrate in SAPs how underwater noise will be avoided, minimized, and mitigated to the fullest extent feasible, including via the use of adaptive measures such as real-time observing systems to trigger shutdowns when marine mammals and other sensitive wildlife are present.
  - Require developers to use best available and safest technology for effective monitoring, avoidance, and mitigation strategies.
- **Recommendation 12**—Continue to conduct robust programmatic and project-specific environmental assessments throughout the leasing and permitting process, applying lessons learned from each stage to future stages of development.

CONSIDER REQUIRING ADDITIONAL ADAPTIVE MANAGEMENT MEASURES DURING THE CONSTRUCTION AND OPERATIONS PHASE

- **Recommendation 13**—Ensure that new or improved design elements are implemented where feasible as projects become operational and monitoring data help build understanding around design and risk reduction.
- **Recommendation 14**—Require developers to detail compensatory mitigation actions in their COPs when unavoidable and irreparable impacts are expected to occur during the project's lifetime.
- **Recommendation 15**—Consider voluntary offsetting measures.

2. POTENTIAL IMPACTS OF OFFSHORE WIND ENERGY ON MARINE SPECIES AND HABITATS

Potential Impact	Description	Phase of Development	Taxa and/or Habitats Likely Affected[99]
Bird and bat strikes	Spinning turbine blades can strike birds and bats as they pass through the rotor-swept area, causing injury or mortality.	Construction, operations	**Birds:** ▪ More than 500 migratory and coastal bird species using the Atlantic Flyway ▪ More than 350 migratory and coastal bird species using the Pacific Flyway (though migratory paths are concentrated primarily around coastal areas) ▪ An estimated 2.1 billion individual birds using the Gulf of Mexico migration corridor **Bats**: ▪ At least 7 species of bats observed off the Atlantic Coast ▪ Up to 25 bat species present along the Pacific Coast
Displacement, avoidance, or attraction	Some species may avoid, be attracted to, or be displaced by wind farms, disrupting normal behaviors and expending additional energy. For instance, birds can be attracted to lighting on platforms and vessels, especially at night, putting them at higher risk of strikes/collisions.[100]	Siting, construction, operations	▪ Marine mammals ▪ Seabirds ▪ Sea turtles ▪ Some species of fish
Entanglement	Marine life can become entangled in or ensnared by cables or mooring lines associated with offshore wind infrastructure or marine debris caught on offshore wind infrastructure, leading to injury or mortality. Secondary entanglement—in which marine debris becomes ensnared around mooring lines, mid-water cables, or other infrastructure and subsequently entangles marine wildlife—is thought to represent a great risk for a broad range of species.[101]	Construction, operations	▪ Marine mammals ▪ Sea turtles ▪ Sharks ▪ Diving sea birds

Potential Impact	Description	Phase of Development	Taxa and/or Habitats Likely Affected[99]
Noise pollution	Underwater noise generated during siting, construction, operations, and decommissioning activities has the potential to displace or harm marine species, including whales or dolphins that use sound to communicate, navigate, hunt for prey, and avoid predators.[102]	Siting, construction, operations	■ Marine mammals ■ Fish that use sound for reproduction ■ Diving birds
Vessel strikes	Increased vessel traffic associated with siting, construction, and operations has the potential to impact marine mammals and sea turtles through strikes and disturbance.	Siting, construction, operations	■ Marine mammals, especially slow-moving, large-bodied whales ■ Sea turtles
Invasive species introduction	Invasive species could be introduced to U.S. waters through the transport of materials and construction components from other countries or regions. Offshore infrastructure has also been shown to be used as a "stepping stone" for the spread of invasive species.	Construction, operations	■ Any taxa displaced by or impacted by an invasive species, such as invertebrates, marine plants, algae, and fish ■ Any taxa affected by a nonnative marine virus or disease, such as oysters affected by invasive virus OsHV-1
Changes to oceanographic processes	Offshore wind infrastructure may have potential impacts on hydrodynamic processes such as wind-driven upwelling, which could affect plankton abundance and species that forage plankton at local and regional scales.[103]	Operations	■ Habitats and species of upwelling-associated ecosystems
Electromagnetic field (EMF) generation	Electromagnetic fields generated by offshore wind infrastructure—especially subsea power cables—can affect marine life that relies on EMFs for navigation and migration, through changes in activity patterns, foraging behavior, or spatial use near energized cables.	Operations	■ Crustaceans ■ Sharks ■ Rays ■ Sea turtles ■ Skates ■ Some species of bony fish
Habitat disturbance or destruction	Disturbance during construction may include dredging, crushing, or burial of habitats by construction equipment and materials placement; burial effects from suspended sediment deposition; habitat displacement by structures, anchors, export cable installation and maintenance; habitat modification by placement of scour protection and concrete mattresses; alteration of soft-bottom or complex benthic habitat function; port development in coastal areas.	Siting, construction, operations, decommissioning	Habitats: ■ Deep sea soft- and hard-bottom habitat ■ Essential fish habitat ■ Coastal habitats found around ports, such as wetlands, beaches, or coastal dunes **Taxa:** ■ Benthic invertebrates (e.g., sea pens, calcareous sponges, demosponges, deep-sea corals, soft corals, shellfish, crustaceans) ■ Some species of bottom-dwelling fish

Note that many of these potential impacts are considered during environmental review and permitting of OSW projects, and have associated avoidance, minimization, mitigation, and monitoring measures that are included in project COPs.

