Offshore Wind Farm Contributions to a Regional Environmental and Ecological Monitoring System to Address Multi-User Needs

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Executive Summary

The responsible development of offshore wind energy in the New Jersey/New York Bight and the broader mid-Atlantic region depends on a robust, long-term environmental and ecological monitoring system. Implemented through two coordinated tasks, this project supports New Jersey's Research and Monitoring Initiative (RMI) by advancing offshore wind farm contributions to a regional environmental and ecological monitoring system designed to address multi-user needs. The conceptual framework developed through this project provides guidance for such a system, leveraging offshore wind energy infrastructure, fixed and mobile platforms, and shore connectivity to generate and transmit valuable data.

Task 1: Language for New Jersey's Third Offshore Wind Solicitation

Task 1 provided recommended language for inclusion in New Jersey's third Offshore Wind Solicitation, ahead of the final decision issued by the New Jersey Board of Public Utilities (NJBPU) on January 24, 2024. The language was intended to guide applicants seeking Offshore Wind Renewable Energy Certificates (ORECs) in preparing Offshore Wind Infrastructure Monitoring Plans that leverage infrastructure in and around wind energy areas (e.g., wind turbines, foundations, substations, and associated non-mobile and mobile platforms) and contribute to regional environmental and ecological observing efforts.

The recommended language directs applicants to:

- Identify an incremental investment and implementation plan for incorporating multiple sensors, platforms, and data systems into offshore wind energy infrastructure.
- Demonstrate how proposed monitoring will address RMI and regional research priorities, including baseline development, detection of changes in marine resources, and application of existing and novel technologies.
- Address the full project footprint, including lease areas, cable routes, and landfall locations, and describe how implementation will inform outstanding questions and reduce potential impacts from offshore wind development.
- Include a data management section describing data standardization, transparency, sharing, and accessibility consistent with community best practices and quality assurance/quality control (QA/QC) requirements.
- Collaborate with federal, state, academic, and regional partners such as the Regional Wildlife Science Collaborative (RWSC), the Responsible Offshore Science Alliance (ROSA), and the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS), among others.

To support applicant planning, the Task 1 deliverable also provided cost estimates for two monitoring approaches: a network of fixed offshore stations and seasonal autonomous underwater vehicle (AUV) deployments. These estimates, provided for guidance only, indicated the order of magnitude of costs associated with acquisition, installation, and operations.

Task 2: Conceptual Framework for an Environmental and Ecological Regional Monitoring System in Offshore Wind Energy Areas (WEAs).

Motivation

The marine user community relies on oceanographic, meteorological, and ecological data for multiuse decision-making. While surface ocean conditions are routinely observed via satellites and shore-based systems, data on marine life and subsurface conditions remain scarce. Challenges such as limited power for instruments, communication constraints, and lack of monitoring platforms hinder data collection in the offshore environment. Offshore wind energy infrastructure, with its connectivity to shore, presents a unique opportunity to host long-term, in situ environmental and ecological monitoring systems that provide real-time and recovered data.

Overview

Funded by New Jersey's Research and Monitoring Initiative (RMI), this is a guidance document intended for use by state and federal regulators and policymakers, wind energy developers, original equipment manufacturers (OEMs), and data managers. This framework focuses on monitoring metocean and ecological data, with an emphasis on the subsurface and near-surface (just above the water) ocean environment. It also prioritizes subsurface monitoring of oceanographic conditions, fisheries, and, where complementary, marine mammals.

Organized into five chapters, the framework outlines identification of monitoring objectives, sensors and data variables, deployment strategies, data quality and management standards, and final recommendations. Its development was guided by extensive stakeholder engagement, including surveys, webinars, and expert discussions held throughout 2024–2025.

Key Monitoring Objectives

Targeted stakeholdering identified three primary objectives for coordinated monitoring:

1. Contribute local atmospheric, oceanographic, and biological data to coordinated regional monitoring efforts, helping to differentiate short-term variability and/or long-term changes in environmental conditions from potential impacts of offshore wind energy development.

2. Provide the necessary data to address regulatory compliance, mitigation needs, and inform the management of living marine resources.

3. Contribute monitoring data to regional ocean planning and management initiatives.

Sensors, Data Variables, and Research Platforms

Commercially available sensors capable of measuring key atmospheric, oceanographic, and biological variables were identified, including physical, biological/optical, and chemical parameters. Sensors were assessed for size, power needs, maintenance requirements, and temporal/spatial/vertical resolution of data. The highlighted deployment platforms include fixed offshore wind energy infrastructure, buoys, moorings, autonomous underwater vehicles (AUVs), ships of opportunity, and bottom mounts.

Deployment Strategies and Cost Estimates

Monitoring of offshore wind energy projects falls under the regulatory authority of the Bureau of Ocean Energy Management (BOEM) and, in some states such as New Jersey, is also shaped by requirements in power purchase agreements and state permitting processes. A key objective is to generate data that help distinguish short-term variability and/or long-term changes in environmental conditions from potential project-induced impacts, which must be tailored to site-specific conditions. Effective monitoring further depends on capturing regional variability at appropriate spatial and temporal scales. This document is therefore intended to guide the development of a monitoring system for a generic offshore wind energy area with four lease areas, illustrating the target spatial scale for fixed monitoring stations in the Mid-Atlantic Bight and demonstrating how coordination among adjacent leaseholders can reduce costs and maintenance.

Uncertainty in offshore wind energy planning and the complexities of permitting remain significant hurdles for standardizing wind turbine-based monitoring, highlighting the need for complementary, scalable, and flexible approaches. This framework considers both fixed stations and AUVs, specifically ocean gliders. Both platforms are vital tools for oceanographic research, but they answer different scientific questions based on their strengths.

Fixed stations, such as moored buoys, are anchored in one location and are designed for continuous, long-term monitoring. They are uniquely suited for studying temporal changes and events at a specific site. Fixed stations track variability and/or long-term changes in environmental conditions, including ocean acidification, ocean warming, and circulation. Additionally, continuous fixed station time series capture episodic events like coastal storms and phytoplankton blooms.

Mobile and autonomous platforms, such as buoyancy-driven gliders, enhance fixed-station monitoring by providing high-resolution spatial coverage, targeted sampling of biological hotspots, and improved marine mammal detection through low-noise passive acoustics. Coordinated seasonal deployments of two gliders can effectively survey up to four adjacent wind energy areas, delivering comprehensive coverage at significantly reduced cost compared to independent, uncoordinated operations.

Estimated costs:

- **Single fixed station**: $660,000–$860,000 purchase and installation; $165,000–$215,000 annual maintenance.

- **Single glider**: $250,000–$350,000 purchase; $75,000 per 30-day deployment

These figures provide planning guidance but exclude project-specific costs like safety compliance or data processing.

Data Quality and Management Standards

As offshore wind energy development expands, so will the volume of environmental and ecological data collected. A strong data governance framework, built on the principles of quality, security, transparency, and stewardship, is essential to ensure these data remain accurate, accessible, and useful over the long term.