3. DATA GAPS FOR BIRDS AND BATS

At present, there are limited data on the use of the offshore space by bird and bat species and on bird and bat fatalities related to offshore wind projects, given the unique challenges of monitoring at sea, particularly as it relates to small-bodied organisms. Understanding which species are most at risk of collision is essential in order to accurately estimate the impact of offshore wind energy projects on birds and bats and to improve mitigation measures accordingly. This requires an understanding of their spatial and temporal distributions: their physical distribution, the heights at which different species fly, their behavior around turbines, and the timing and location of different species' migratory pathways. Data from onshore wind can inform offshore risk, but because there are key differences in species of concern, flight altitudes, turbine height, and blade lengths (rotor-swept area) in offshore as compared with onshore wind farms, such data are insufficient to understand the full risk of offshore wind on birds and bats. This lack of data currently hinders our confidence about which species are most at risk of collision in the offshore environment and the significance of impacts, affects the accuracy of models used to evaluate population impacts, and impedes understanding of which management measures may be best for avoiding, minimizing, and mitigating fatalities for those species. In some regions, projects that are already fully or partially operational are helping to fill gaps through project-related monitoring and data collection. As data gaps are filled over time, project-specific management plans and planning for offshore wind development as a whole should be updated with new information, especially as it relates to improvements needed in mitigation measures.

4. EXAMPLES OF EXISTING ADAPTIVE MANAGEMENT MODELS

INTERNATIONAL ADAPTIVE MANAGEMENT MODELS

In addition to those mentioned throughout the text of this report, examples of successful wind adaptive management from around the world are summarized by the International Energy Agency's 2016 *Assessing Environmental Effects (WREN): Adaptive Management White Paper,* and below.[104]

Netherlands: The Netherlands is currently implementing double-loop learning at the programmatic level of offshore wind development: Knowledge is acquired as one round of wind farms is leased, constructed, and made operational in the country's waters, and then informs subsequent rounds of wind farm planning and development. This process is relatively new and still being evaluated but represents a growing trend toward industry-wide learning and adaptation in the country's wind energy sector.[105]

Switzerland: While not officially an adaptive management program or plan, the Gries wind farm in Switzerland is implementing adaptive management principles for bird and bat conservation.[106] As a condition of its construction permit for three turbines whose potential impact on birds and bats is highly uncertain, the wind farm is required to monitor bat activity for three years, reassess the data annually to optimize its mitigation strategy, and adjust operations with approval from a diverse operations commission. Switzerland does not have legislation that explicitly calls for adaptive management in wind energy projects, so integration of adaptive management principles and frameworks is up to each project.

Norway: Norway also does not officially implement adaptive management in offshore wind programs or projects, but research into the effectiveness of mitigation measures and subsequent adjustments based on the information learned embodies the principles of learning and iterative development commonly associated with adaptive management.[107] The renewable energy company Statkraft co-financed the testing of various mitigation strategies for their effect on white-tailed eagle conflicts at the Smøla wind farm.[108] The testing was question driven, as it was informed by a preceding literature review that established expected efficacy levels for each measure. The results of the testing allowed development of a model to identify periods and turbines posing a heightened risk to birds. This research ultimately reduced scientific uncertainty regarding both the extent of the impacts and the effectiveness of mitigation measures and reflected an adaptive management approach of continual learning and adaptation based on results.

U.S. ADAPTIVE MANAGEMENT MODELS

Many examples of adaptive management exist in the United States. In addition to those referenced throughout the text of this report, a few more examples—at both the programmatic and project-specific levels—are summarized below.

Programmatic: U.S. Fish and Wildlife Service and Eagle Take

Onshore wind facilities are known to result in occasional eagle mortalities.[109] Recognizing the need to balance renewable energy benefits against negative impacts to eagles, which are federally protected species, the USFWS has developed a permitting process that authorizes eagle take at onshore wind facilities provided that actions are consistent with the eagle preservation standard and accompanied by mitigation and monitoring measures.[110] One tool this permitting process uses is a peer-reviewed collision risk model (CRM) to predict eagle mortalities likely to be caused by a project and measures this mortality prediction against the species' estimated capacity to withstand fatalities. If the prediction falls within the estimated capacity or can be offset with compensatory mitigation, an individual permit can be issued for the project.