Key stakeholder recommendations include:

- Leveraging existing infrastructure and repositories such as the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS), National Centers for Environmental Information (NCEI), and the US Integrated Ocean Observing System (IOOS).
- Standardizing data formats, metadata, quality assurance, and quality control procedures to ensure interoperability.
- Establishing clear data ownership, licensing, and sharing agreements.
- Integrating data systems and transfer pathways early in project planning.
- Designating funded data stewards within lease-holding entities.
- Supporting a jointly funded third-party regional data manager to oversee acquisition, security, and management work across multiple lease areas.

Conclusions and Next Steps

This document represents a critical step toward building a science-driven, standardized, and regionally consistent monitoring system capable of supporting both offshore wind energy development and broader marine users in the mid-Atlantic.

Developing an implementable monitoring plan at both the individual lease and regional scales will require a strategic approach. A phased implementation process will be needed to establish clear timelines, further define roles, and outline funding strategies, with these elements integrated early in the planning stage. Pilot deployments in priority areas can be used to test combinations of sensors, platforms, and retrofits to existing wind energy infrastructure, with results informing feasibility, data quality, and operational workflows. Active participation from industry, including wind energy developers, OEMs, sensor and technology providers, and other maritime sectors, will be essential for advancing standardization efforts, while regional coordination will help expand coverage and minimize redundancy.

Data management and governance should be strengthened by investing in scalable, secure data infrastructure and by establishing governance structures that align monitoring activities across wind energy developers and jurisdictions. Implementation should align with regulatory and scientific priorities by defining actionable indicators and thresholds and integrating with existing ocean observing systems.

Emerging technologies in sensors, power systems, and artificial intelligence should be tracked and incorporated to ensure long-term adaptability. Health, safety, and environmental (HSE) planning protocols should be embedded into every phase of deployment and maintenance to protect both personnel and ecosystems. A centralized cost database should be maintained, and pilot deployment results should be used to inform cost-benefit analyses and strategic planning. Throughout implementation, stakeholders should be engaged continuously to refine system design, improve deployment practices, and establish feedback loops that support ongoing improvement.

Introduction

Motivation

The marine user community depends on oceanographic, meteorological, and ecological data to support multiuse decision-making, regulation, and policy. The surface ocean over the continental shelf is observed regularly via satellite and shore-based remote sensing. However, information on marine life and subsurface conditions (e.g., temperature, salinity, turbidity) is sparse. Environmental and ecological data serve the many shared users of the marine space, including state and federal regulators, offshore wind energy developers[1], commercial and recreational fishermen, shipping and maritime operators, marine safety authorities, scientists and academic researchers, environmental conservation groups, and Tribal communities. Associated marine safety, ecological monitoring, assessment, and management decisions rely on such data (National Oceanic and Atmospheric Administration [NOAA], 2022).

Collecting data in the marine environment is challenging because of limited power supplies for marine instruments, insufficient communication capabilities for data telemetry, and a lack of platforms to host ocean and marine life monitoring systems. The physical infrastructure of offshore wind farms, such as wind turbines, foundations, and substations, as well as a wind farm's connectivity to shore, offer potential solutions to these issues and presents a unique opportunity to support long-term, in situ monitoring stations that collect both real-time[2] and recovered[3] data. Leveraging offshore wind energy infrastructure and connectivity throughout a wind farm's lifespan can enhance long-term data collection to meet the monitoring requirements of the wind energy sector and the broader needs of the marine user community (NOAA, 2022).

To support the responsible implementation of offshore wind energy off New Jersey's coastline and to ensure the collection of the best available data in line with the state's mandate to protect and manage marine and coastal resources, a long-term, well-defined, feasible, and purpose-built environmental and ecological monitoring system is needed within the New Jersey/New York Bight. This document offers guidance for the development of such a system and could serve as a model for other regions. It outlines key components of offshore wind energy infrastructure and fixed or mobile offshore platforms, such as moorings, vessels, and autonomous vehicles, on which sensors could be deployed to address environmental and ecological priorities at both local and regional scales. Developed in collaboration with wind energy developers and a broad community of marine users, the framework identifies prioritized objectives for individual wind farm contributions and promotes standardization and data consistency across wind energy areas (WEAs), enabling the effective assessment of cumulative and regional environmental and ecological impacts.

[1] Terms wind energy developer(s) and wind energy company(ies) are used interchangeably.

[2] Data relayed via satellite typically involves some data processing time, and should therefore be considered "near real-time" and not immediate.

[3] High resolution data not available in real-time due to the high costs of satellite data transmission.

Intended Audience and Scope

This document is designed to guide how observation technologies deployed within WEAs can contribute to a coordinated, long-term, regional environmental and ecological monitoring system, one that ideally addresses the individual goals of government decision makers and offshore wind energy developers.

The primary audience includes state and federal regulators and policymakers, wind energy developers, original equipment manufacturers (OEMs), and data managers. Each of these groups brings distinct motivations for participating in an environmental and ecological monitoring system and has varying needs and uses for the resulting data.

Establishing an offshore environmental and ecological monitoring system will require close partnership among the intended audience, as well as with key collaborators such as sensor and technology providers, commercial fishermen, and other maritime operators. These partnerships must be grounded in regulatory guidance to ensure the monitoring system is technically feasible, scientifically robust, and aligned with federal and state mandates.

While the system is centered on offshore wind energy development, it would generate both real-time data and recovered data to support the broad community of marine users. Scientific and academic researchers, environmental and marine resource managers, fishing and Tribal communities, and many others involved in ocean-based operations will benefit from access to reliable, high-quality data that can support studies of ecosystem dynamics, environmental assessments, and cumulative impact analyses within the New Jersey/New York Bight region.

The information provided here can be used as a guidance framework to support cross-sector decision-making, promote data interoperability, and enable adaptive management as offshore wind energy projects evolve. It may also provide added value to wind energy developers by helping them meet monitoring and data collection requirements more efficiently and transparently.

Regulatory Context

The framework was developed to align with guidance provided by federal and state agencies including the Bureau of Ocean Energy Management (BOEM) and the New Jersey Board of Public Utilities (NJBPU).

BOEM requirements for monitoring and data collection within wind farms are outlined in the Conditions of Construction and Operations Plan (COP) for each approved project. These requirements generally focus on assessing acute impacts to protected species during construction activities and the first few years of operation. In most cases, BOEM requirements do not mandate long-term monitoring at offshore wind farms. Many post-construction monitoring plans include an “adaptive monitoring” component, in which the wind energy developer works with BOEM and other federal agencies to determine the need for adjustments to monitoring approaches, consider new monitoring technologies, and/or extend monitoring periods based on ongoing assessments of monitoring results. The conditions of COP approval and post-construction monitoring plans may be amended at any time. For example, the COP conditions for Vineyard Wind 1 were amended in January 2025, after construction was well underway.