However, uncertainties existed when this process was set up. No bald eagle data were available for onshore wind projects—a critical need for the CRM to be accurate for this species.[111] Golden eagle risk levels were relied on until new data became available, and USFWS designed a formal adaptive management process to update the permitting program's CRM as new data came online. In addition, it adopted a process for updating project-specific take predictions and implementing mitigation measures as needed (see Shiloh IV example below).

Under the permitting program, USFWS requires onshore wind facilities to collect and share back all eagle take and monitoring data over the lifetime of the project. These data are then used not only for the project's own specific adaptive management, but also to clarify and reduce uncertainty for the industry overall and to help estimate eagle population levels. Under the eagle permitting process, USFWS incorporates new data and analyses every five years, thereby improving its ability to manage and conserve bald and golden eagles as it gains an improved understanding of eagle populations and risk levels posed by onshore wind facilities and other stressors over time.

Using this adaptive management framework, USFWS updated its permitting process in 2021 using the data collected from permitted wind facilities.[112] The eagle permitting process now includes a new CRM with datasets specific to both golden eagles and bald eagles, and a new bald eagle–specific permitted take estimate. In 2024, USFWS further refined the eagle permitting process by introducing the availability of general permits based on standardized mitigation measures and eagle abundance models.[113] This example of adaptive management at the programmatic level demonstrates how U.S. regulatory agencies can and should update permitting and other processes over time as new data, technology, and circumstances arise.

Project-Specific: Shiloh IV Wind Project Eagle Conservation Plan

In accordance with the permitting requirements set forth by USFWS described above, onshore wind projects that acquire permits for eagle take must monitor for eagle take. Projects that have not been permitted for eagle take may voluntarily follow USFWS guidelines. The monitoring program for the Shiloh IV Wind Project in Solano County, California, entails three major field components: 1) avian use surveys to determine the seasonal and annual variations in relative abundance and species use patterns; 2) carcass surveys to search for the bodies of birds and bats killed by turbines or power transmission structures, and 3) carcass detection probability and removal monitoring for bias correction.[114] Results of monitoring are used to determine the effectiveness of existing mitigation measures, to identify which, if any, turbines produce disproportionately high levels of mortality, and to inform the project's adaptive management.

The project developed an adaptive management framework describing alternative management measures—called ACPs—that should be implemented in the event golden eagle take occurs.[115] ACPs are "scientifically supportable measures that are approved by the Service and represent the best available techniques to reduce eagle disturbance and ongoing mortalities to a level where remaining take is unavoidable."[116] ACPs identified in the adaptive management plan range from visual modifications of turbines, such as painting blades to increase visibility for birds, to enhancements in monitoring, such as installing radar and employing on-site biologists to monitor daytime presence of eagles; to operational adjustments, such as seasonal curtailment (see table A1 below). The adaptive management framework takes a stepwise approach that outlines thresholds at which Shiloh IV will implement ACPs and relies on comprehensive monitoring as well as a technical advisory committee (TAC) of USFWS staff to determine when and how to implement them.

Importantly, the adaptive management plan is not intended to limit or preclude other, equivalent ACPs that are identified in consultation with the TAC or that may be developed as a result of new information, techniques, or science.[117] However, identifying ACPs ahead of time and determining which actions should be considered at different thresholds help reduce uncertainty for developers and regulators.

TABLE A1: SUMMARY OF ADVANCED CONSERVATION PRACTICES USING A STEPWISE APPROACH, TO BE IMPLEMENTED WHEN EAGLE TAKE OCCURS ON SHILOH IV

Step	Advanced Conservation Practices	Threshold or Trigger
Step I	Initiate consultation with the Shiloh IV TAC to illuminate appropriate conservation measures that will minimize the likelihood of further take. Monitor mortality for eagles using approved protocols for 3 consecutive years.	1 eagle taken
Step II	Initiate ACPs involving visual and/or auditory deterrence procedures and consultation with the TAC to design a protocol evaluating effectiveness of these methods (e.g., painting a statistically meaningful subset of blades or installing auditory deterrence measures on a subset of blades). Intensify eagle monitoring studies to define seasonal and diurnal flight patterns within the project area to inform development/implementation of future ACPs (e.g., monitoring flight patterns in the wind resource area). Conduct 3 years of mortality monitoring to evaluate effectiveness of deterrence methods.	2 eagles taken within any 12-month period or 3 eagles taken within any 5-year period
Step III	Employ qualified biological monitors with suitable eagle experience on-site during daylight hours with the ability to temporarily modify the operation of particular turbine(s) (i.e., feathering turbines) when an eagle/large raptor approaches the rotor-swept area. Alternatively, select and implement the latest proven avoidance techniques or experimental techniques, such as radar systems, in consultation with the TAC. Initiate consultation with the TAC to refine and evaluate the operations modification protocol utilizing data from monitoring efforts undertaken in Step II. Extend or reinitiate eagle movement studies if such are demonstrated to generate useful information. Conduct 3 years of mortality monitoring to evaluate effectiveness of deterrence methods.	3 eagles taken within any 12-month period or 4 eagles taken within any 5-year period
Step IV	Deploy radar system(s) designed to allow real-time, temporary operational modifications to turbine blade rotation as eagle(s)/large raptors approach particular turbines, or deploy the latest proven avoidance techniques or experimental techniques that would provide an equivalent level of potential protection for eagles. In consultation with the TAC, design and implement a protocol for determining the effectiveness of the radar system(s) or other techniques. Conduct 3 years of mortality monitoring to evaluate effectiveness of radar systems at reducing eagle take.	4 eagles taken within any 12-month period or 5 eagles taken within any 5-year period
Step V	Initiate consultation with the TAC to determine operation modification schedules based on evaluation of data collected in previous phases. Options may include operational modification at appropriate season and time of day or at identified problem turbines/strings. Extend eagle movement monitoring and mortality monitoring for a 3-year period.	5 eagles taken within any 24-month period or 6 eagles taken within the first 5 years of operations
Step VI	In consultation with the TAC, determine other appropriate actions necessary to minimize and compensate for additional impacts on eagle populations.	7 eagles taken within a 5-year period

Programmatic: U.S. Fisheries Management

Marine fish populations are dynamic and sensitive to environmental conditions as well as harvest. Fisheries management must therefore be adaptive in nature, adjusting harvest limits over time as fish populations fluctuate, to avoid mismanagement, overfishing, or fishery collapse. The primary law that governs marine fisheries management in U.S. federal waters, the Magnuson–Stevens Fishery Conservation and Management Act (MSA), integrates adaptive management into the foundations of fisheries management to prevent overfishing, quickly stop overfishing when it occurs, and rebuild overfished stocks.[118]

Under the MSA, scientific research and assessments are routinely conducted to determine the status or trend of a fish stock, and annual limits for the amount of fish that can be caught that year (catch limits) are set by regional, multi-stakeholder councils on the basis of this information. Catch is then monitored using fishery-dependent and independent data. The next year, adjustments are made to catch limits according to catch overages from the previous year and updated population assessments, and the cycle is repeated.

Several key elements contribute to the MSA's success. First, the law includes national standards detailing principles that must be followed by all fishery management plans. In particular, National Standard 1 states that "Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry." Optimum yield is defined as the scientifically determined maximum sustainable yield, reduced by any relevant economic, social, or ecological factors to prevent overfishing. The use of optimum yield sets a science-based threshold against which to measure all stocks—in other words, a threshold value for each species that helps set harvest limits that should not be exceeded. This is similar to the concept of decision triggers or thresholds discussed in this report's text (see section 3.2).

In addition, National Standard 2 states, "Conservation and management measures shall be based upon the best scientific information available." This requires the multi-stakeholder councils that manage each region's fisheries to base their strategies and quotas on scientific population surveys—a crucial safeguard against the possibility of industry or special interests overly influencing annual catch limits to maximize profit at the expense of environmental sustainability. This is analogous to the comprehensive collection of monitoring data discussed in section 3.1.3 of this report.

Finally, National Standard 1 mandates rebuilding timelines of 10 years, with some exceptions.[119] In the early 1990s, many of the United States' fish populations were in decline or depleted because of overfishing. In response, Congress amended the MSA in 1996, requiring managers to develop rebuilding plans for all overfished stocks that ensure that overfished stocks are rebuilt to sustainable levels in as short a time as possible, not to exceed 10 years, with certain exceptions. Because of the MSA's rebuilding mandate and the guideposts it provides, the United States has made remarkable strides toward restoring overfished populations to healthy, sustainable levels.

Critical to the MSA's success is having funding and scientific infrastructure in place to implement its science-based requirements. Each year, Congress appropriates funding toward comprehensive fisheries monitoring and population assessments, which are carried out by the National Marine Fisheries Service's Science Office and Regional Science Centers. Federal scientists, as mandated by the MSA, gather data, evaluate the status of the stocks, and make recommendations for what levels of catch are sustainable for the future. The federal agency's science and recommendations then go out for external peer review, are discussed by a series of committees within the multi-stakeholder regional fishery management councils, and the councils then propose annual catch limits based on the information. NMFS then approves or rejects the councils' proposals. In this way, U.S. fisheries management is based on sound scientific information, takes into account stakeholder input, and is guided by science-based national standards that provide guideposts for the process.