Beyond requirements related to passive acoustic monitoring (PAM) (which range from 3-10 years depending on the project), there is currently no regulatory requirement to establish or contribute to a long-term environmental and ecological monitoring system within an offshore wind farm. The requirement most closely aligned with this concept is the high-frequency radar mitigation requirement that applies to all approved projects. As part of this requirement, each project must coordinate with the U.S. Integrated Ocean Observing System (IOOS) Surface Currents Program to determine whether wind turbines interfere with the high-frequency radar system maintained by IOOS to track surface current speeds and direction. If interference is found, the project must provide real-time surface current data (replacing the "lost" data) to the IOOS Surface Currents Program, presumably for the life of the project or for as long as interference persists (BOEM, 2023).

New Jersey and other states require longer-term monitoring of offshore wind farms as conditions of purchasing power agreements. New Jersey's 2nd, 3rd, and 4th offshore wind energy solicitations included requirements for plans to detect environmental and fisheries impacts. Unique to the state, New Jersey also required an Offshore Wind Infrastructure Monitoring Plan – "a description of whether and how the wind turbine arrays, including foundations, and offshore platforms could be utilized as an infrastructure to provide direct ocean and ecological observations throughout the water column" (see Appendix A).

Along the Atlantic coast, states share information and coordinate on offshore wind energy monitoring requirements through the Regional Wildlife Science Collaborative (RWSC). Because each state approaches offshore wind energy procurement and contracting differently, their monitoring requirements are expected to vary. Through RWSC, states are working to ensure that any requirements applied during state procurement and contracting produce consistent, interoperable data (RWSC, 2024).

While the regulatory guidance for monitoring within offshore wind farms from federal and state agencies will continue to evolve, the current landscape as described above may impact the planning and development of an environmental and ecological regional monitoring system in several key ways:

Financial and Technical Support for Monitoring

- Lease applicants must allocate financial and technical resources to monitor environmental impacts, wildlife, and fisheries during construction and for a period of time after the wind farm becomes operational. The receptors for monitoring and duration of monitoring are project-specific. However, long-term monitoring within a wind farm may not be a part of a wind energy company's business plan, especially if not required by regulation.
- Some states require wind energy companies to provide funding to support regional, Tribal, and/or research initiatives.
- Absent federal or state requirements, financial incentives will be necessary to ensure wind energy companies contribute to long-term monitoring. Incentives could include the

value of the coordinated system data in demonstrating little to no impact from wind farm operations or in contributing to the company's regular assessment of wind farm performance and infrastructure integrity.

- Certain environmental variables may go unmeasured if they are not linked directly to a project's required monitoring plans or internal performance/integrity assessments.

Coordinated Environmental Monitoring

- States and federal agencies generally require projects to coordinate regionally through entities such as RWSC, the Responsible Offshore Science Alliance (ROSA), fishery management councils, and others. However, these requirements stop short of mandating participation in a coordinated environmental monitoring network.

- At present, "coordinated environmental monitoring" occurs more informally, with agencies and organizations providing voluntary guidance on data collection, metadata standards, and other data management protocols that ensure findable, accessible, interoperable, and reusable data.

- Even without coordinated planning, these standards can enable data from multiple entities/projects to be integrated for regional analyses and broader scale assessments.

Long-Term Data Collection and Reporting

- Monitoring must continue post-construction at appropriate spatial and temporal scales to assess long-term impacts.

- At many wind farms there could be a near-cessation of monitoring 5–10 years after construction is completed, especially if post-construction monitoring shows little to no impact.

- Sustaining data streams beyond 10 years will require collaboration among multiple entities to share technical, logistical, and financial responsibilities.

Focus and Format

Funded by New Jersey's Research and Monitoring Initiative (RMI), this document addresses several critical aspects related to the creation of a regional monitoring system, including:

- Outlining instrumentation that could leverage the infrastructure of offshore wind farms including recommendations on sensor variables and maintenance, standardization, and data sharing.

- Identifying fixed and mobile autonomous technology solutions based on their ability to accurately measure high-priority variables in a cost-effective manner while also ensuring access to the data through an integrated network.

- When possible, providing current estimated costs for implementing various components of the framework.

- Developing strategies that allow the proposed monitoring system to accommodate evolving sensor technologies.
- Ensuring the final framework adheres to the guidance provided by federal and state agencies, including BOEM and NJBPU.
- Emphasizing the importance of communication and timing protocols. This framework highlights the need for ongoing collaboration, early implementation of monitoring system plans during the budgeting and design phases, consideration of retrofitting where early integration is not possible, and attention to varying project timelines throughout the regional offshore wind energy buildout.

This framework focuses on monitoring metocean and ecological data, with an emphasis on the subsurface and near-surface (just above the water) ocean environment. It includes above-surface atmospheric measurements (e.g., air temperature, pressure, wind speed, solar radiation) as well as below-surface physical oceanographic data (e.g., temperature, salinity, current speeds), chemical oceanographic data (e.g., dissolved oxygen, nitrate, pH), and biological and optical data (e.g., PAM, chlorophyll, turbidity, animal tag detections).

Intended to complement other community-led efforts, particularly those focused on upper-trophic-level species such as the National Offshore Wind Research and Development Consortium's (NOWRDC) project on technology development priorities (NOWRDC, n.d.), this framework focuses on subsurface monitoring of oceanography, fisheries, and where complementary, marine mammals. Its aim is not to duplicate existing initiatives but rather to contribute to a broader, coordinated monitoring framework that integrates diverse environmental and ecological observations. This focus also sidesteps potential complications related to accessing proprietary hub-height data (i.e., wind speed and direction profiles, turbulence intensity, shear profiles, etc.) which are often commercially sensitive.

This conceptual framework is organized into five chapters:

Chapter 1: Identification of Monitoring System Objectives

Chapter 1 defines the key objectives guiding the monitoring system's design. These objectives, established through targeted stakeholdering, provide the foundation for additional engagement, refinement, and framework development presented in the subsequent chapters.

Chapter 2: System Components – Recommended Sensors and Data Variables

Building on the defined objectives, Chapter 2 identifies recommended sensors, variables, and potential platforms for the monitoring system. These recommendations are informed by engagement with a diverse range of stakeholders and observing experts.

Chapter 3: Considerations for Deployment Strategies

Given the system objectives and components identified in Chapters 1 and 2, Chapter 3 focuses on recommended deployment configuration, installation feasibility, standardization, spatial and temporal sampling strategies, and maintenance procedures. These strategies are informed by input from the sensor and technology provider community, wind turbine manufacturers, and wind energy developers.

Chapter 4: Data Quality and Management Standards

Chapter 4 provides guidance on data governance and the sharing of oceanographic and environmental data through existing regional ocean observing infrastructure. Engagement with data managers and end users informs the identification of key issues and priorities related to governance and the development of guidelines that ensure collected data meet high standards for accuracy, quality control, accessibility, and reliability in decision-making.

Chapter 5: Final Conclusions and Recommendations for Application

Chapter 5 presents recommendations and next steps for transitioning from concept to implementation. It acknowledges current limitations in stakeholder input, emphasizes the importance of continued engagement, and outlines key actions to address identified needs and advance implementation.

Methodology: Stakeholder Engagement

The development of this framework was guided by a multi-method approach to stakeholder engagement, including a stakeholder survey and focused discussions with subject matter experts. This approach was designed to ensure inclusivity and address the unique environmental, technological, and regulatory considerations of offshore wind energy projects in the Mid-Atlantic Bight.

A Core Facilitation Team (CFT) led the outreach efforts, conducting both virtual and in-person discussions with a wide range of stakeholders and experts to gather input, identify monitoring needs, and incorporate best practices. The team also built on existing scientific partnerships and ongoing research to ensure the integration of relevant expertise in science and technology. Details of stakeholder engagement activities and outcomes by chapter are provided in Appendix B.

While stakeholder input laid a strong foundation, the evolving scope of the effort and varying levels of stakeholder capacity and availability influenced both the breadth and depth of feedback received. Continued collaboration, expanded participation, and coordinated action will be essential to build a responsive, inclusive, and science-driven offshore monitoring system that can adapt to emerging needs and challenges of the offshore wind energy sector.

CHAPTER 1: IDENTIFICATION OF MONITORING SYSTEM OBJECTIVES

Stakeholder Engagement

For detailed stakeholder engagement activities and outcomes, see Appendix B.

To ensure the success and regional consistency of an environmental and ecological monitoring system, it was crucial to first clearly identify the goals and objectives of such a system. The CFT engaged key community and expert stakeholder groups, including representatives from state and federal agencies, offshore wind energy developers, academic researchers, nonprofit environmental and marine wildlife organizations, the fishing industry, and other marine users. Stakeholder input was gathered through a spring 2024 survey, two webinars, and a dedicated session at the May 2024 New Jersey RMI Symposium (see Appendices B–D for details).

Across these efforts, several consistent themes emerged. Stakeholders emphasized:

- The importance of distinguishing potential offshore wind energy impacts from broader environmental drivers, including short-term variability and/or long-term changes in environmental conditions, seasonal shifts, and interannual variability.
- The need for monitoring that directly informs regulation, decision-making, and adaptive management of marine resources.
- The priority of mitigating potential impacts on protected species, marine mammals, and marine habitats and ecosystems.
- The recognition that monitoring objectives vary among stakeholders, underscoring the importance of a comprehensive, multi-faceted system that supports both research and management.
- The distinction between monitoring and mitigation, with monitoring providing knowledge to inform future mitigation strategies, and mitigation requiring specific actions to reduce impacts.
- The expansion of living marine resource management considerations to include socio-ecological dimensions and human community connections.
- The need to address critical knowledge gaps and data needs, including long-term, integrated monitoring across trophic levels; improved understanding of the mid-Atlantic “cold pool” and wind turbine-driven mixing effects; assessment of individual versus cumulative wind turbine impacts; expanded visual and acoustic monitoring for marine megafauna; and enhanced data integration across sectors and scales.

Monitoring System Objectives

The extensive stakeholder engagement efforts conducted throughout this process provided the CFT with valuable input and informed the identification of three key objectives for a regional environmental and ecological monitoring system in offshore WEAs:

1. **Contribute local atmospheric, oceanographic, and biological data to coordinated regional monitoring efforts, helping to differentiate short-term variability and/or**

long-term changes in environmental conditions from potential impacts of offshore wind energy development.

Distinguishing between environmental impacts driven by short-term variability and/or long-term changes and those resulting directly from offshore wind energy development is a complex task. Given the need for data over 30–50 years to evaluate environmental impacts, this objective prioritizes long-term, high-resolution monitoring designed to be consistent with existing and historical data collection methods. By tracking shifts in temperature, ocean currents, species distributions, and ecosystem productivity over time, researchers can begin to disentangle these intertwined influences and better understand how offshore wind energy installations interact with existing environmental driven trends. This differentiation is essential for regulatory decision-making, impact assessments, and adaptive management strategies.

2. **Provide the necessary data to address regulatory compliance, mitigation needs, and inform the management of living marine resources.**

   The expansion of offshore wind energy in marine environments presents both opportunities and challenges for the management of living marine resources, including commercially and ecologically important species. The ability to leverage offshore wind energy infrastructure to monitor species behavior, movement patterns, foraging success, and population dynamics is needed to inform fisheries and other marine resource decision-making and conservation efforts. Understanding how offshore wind energy may influence these factors is also important in informing regulatory compliance and mitigation needs.

3. **Contribute monitoring data to regional ocean planning and management initiatives.**

   As offshore wind energy projects expand, it is important to ensure that data collected through monitoring efforts are integrated into broader ocean management frameworks. Collaboration with existing regional planning initiatives is essential to align offshore wind energy research with ongoing marine spatial planning, fisheries management, and conservation efforts. By contributing high-quality, standardized datasets, the observing system can support ecosystem-based management approaches and improve the accuracy of cumulative impact assessments.

Conclusions and Recommendations

The above monitoring system objectives are intended to address important environmental and ecological monitoring needs at offshore wind farms throughout their operational lifespan, while also informing broader regional observational priorities across the marine community. These objectives guide the selection of parameters and requirements for this conceptual framework and shape the selection of variables, sensor types, deployment strategies, and data governance considerations presented in the following chapters.

While stakeholder input laid a strong foundation, continued collaboration and expanded participation will be necessary to build a responsive, inclusive, and science-driven offshore monitoring system that can adapt to emerging needs, technologies, and challenges.

Additional Considerations and Next Steps

Despite concerted efforts to engage a broad range of stakeholders, potential limitations and biases in stakeholder participation were observed. The framing of the survey around offshore wind energy may have narrowed the scope of responses. Moreover, some groups may have faced logistical or financial barriers to full participation in surveys and webinars. As a result, input may have been disproportionately shaped by more well-resourced or actively engaged entities.

Expanded and ongoing engagement will be essential to refine and operationalize a regional monitoring system as offshore wind energy development evolves.

Stakeholder groups requiring further engagement include:

- Small-scale fishermen and under-resourced nongovernmental organizations (NGOs) or Tribes.
- The U.S. Coast Guard (USCG), U.S. Army Corps of Engineers (USACE), maritime shipping industry and National Weather Service (NWS) for maritime safety considerations.

More input is needed to:

- Define additional metrics and thresholds for evaluating potential offshore-wind energy impacts and variable and/or long-term environmental changes.
- Identify priority data gaps that may require targeted research or new monitoring strategies.
- Accurately forecast weather, which is essential for offshore operations, maritime safety, and ecosystem monitoring.
- Monitor technology innovation, which is critical for enabling real-time and robust data collection, enhancing predictive modeling, and supporting adaptive response strategies.

Incorporating these perspectives and elements into the design and evolution of a regional monitoring system will enhance its relevance and ensure it addresses the needs of a broad range of stakeholders.

CHAPTER 2: SYSTEM COMPONENTS – RECOMMENDED SENSORS AND DATA VARIABLES

The monitoring system objectives identified in Chapter 1 emphasize the need for atmospheric, oceanographic, and biological monitoring, along with sufficient data collection to distinguish the effects of offshore wind energy development from the effects of short-term variability and/or long-term changes in environmental conditions. Equally important is the sharing of these data to support a variety of priorities, including ocean planning and management, weather prediction models, and evolving technologies. Meeting these objectives requires the collection and analysis of a wide range of environmental and biological data at temporal and spatial scales relevant to ocean users. Careful selection of sensors and the platforms on which they are deployed is therefore fundamental to effective monitoring and meeting these objectives.