While this process is federally funded in the United States, other countries with similar approaches require industry to provide some funds for scientific monitoring and assessment. In New Zealand, fishers pay into a fund used for scientific monitoring, similar to how the offshore wind industry pays into a fund for scientific monitoring on the East Coast. In addition, the regulatory elements of fisheries management can be conducted in a different order, sometimes to a greater effect. In New Zealand, the scientific monitoring and data collection are done by independent labs, which bid for contracts; this helps to keep costs down while also allowing the use of more nimble and cutting-edge science. Multi-stakeholder groups then discuss the science produced by the independent labs and provide their input to the federal government. The New Zealand government then assesses all information, makes a decision, and implements. This process puts full decision-making power in the hands of the government rather than industry and other stakeholders, whose motives include profit in addition to sustainable harvest.

Species-Specific: California Fishery Management Plan for the Spiny Lobster

Similar to the Magnuson–Stevens Act's programmatic framework, species-specific fishery management plans are often based on adaptive management principles. The California spiny lobster fishery, located largely in state waters (within three nautical miles offshore) and managed by the state through the Fish and Game Commission (FGC) and the California Department of Fish and Wildlife (CDFW), is a highly sought-after target for both recreational and commercial fishers. Management of this fishery is highly adaptive to respond to emerging threats and fluctuations in population size. In addition to a minimum size limit and closure during spawning season, a harvest control rule (HCR) provides CDFW with flexibility to adjust the management approach as threats to the sustainability of the spiny lobster fishery are identified.[120]

Under the HCR, CDFW first gathers data on three reference points related to the spiny lobster fishery annually: catch, catch per unit effort, and spawning potential ratio. Then it compares that year's reference points with previously determined, science-based thresholds (see table A2) that were developed to help managers understand when changes in management are required—analogous to the decision triggers discussed in this report's main text. These thresholds are based on a strong scientific understanding of lobster life history and population dynamics.

TABLE A2: REFERENCE POINTS, THRESHOLDS, AND RATIONALES PROVIDED IN THE "HARVEST CONTROL RULE TOOLBOX" FOR MANAGEMENT OF THE CALIFORNIA SPINY LOBSTER FISHERY[121]

Reference Point	Threshold	Rationale
Catch	$\frac{\text{Average catch for 3 most recent seasons}}{\text{Average catch for 10 most recent reasons}} \leq 0.9$	Identifies possible change in stock stability, particularly growth overfishing
CPUE	$\frac{\text{CPUE for 3 most recent seasons}}{\text{CPUE for 10 most recent seasons}} \leq 0.9$	Identifies potential adverse changes in the fishery, mainly economic overfishing
SPR	$SPR_{CURRENT} \leq SPR(\text{Average 2000-2008})$	Detects biological sustainability, particularly recruitment overfishing

If the reference points taken that year exceed, fall below, or match the related, specified thresholds, CDFW then takes previously determined management measures in response. These measures are presented as a list of eight regulatory options in an "HCR Toolbox" and are accompanied by an "HCR Matrix" that provides an interpretation of different scenarios in which threshold reference points are exceeded, along with recommended management responses.[122] Before taking any action, the HCR also directs CDFW to investigate the underlying causes of any significant change relative to the threshold reference points. Once the underlying cause of a change is identified, CDFW undertakes an analysis (e.g., using models or constituent input) to determine the most appropriate course of action using the HCR toolbox. The use of predetermined management alternatives allows greater regulatory certainty and helps with setting stakeholder expectations, but managers still have the flexibility to choose appropriate management strategies from within the toolbox based on the context at hand, using the matrix to interpret the scenario and understand recommendations. Chosen management measures are then implemented, and CDFW repeats the cycle the next year with new information.

The California spiny lobster fishery provides an example of effective adaptive management. By design, the California spiny lobster HCR is adaptive in nature. It recognizes that the ocean is a dynamic environment, and effective management is highly dependent on the collection of critical data to shed light on the fishery's status every year.[123] However, the California spiny lobster is also an example of a marine species with relatively well-known life history and population dynamics, which has allowed managers to set science-based thresholds that are highly specific, evidence based, and quantitative. Not all marine species or other indicators are as well understood, which makes the development of decision triggers or thresholds more challenging (see section 3.2.1 in the report).

ENDNOTES

1 Luke Hanna et al., *Assessing Environmental Effects (WREN): Adaptive Management White Paper*, International Energy Agency (hereinafter IEA), December 2016, https://tethys.pnnl.gov/publications/assessing-environmental-effects-wren-adaptive-management-white-paper; Byron K. Williams et al., *Adaptive Management: The U.S. Department of the Interior Applications Guide*, U.S. Department of the Interior, 2012, https://www.doi.gov/sites/doi.gov/files/uploads/DOI-Adaptive-Management-Applications-Guide-WebOptimized.pdf.