Stakeholder Engagement

For detailed stakeholder engagement activities and outcomes, see Appendix B.

RMI Ocean Instrument Specifications

Drawing on the expertise of CFT members, potential ocean sensors and instrument specifications were developed and shared with stakeholders, who were invited to expand the sensor inventory and refine the associated data parameters.

State of the Science on Offshore Wind, MTS Mini TechSurge Session

As part of the July 2024 State of the Science conference hosted by the New York State Energy Research and Development Authority (NYSERDA) and in partnership with the RWSC, the Marine Technology Society (MTS) hosted a Mini TechSurge (MTS, 2004). CFT members attended and helped facilitate a breakout session. Appendix E highlights the breakout session worksheet and questions.

Breakout session discussions provided the CFT with valuable insights into key variables focused on research and monitoring to align with monitoring system objectives. Session participants also highlighted sensors for inclusion in the monitoring system and helped guide discussions with wind energy developers and OEMs, which are detailed in Chapter 3.

Sensors, Parameters and Data Variables

Offshore wind farms have lifespans of several decades, spanning site characterization, planning, construction, operations, and decommissioning phases. Impacts to living marine resources and environmental parameters may occur in any of these phases; result in short-, medium-, and/or long-term effects; and range in spatial scale from highly localized to regional. An effective monitoring system must therefore be able to collect information to detect change on the order of several hours to several decades, at distances from several meters to hundreds of kilometers. Further, one of the monitoring system objectives identified via stakeholder engagement is the ability to differentiate the effects of short-term variability and/or long-term changes in environmental conditions and weather patterns from the impacts of offshore wind energy development. This requires long-term monitoring that takes preconstruction baseline environmental and ecological conditions into account.

To meet the regional monitoring system objectives, three broad categories of parameters were identified: physical, biological/optical, and chemical. These parameters can observe temporal and spatial variability within offshore wind farms and the surrounding region. Below is a summary of the currently available sensor/data types that can deliver the oceanographic and ecological data needed to meet the monitoring objectives described in the previous chapter.

Physical

- **Meteorological data:** Used to understand impacts to wind turbines, support full meteorological forecasts, and provide sea state estimates.

- **Oceanographic and conductivity, temperature, and depth (CTD) data:** Includes capturing uncertainties and changes in oceanography, such as salinity and sea surface temperature.

- **Acoustic doppler current profilers (ADCP) and wave measurements:** Used to understand the underlying physics of the ocean.

- **Thermal and visible cameras:** Includes thermal and visible cameras for detecting sea state, temperature, and whale breaches. May also deter vandalism to protect data and equipment from tampering.

Biological/Optical

- **PAM:** Suitable for long-term deployment, PAM is widely used for monitoring marine mammals and sound-producing fish, supporting both scientific research and mitigation. It can also provide valuable information on the ambient acoustic landscape and noise generated by wind turbines. Coastal Acoustic Buoy for Offshore Wind (CABOW)/CAB Guardian real-time bioacoustics are PAM systems that could serve a variety of applications from research to real-time marine mammal alerts.

- **Acoustic telemetry receivers:** Useful for understanding species distribution and movement of tagged individuals.

- **Phyto- and zooplankton sensors:** Useful as an indicator of ecosystem health and driver of predator behavior and distribution.

- **Underwater echosounders:** Used to monitor the location of acoustically detected organisms. These data are used to detect or predict the presence of fish, marine mammals, and other prey species that can be associated with other environmental covariates.

- **Optical detection sensors:** Optical sensors include instruments measuring optical (light) properties underwater like sediment load, chlorophyll-a (phytoplankton), attenuation at multiple wavelengths, color dissolved organic matter (CDOM), and underwater visibility.

- **Absence data:** The absence of biological events and wildlife presence can still provide important information for stakeholders.

Chemical

- **pH sensor:** pH sensors detect the acidity of the water. Increasing ocean acidification is a significant environmental issue impacting marine ecosystems and potentially affecting human activities.

- **Nitrate sensor:** Ocean nitrate measurement is important for understanding phytoplankton growth, ocean productivity, and short-term variability and/or long-term changes in environmental conditions.

- **pCO_2 sensor:** partial pressure of carbon dioxide (pCO_2) in the ocean is important for understanding ocean acidification, the carbon cycle, and short-term variability and/or long-term changes in environmental conditions.

Important variables to characterize the present state and long-term variation of each parameter were identified by stakeholders and are described in Table 1, along with the types of sensors that are presently available to measure each variable, sensor size, and platform type. Platform types include: 1) buoy, 2) mooring, 3) autonomous underwater vehicle (AUV), 4) mounted to the wind turbine subsurface, 5) ships of opportunity, 6) and bottom mounts.

Stakeholders also identified the current spatial, temporal, and vertical resolution of each sensor type based on commercially available instruments. Table 1 lists the sensor resolutions provided during the Mini TechSurge session and on the instrumentation spreadsheet. There is a broad range of temporal (seconds to weeks), spatial (millimeter to kilometer) and vertical (centimeter to kilometer) ranges that are dependent on the sensor type and instrument platform utilized.

Stakeholders also listed the power requirements, dimensions, weight, and maintenance requirements for each sensor identified. Similar to instrument resolution, there is a broad range of power (AA batteries to continuous), dimensions (centimeter to meter), weight (0.1kg–150kg), and maintenance frequency (weekly to annually) requirements, primarily driven by instrument type, vehicle payloads, and observing platforms. Specific instrument specifications must be referenced to determine power, dimension, weight, and maintenance requirements; however, examples of general instrumentation sizes and weights required for acquisition of the above parameters are as follows:

- Small in situ sensors, 10–35 cm, less than 5 kg.

- Medium in situ sensors, 35 cm–1m, 5–30 kg.

- Large in situ sensors, 1–3 m, 30–150 kg.

Table 1. Summary of variables, temporal/spatial/vertical resolution of data, sensor types, sensor size, and platforms that can be leveraged to host the instrument. Platform types include: 1) buoy, 2) mooring, 3) autonomous underwater vehicle (AUV), 4) mounted to the wind turbine subsurface, 5) ships of opportunity, and 6) bottom sensors.

Variable	Above Below Surface	Temporal Resolution	Spatial Resolution	Vertical Resolution	Example Sensor Type	Sensor Size	Platform Type
Physical							
Air temperature	Above	Seconds to minutes	Point	N/A	Thermometer	Medium	1
Air pressure	Above	Seconds to minutes	Point	N/A	Barometer	Medium	1
Wind speed and direction	Above	Seconds to minutes	Point	N/A	Anemometer	Medium	1
Humidity	Above	Seconds to minutes	Point	N/A	Hygrometer	Medium	1
Precipitation	Above	Seconds to minutes	Point	N/A	Hydrometeorological instrument	Medium	1
Solar radiation	Above	Seconds to minutes	Point	N/A	Pyranometer (PAR)	Medium	1
Visible/thermal video	Above	Seconds to minutes	Variable	N/A	Visible or thermal camera or multispectral imager	Small	1,4,5
Surface currents	Above	Hourly	Meters to 6 kilometers	N/A	Acoustic doppler current profiler, HF-radar	Med/large	1,2,5
Sea state	Above	Minutes	Point	N/A	Wave buoy	Med/large	1
Conductivity	Below	Seconds to minutes	Point to transect	Surface to bottom, cm	Conductivity, temp, depth sensor	Small	1-6
Temperature	Below	Seconds to minutes	Point to transect	Surface to bottom, cm	Conductivity, temp, depth sensor	Small	1-6
Depth (pressure)	Below	Seconds to minutes	Point to transect	Surface to bottom, cm	Conductivity, temp, depth sensor	Small	1-6
Salinity	Below	Seconds to minutes	Point to transect	Surface to bottom, cm	Conductivity, temp, depth sensor	Small	1-6
Water velocity profiles	Below	Seconds to minutes	User defined resolution	Meter to several meters	Acoustic doppler current profiler	Medium	2,3,5,6
Sea state	Below	Seconds to minutes	Point	N/A	Wave logger, pressure sensor, HF-radar	Small	1,2,4,5
Biological/Optics							
Optics (fluorescence, optical backscatter, CDOM, turbidity, beam attenuation)	Below	Seconds to minutes	Point to transect	Centimeters	Optics sensors (fluorometer, transmissometer, radiometer, visible camera)	Small	1-6

Chlorophyll (phytoplankton abundance)	Below	Seconds to minutes	Point to transect	Centimeters	Optics sensors (fluorometer)	Small	1-6
Phytoplankton type	Below	Hours to days	Point	Millimeters	Imaging flow cytobot	Medium	1-6
Tagged wildlife location	Below	Seconds to minutes	Point to transect	Bottom to surface	Passive acoustic receiver	Small	1-6
Fish/zooplankton identification & abundance	Below	Seconds to minutes	Profile to transect	Centimeters	Acoustic zooplankton fish profiler	Small/med	1-6
Underwater sound (PAM)	Below	Continuous	10-20km for marine mammals	Full water column	Passive acoustic sensor	Small/med	1-6
Chemical							
Dissolved oxygen	Below	Seconds to minutes	Point to transect	Centimeters	Dissolved oxygen sensor	Small	1-6
pH	Below	Seconds to minutes	Point to transect	Centimeters	Carbonate chemistry sensor	Small	1-6
pCO2	Below	Seconds to minutes	Point to transect	Centimeters	Carbonate chemistry sensor	Small	1-6
Aragonite	Below	Seconds to minutes	Point to transect	Centimeters	Carbonate chemistry sensor	Small	1-6
Nitrate	Below	Seconds to minutes	Point to transect	Centimeters	Nitrate sensor	Medium	1-6

Environmental Data Sensor Platforms

Below is a summary of the platforms that are currently available to host sensors and deliver the oceanographic and ecological data needed to meet regional monitoring system objectives. Unless otherwise stated, these platforms can support the acquisition of all the ocean variables listed in Table 1.

Sensor Platforms

- **Fixed offshore wind energy infrastructure**: Wind turbine foundations or substations that are directly secured to the seabed in relatively shallow waters. Using current acoustic monitoring technology, wind turbine bases cannot support PAM sensors as wind turbine noise would interfere with detecting whale calls.

- **Ocean buoys**: Floating platforms deployed in the ocean to collect data about the marine environment and atmosphere. Ocean buoys can be several meters in diameter and can typically support both the meteorological and oceanographic instrumentation, including instruments to measure surface currents.

- **Ocean mooring**: An ocean mooring is a system used to anchor and secure a floating platform in the ocean. It typically involves a mooring line, which can be made of rope, chain, or wire, and a ground anchor that holds the mooring in place on the seabed. Sensors can be attached to the mooring line at specific depths.

- **Bottom mounts**: Platforms deployed on the seafloor to collect data about various aspects of the ocean. Bottom mounts can be designed to withstand high pressures and can operate for extended periods, often months or years.
- **AUVs**: Autonomous vehicles may include ocean gliders (e.g., Slocum gliders) capable of being deployed 1–9 months, or propeller-powered vehicles designed for shorter missions lasting 1–24 hours. While these platforms can support the acquisition of all the variables listed in Table 1, they are currently limited to hosting approximately four to six sensors, depending on the platform configuration and sensor combinations.
- **Ships of opportunity**: These vessels are not primarily designed for environmental monitoring, but they can host sensors while carrying out their main operations. Examples include ships used to maintain the offshore wind energy infrastructure, crewed fishing boats, or recreational vessels.

Sensors mounted on these platforms can deliver real-time data or recovered data, and in many cases, both. Real-time data is typically transmitted via satellite and available to end users within 15 minutes of acquisition. In order to limit real-time data transmission costs, the data are subsampled (e.g. only one of every five measurements is transmitted). Recovered data are downloaded from the instrument when it is recovered from the ocean, and contain all measurements. Typically, real-time data are available from platforms that have a surface antenna which can communicate with satellites (e.g. fixed to offshore wind turbines, buoys, gliders, moorings with surface platforms, ships of opportunity). Bottom mount platform data may only be available in recovered format unless a surface antenna is attached.

This framework does not include the following potential platforms:

- Certain animal-borne tags (e.g., satellite-tracked and CTD tags), as their locations cannot be controlled to stay in the lease area or surrounding waters.
- Aircraft (manned and unmanned) were not included, as data from these are intermittent, and this framework focuses on long-term sustained scientific observation.

Conclusions and Recommendations

The technical experts and stakeholders engaged by the CFT identified a suite of commercially available sensors capable of measuring key atmospheric, oceanographic, and biological variables within offshore wind farms to address the monitoring system objectives. For each sensor, relevant specifications, including sampling resolution, physical dimensions, weight, and power and maintenance requirements, were documented.

Most sensors are compatible with multiple deployment platforms, such as fixed structures, buoys, vessels, submerged moorings or bottom mounts, and autonomous vehicles, although some exhibit platform-specific constraints. Sensor power and maintenance requirements vary greatly between sensor types, which could significantly impact the operational cost of an offshore monitoring system. With these considerations in mind, recommendations and next steps are highlighted.

Additional Considerations and Next Steps

- Establish a dedicated working group; potential collaborators could include state regulators, the research community, and wind energy developers to:
    - Develop a decision framework to prioritize sensors based on their ability to address multiple objectives and compatibility with wind farm operations and infrastructure.
    - Monitor developments in sensor miniaturization, battery life, and data transmission to periodically update the list of viable instruments.
    - Assess gaps in technology and encourage innovation through TechSurges and exercises similar to NOWRDC's Assessment of Technology Gaps for Statistically Robust Data (Courbis, et. al., 2024).
- Encourage partnerships between sensor and technology providers, wind energy developers, and OEMs to resolve feasibility issues such as infrastructure integration and power constraints.
- Although an order-of-magnitude cost estimate for the monitoring system is provided in the following chapter, it is anticipated that deployment requirements within offshore wind farms may necessitate modifications to the design and cost of certain existing sensors or the retrofitting of existing infrastructure.