2 National Oceanic and Atmospheric Administration (hereinafter NOAA), "What Percentage of the American Population Lives Near the Coast?," accessed January 6, 2026, https://oceanservice.noaa.gov/facts/population.html; Walter Musial and Bonnie Ram, *Large-Scale Offshore Wind Power in the United States*, National Renewable Energy Laboratory (renamed National Laboratory of the Rockies), 2010, https://docs.nlr.gov/docs/fy10osti/49229.pdf.

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4 Northeast Ocean Data, "Offshore Wind Projects," accessed January 6, 2026, https://www.northeastoceandata.org/offshore-wind-projects/; Offshore Wind Power Hub, web home page, accessed January 6, 2026, https://offshorewindpowerhub.org/.

5 Corrie E. Clark et al., *Potential Impacts of Offshore Wind on the Marine Ecosystem and Associated Species: Background and Issues for Congress,* U.S. Congressional Research Service, January 19, 2024, 2 https://crsreports.congress.gov/product/pdf/R/R47894.

6 Angel McCoy et al., *Offshore Wind Market Report: 2024 Edition*, National Renewable Energy Laboratory, 2024, https://docs.nlr.gov/docs/fy24osti/90525.pdf; Offshore Wind Power Hub, offshorewindpowerhub.org.

7 Ibid.

8 Ibid.

9 McCoy et al., *Market Report* at 23–25. These states include Maine, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Maryland, Virginia, North Carolina, California, Louisiana, and Oregon.

10 See White House, *Memorandum re: Temporary Withdrawal of All Areas on the Outer Continental Shelf from Offshore Wind Leasing and Review of the Federal Government's Leasing and Permitting Practices for Wind Projects,* January 20, 2025, https://www.whitehouse.gov/presidential-actions/2025/01/temporary-withdrawal-of-all-areas-on-the-outer-continental-shelf-from-offshore-wind-leasing-and-review-of-the-federal-governments-leasing-and-permitting-practices-for-wind-projects/; U.S. Department of Interior, Secretarial Order No. 3415, Amendment No. 1, *Temporary Suspension of Delegated Authority*, January 29, 2025, https://www.doi.gov/document-library/secretary-order/3415-a1-temporary-suspension-delegated-authority-amendment-1.

11 Sara Maxwell et al., "Potential Impacts of Floating Wind Turbine Technology for Marine Species and Habitats," *Journal of Environmental Management* 307 (April 1, 2022), https://doi.org/10.1016/j.jenvman.2022.114577.

12 M. Wing Goodale and Anita Milman, "Cumulative Adverse Effects of Offshore Wind Energy Development on Wildlife," *Journal of Environmental Planning and Management* 59, no. 1 (2016): 1–21, https://www.tandfonline.com/doi/full/10.1080/09640568.2014.973483.

13 Ibid.

14 Maxwell et al., "Potential Impacts" at 12.

15 Malin Pinsky, Rebecca Selden, and Zoë Kitchel, "Climate-Driven Shifts in Marine Species Ranges: Scaling from Organisms to Communities," *Annual Review of Marine Science* 12 (2020): 153–79, https://doi.org/10.1146/annurev-marine-010419-010916; G. Beaugrand et al. "Prediction of Unprecedented Biological Shifts in the Global Ocean," *Nature Climate Change* 9 (February 25, 2019): 237–43, https://doi.org/10.1038/s41558-019-0420-1; Andrew Pershing et al., "Climate Impacts on the Gulf of Maine Ecosystem: A Review of Observed and Expected Changes in 2050 from Rising Temperatures," *Elementa: Science of the Anthropocene* 9 (August 4, 2021): 00076, https://doi.org/10.1525/elementa.2020.00076.

16 DOE, *Advancing Offshore Wind Energy* at 7–8; Maxwell et al., "Potential Impacts" at 2.

17 California Energy Commission, *Assembly Bill 525 Offshore Wind Strategic Plan: Vol. II Main Report*, January 2024, 8; https://www.energy.ca.gov/data-reports/reports/ab-525-reports-offshore-renewable-energy.

18 Maxwell et al., "Potential Impacts" at 5–7.

19 U.S. Offshore Wind Synthesis of Environmental Effects Research (hereinafter SEER), "Risk to Marine Life from Marine Debris & Floating Offshore Wind Cable Systems," 2022, 5, https://tethys.pnnl.gov/sites/default/files/summaries/SEER-Educational-Research-Brief-Entanglement-Considerations.pdf; Irene Gutierrez, Francine Kershaw, and Rebecca Loomis, *Untangling the Way Forward for Responsible Offshore Wind Energy,* Natural Resources Defense Council (hereinafter NRDC), October 2025, https://www.nrdc.org/resources/untangling-way-forward-responsible-offshore-wind-energy.