CHAPTER 3: CONSIDERATIONS FOR DEPLOYMENT STRATEGIES

For a regional monitoring system to be effective, deployment strategies for sensors and platforms must balance feasibility, cost-efficiency, and safety while ensuring that the resulting data are accessible and provide information at spatial and temporal scales appropriate to the needs of key users.

Stakeholder Engagement

For detailed stakeholder engagement activities and outcomes, see Appendix B.

The engagement effort conducted for Chapter 3 represented a critical step in ensuring that the framework was grounded in the practical realities, technical expertise, and operational constraints encountered by those directly involved in offshore wind energy development. While general recommendations from the MTS Mini TechSurge informed the development of deployment configurations, the CFT focused this engagement specifically on stakeholders from original equipment manufacturers (OEMs) and wind energy developers, whose insights were most directly applicable to this topic.

OEM/Developer Virtual Focus Group Webinar

On October 8, 2024, a virtual focus group of offshore wind energy developers and equipment manufacturers was convened to provide input on the draft conceptual framework given the stated objectives and observing requirements described in previous chapters.

Stakeholder engagement provided valuable insights into deployment strategies, from sensor-specific guidance to broader strategic priorities. Key recommendations included standardizing sensor placement and performance requirements, leveraging diverse platforms (e.g., buoys and mobile sensors), and investing in improved data storage, transmission, and integration technologies. Stakeholders also emphasized the need for early and ongoing coordination between wind energy developers and wind turbine suppliers to support implementation. The deployment strategy presented in this chapter integrates CFT expertise with stakeholder input to balance standardization and flexibility, ensuring an efficient, reliable, and adaptable monitoring approach.

Timeline, Budgeting, and Standardization

Several key barriers to the inclusion of sensors on offshore wind energy substructures were identified. One major challenge is that wind energy companies are already under significant pressure to meet regulatory data requirements and often lack the time and budget to incorporate additional sensors deemed "nice to have" rather than essential. Other barriers include the lack of detailed cost information needed for accurate budgeting as well as the difficulty of integrating sensor requests that arise late in the process, after supplier contracts have been finalized.

Standardization and early planning were emphasized as strategies to overcome or alleviate these challenges. Effective standardization initiatives would include guidance on proposed sensor locations and integration on wind turbine infrastructure, as sensor accommodation may need to be considered as early as the wind turbine manufacturing stage. One suggested approach was to designate standardized areas on infrastructure with "plug-and-play" capability, similar to the standard placement of outlets in a kitchen for plugging in multiple appliances. Other suggestions included prioritizing the use of commercial off-the-shelf sensors that require data transmission and external power, which would facilitate sensor deployment directly on wind turbines and reduce costs. Additional areas for standardization include sensor performance requirements and communication protocols among wind energy developers, sensor and technology providers, and OEMs.

Knowledge Gaps and Information Needs

Broader informational needs were identified, including gaining a better understanding of potential interference between sensors from different vendors and how such interactions might affect sensor performance. Also highlighted was a need for more clarity on current practices for sensor placement and maintenance on active projects, particularly in relation to legal considerations, health, safety, and environmental (HSE) protocols, and data security measures.

Deployment Configuration

There are many factors that will inform a specific deployment configuration for a wind energy project. The primary focus for any monitoring plan is to optimize the deployed sensors to resolve the environmental and biological variability associated with the monitoring objectives. An effective deployment configuration will enable monitoring of the regional marine environment at meaningful temporal and spatial scales to detect long-term environmental change and distinguish impacts from offshore wind energy development from other activities and stressors. The implementation of the monitoring system described below should be maintained throughout the respective projects' life cycles, and potentially beyond, to meet project-specific and regional monitoring objectives.

Stakeholders also emphasized the distinction between monitoring, which involves the collection of information, and mitigation, which requires action. The monitoring system described here is designed to collect environmental data over multiple decades. This information can, in turn, support the development of improved mitigation procedures. For example, it can refine understanding of the seasonal presence of vulnerable species, assess changes in the underwater soundscape resulting from operational and vessel noise, and detect oceanographic variations that have the potential to disrupt food webs. Additionally, data from the monitoring system can provide valuable site-specific inputs to regional ocean planning and management initiatives.

Depending on the location of the site, known scales of environmental variability will determine the appropriate spacing and timing of measurements. For the purposes of illustration, Figure 1A depicts a generic WEA located on the continental shelf in the Mid-Atlantic Bight that includes four separate lease areas, each approximately 20 km long in the east and north directions. In the Mid-Atlantic Bight on the shelf, the known scales of oceanographic variability fluctuate in the along-shore and cross-shore directions for temperature, salinity, phytoplankton blooms, currents, and frontal boundaries, but are approximately on the order of 20 km (Lentz, 2008; Wilkin et al., 2022; Beardsley & Boicourt, 1981). In order to resolve the primary spatial scales of environmental variability, a minimum spacing of approximately 20 km would be needed between a sensor station, and the dimensions of this generic wind farm layout would require four stations for each lease area (Figure 1A). For the purposes of illustration, each yellow dot represents a fixed sensor station that delivers a suite of the physical, biological and chemical data provided in Table 1. As an alternative deployment strategy, Figure 1B shows the efficiency gained if neighboring leaseholders coordinate across their monitoring areas. Under this second scenario, the approximate 20 km spacing can be maintained across the entire WEA, resulting in a 35% reduction in the number of required stations, from 16 in the original layout to 10. This efficiency will not only reduce capital costs but also significantly reduce operations and maintenance costs over the life of the array.

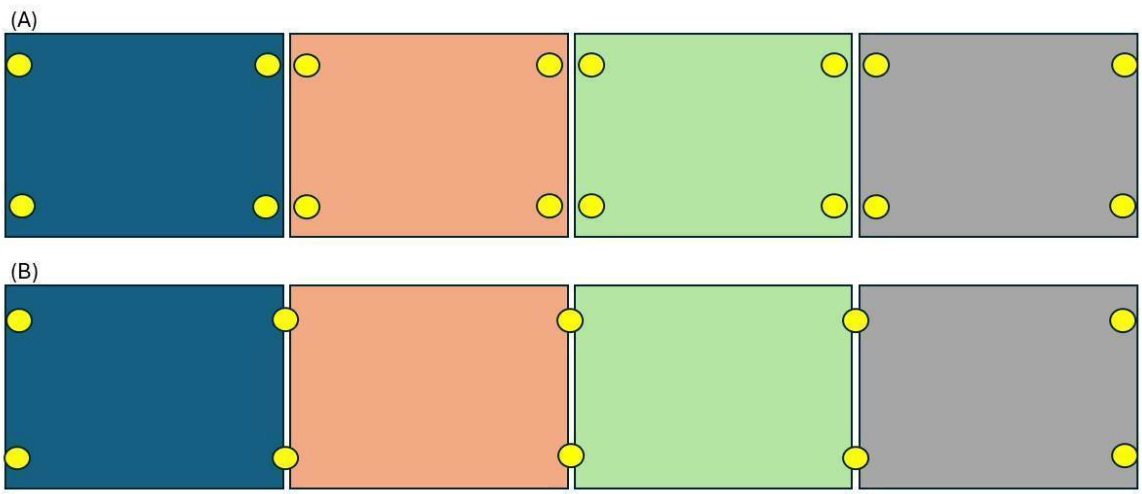

Figure 1. Example sensor configuration on four adjacent lease areas within a WEA, showing (A) lack of coordination among individual lease holders versus (B) coordination among lease holders across the WEA. Yellow dots represent fixed sensors that collect a suite of physical, biological, and chemical data. Each rectangle is approximately 15km x 20km.