20 As recommended by the National Wildlife Federation, NRDC, National Audubon Society, Mass Audubon, New Jersey Audubon, Surfrider Foundation, and Maine Audubon in response to BOEM Atlantic Wind Lease Sale 11 in the Gulf of Maine on July 1, 2024, docket ID: BOEM-2024-0026; https://www.regulations.gov/comment/BOEM-2024-0026-0256

21 Hanna et al., *Assessing Environmental Effects* at 12; Williams et al., *Adaptive Management Applications Guide* at v.

22 It is important to note that adaptive management is distinct from, but compatible with, the mitigation hierarchy and the precautionary principle. The mitigation hierarchy provides developers and regulators with a framework by which to address negative impacts on the environment through the sequential application of four actions: avoid, minimize, mitigate, and compensate (or offset). First, impacts must be avoided, then any unavoidable impacts must be minimized, mitigated, and compensated for or offset. See, e.g., Cross Sector Biodiversity Initiative, *A Cross-Sector Guide for Implementing the Mitigation Hierarchy*, 2015, https://www.icmm.com/en-gb/guidance/environmental-stewardship/2015/implementing-mitigation-hierarchy. The precautionary principle is an approach in which developers and regulators seek to avoid negative impacts as much as possible, by proceeding very cautiously or even halting a project when significant uncertainty or high likelihood of negative impacts exists. See Hanna et al., *Assessing Environmental Effects* at 18. While all three management approaches aim to minimize adverse environmental effects, neither the mitigation hierarchy nor the precautionary principle is iterative or designed to reduce scientific uncertainty and improve future decision making. Adaptive management, on the other hand, allows wind energy projects and programs to adapt monitoring and mitigation strategies over time, leading to improved decision making. These three management approaches are complementary and should be used together to collectively reduce negative impacts of offshore wind development to the marine environment over time.

23 For example, a decision trigger may be the number of entanglements or collision fatalities reaching a certain threshold, ambient noise reaching a certain decibel level, or the first detection of an invasive species. Note that there is a diversity of terminology used to describe this concept across sectors and fields, such as *triggers*, *thresholds*, *limits of acceptable change*, and *intervention points*. For the purposes of this report, we use *triggers* throughout. See section 3.2.1 for further discussion of decision triggers. Karin Sinclair et al., "Resolving Environmental Effects of Wind Energy," *WIREs Energy and Environment* 7, no. 4 (July/August 2018), https://doi.org/10.1002/wene.291.

24 Hanna et al., *Assessing Environmental Effects* at 26–27.

25 See Sinclair et al., "Resolving Environmental Effects."

26 Hanna et al., *Assessing Environmental Effects* at 13–14.

27 Ibid.

28 See Melissa Jones et al., *Assembly Bill 525 Offshore Wind Energy Permitting Roadmap*, California Energy Commission, updated May 2023,14–37; https://www.energy.ca.gov/publications/2023/assembly-bill-525-offshore-wind-energy-permitting-roadmap.

29 43 U.S.C. § 1337(p); 30 C.F.R. §§ 585.104, 585.201, 585.600, 585.620.

30 See Bureau of Ocean Energy Management (hereinafter BOEM), *Final Environmental Assessment: Commercial Wind Lease and Grant Issuance and Site Assessment Activities, Morro Bay Wind Energy Area*, October 2022, https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/2022-MorroBay-FinalEA.pdf; BOEM, *Atlantic Shores Offshore Wind South Final Environmental Impact Statement*, May 2024, https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/AtlanticShoresSouth_Vol1_FEIS.pdf; 42 U.S.C. § 4332.

31 See e.g., BOEM and California North Floating LLC, *Commercial Lease of Submerged Lands for Renewable Energy Development on the Outer Continental Shelf*, *Addendum C,* April 21, 2023, https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/2023-05-16_BOEM_CA-North-Float_POC-SR_Lease-0562.pdf; BOEM, *Atlantic Shores Offshore Wind Construction and Operations Plan, Lease Area OCS-A 0499: Atlantic Shores South, Volume II: Affected Environment,* May 2024, https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/AtlanticShoresSouth_Volume%20II_AffectedEnvironment_05-01-2024_rev1.pdf.

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34 Enumerating management objectives and quantifiable thresholds for species (or groups of species) and comparing annual data against those objectives and thresholds would trigger a determination of ineffectiveness. CFR §§ 285.615, 285.633.

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36 See, e.g., 30 C.F.R. §§ 285.100 *et seq.*; 33 U.S.C. §§ 403, 1344.

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40 50 C.F.R. §§ 600.905-15, 600.920; BOEM, *California Offshore Wind Draft Programmatic Environmental Impact Statement*, Appendix D at D-3.

41 16 U.S.C. § 1536; 50 C.F.R. § 402.14(h) (Endangered Species Act); 16 U.S.C. § 1855, 50 C.F.R. § 600.925 (Magnuson–Stevens Act).

42 16 U.S.C. §§ 1538, 1540 (Endangered Species Act); 16 U.S.C. §§ 1371, 1375–77, 50 C.F.R. § 216 (Marine Mammal Protection Act); 16 U.S.C. §§ 703–712, 30 C.F.R. §§ 585.701, 585.703 (Migratory Bird Treaty Act).

43 16 U.S.C. §§ 704,1371, 1539. See also 50 C.F.R. § 216.106; NOAA, *Taking of Marine Mammals Incidental to the Maryland Offshore Wind Project*, 89 Fed. Reg. 95,186 (Dec. 2, 2024).

44 Note that Magnuson–Stevens Act's essential fish habitat provisions do not protect against activities unrelated to fisheries.

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51 In addition to science entities around the world and across sectors, adaptive management is often guided by advisory bodies or other external entities that provide nonscientific public input and guidance to regulatory agencies. This type of entity could exist within a regional science body or could exist separately, depending on exact roles and responsibilities.

52 Regional Wildlife Science Collaborative (hereinafter RWSC), web home page, accessed January 28, 2026, https://rwsc.org/.

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54 Ibid.; Francine Kershaw et al. *Monitoring of Marine Life During Offshore Wind Development—Guidelines and Recommendations*, March 2023, https://tethys.pnnl.gov/sites/default/files/publications/Offshore-Wind-Monitoring-Guidelines_Mar-6-2023.pdf.

55 Lyons et al., "Monitoring in the Context of Structured Decision-Making"; Kershaw, *Monitoring of Marine Life* at 3–9.

56 Hanna et al., *Assessing Environmental Effects* at 31.

57 Sofie Van Parijs et al., "NOAA and BOEM Minimum Recommendations for Use of Passive Acoustic Listening Systems in Offshore Wind Energy Development Monitoring and Mitigation Programs," *Frontiers in Marine Science* 8 (October 2021), https://doi.org/10.3389/fmars.2021.760840. The proposed monitoring program—the Partnership for an Offshore Wind Energy Regional Observation Network (POWERON)—would be funded by a combination of federal funds and developer contributions. See BOEM, "BOEM Announces POWERON Acoustic Monitoring Program for Offshore Wind Projects," October 29, 2024, https://www.boem.gov/newsroom/press-releases/boem-announces-poweron-acoustic-monitoring-program-offshore-wind-projects. RWSC would facilitate coordination and data sharing, along with BOEM, NOAA, and the Navy. RWSC, *Long-Term/Archival Passive Acoustic Monitoring,* accessed January 28, 2026, https://rwsc.org/pam/. Public–private partnerships such as POWERON could maximize cost efficiency and leverage synergies with existing ocean and coastal monitoring efforts and technical capabilities.

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61 RWSC, *Science Plan: Data Governance and Data Management*, accessed January 28, 2026, https://rwsc.org/science-plan/; Amy Trice et al., *Challenges and Opportunities for Ocean Data to Advance Conservation and Management,* Ocean Conservancy, 2021, https://oceanconservancy.org/smart-ocean-planning/take-deep-dive/oceandatareport/.

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63 Williams et al., *Adaptive Management Applications Guide* at 49.

64 42 U.S.C. §§ 4331, 4332(J); California Public Resources Code §§ 21003.1, 30006.

65 See, for example, *Comments of Natural Resources Defense Council et al. on Proposed Sale Notice for Commercial Leasing for Wind on the Outer Continental Shelf in California*, regulations.gov, Docket No. BOEM-2022-0017, August 1, 2022, https://www.regulations.gov/comment/BOEM-2022-0017-0050.

66 Thomas A. Wilding et al., "Turning Off the DRIP ("Data-Rich, Information-Poor"—Rationalising Monitoring with a Focus on Marine Renewal Energy Developments and the Benthos," *Renewable and Sustainable Energy Reviews* 74 (July 2017): 848–59, https://www.sciencedirect.com/science/article/pii/S1364032117303295. DRIP conditions can have disastrous consequences in natural resource management settings, such as monitoring a species of conservation concern without triggering adequate or timely intervention to reverse its decline, until it ultimately becomes extinct—as demonstrated, for example, by the local extinction of the greater glider in an Australian protected area. See David B. Lindenmeyer, Maxine P. Piggott, and Brendan A. Wintle, "Counting the Books While the Library Burns: Why Conservation Monitoring Programs Need a Plan for Action," *Frontiers in Ecology and the Environment* 11, no. 10 (December 2013): 549–55, https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/120220.

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