In addition to the fixed sensor array described above, an effective deployment strategy would incorporate AUVs equipped with oceanographic and biological sensors. Mobile platforms, such as gliders, complement fixed sensors by expanding spatial coverage, enabling targeted surveying and sampling of areas around the WEA, certain oceanographic gradients, and biological hotspots. Through the deployment of buoyancy-driven gliders, environmental variability can be resolved at much less than 20 km scale over the spatial extent of the WEA. As an example, a single buoyancy-driven glider deployment can cover the area of the WEA with profile samples every 100–200 m along its path. These data can augment the longer-term time series from fixed arrays and capture varying oceanographic scales in the along-shore and across-shore directions. Gliders are also well-suited for PAM sensors due to their low noise emissions and can complement moored PAM systems by providing increased spatial resolution and improved detection probability for certain marine mammal species (Johnson, et al., 2022; Fregosi, et al., 2020).

Given the significant seasonal variability in the Mid-Atlantic Bight, meeting the stated objectives would require one paired deployment of two gliders per season. This would provide month-long coverage across all the oceanographic seasons, from mixed to stratified conditions, capturing seasonal variation. As shown in the fixed array example in Figure 1, coordination among neighboring leaseholders could reduce the number of seasonal glider deployments from eight (two per lease) to a single paired deployment (two total). This shared approach also enables data consistency across the WEAs. This shared approach would result in a 75% reduction in capital and operating costs over the lifespan of the array.

Deployment planning for both fixed and AUV deployments should also account for staggered construction schedules among neighboring offshore wind energy projects, which may become operational months or years apart. Regional coordination should therefore consider wind farms in all stages of permitting and construction. The notional sensor placement shown in Figure 1B assumes that all four adjacent wind farms in the WEA have, at minimum, progressed to the construction phase.

In addition to fixed infrastructure platforms and AUVs, stakeholders emphasized the value of using buoys and ships of opportunity as sensor platforms. Examples of fixed and mobile platforms are shown in Figure 2.

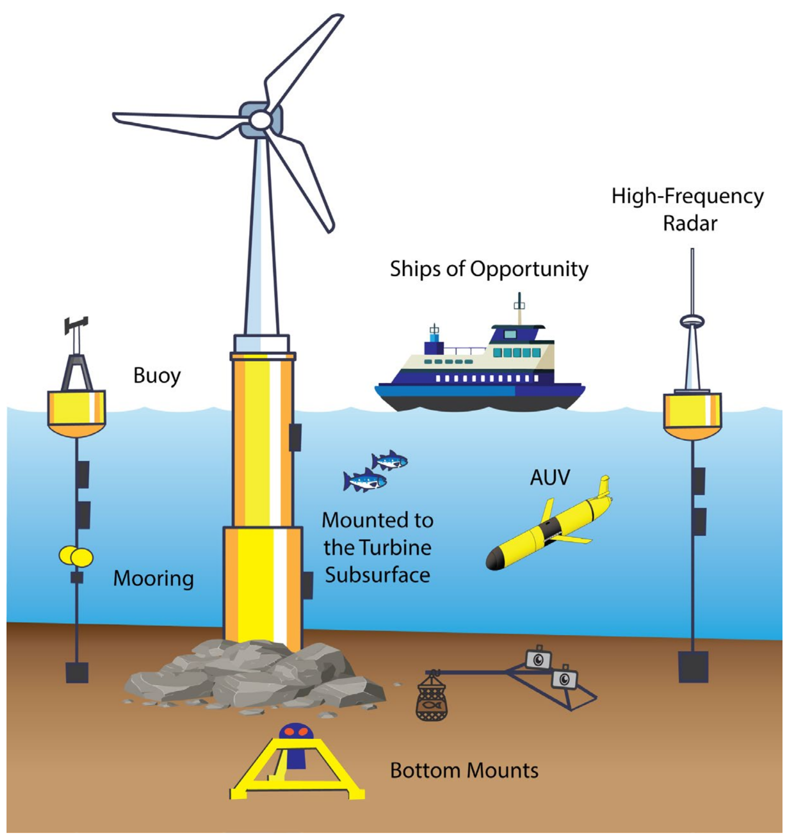

Figure 2. Examples of possible subsurface, near-surface, and just-above-surface fixed and mobile sensor platforms within a WEA. This figure uses Adobe Illustrator stock images and a glider image from https://imgbin.com.

Site-Specific Considerations

- **Site-specific scales of environmental variability:** Leases may be in areas with more complex circulation patterns, requiring sensors to be spaced closer together (i.e., closer to the coast, closer to a bathymetric feature, and/or closer to an area of persistent features like fronts and eddies).
- **Proximity of the site to known monitoring activities:** It is important that monitoring activities coordinate with other ongoing data collection efforts in a given region, such as metocean monitoring, fisheries research, and oceanographic sampling to increase efficacy and reduce redundancy.
- **Particular WEA site layout:** The location of wind turbines and/or substations will determine where and how sensors can be deployed, both on and around these structures.
- **Access to sensors:** Any sensors deployed as part of a monitoring system will need to be accessed for maintenance. Given site-specific configuration, some locations may be more accessible than others, with locations at the perimeter allowing for easier access. Sensors with similar maintenance requirements should be co-located to the extent possible.

Cost Estimates

Based on commercially available sensors capable of measuring the physical, biological, and chemical parameters identified (as of July 2025), the CFT developed rough cost estimates for a single observing system designed to measure variables aligned with the stated objectives.

These estimates are intended for guidance purposes only and represent the approximate order of magnitude of costs. Recognizing the variability in approaches an individual wind energy developer may take, the estimates:

- Assume new equipment purchases in the absence of leased equipment or leveraged resources.
- Exclude equipment replacement costs over the lifespan of the observing effort.
- Exclude contracting costs specific to a particular project or equipment deployment.
- Exclude project-specific health and safety requirement costs.
- Exclude costs for analysis or research conducted using the collected data.

The cost to purchase fixed in situ instruments (no autonomous vehicles) that will measure all the variables listed in Table 1 at one location (yellow dot in Figure 1) within an offshore wind energy project is estimated to be between $360,000 and $460,000 (Table 2), with additional installation costs between $300,000 and $400,000. Installation costs include, but are not limited to, purchases of a met buoy, wire walker profiler mooring, a bottom mount for instruments, and ship time. For annual maintenance and real-time data transfer, estimated costs per location are between $165,000 and $215,000. It is estimated that approximately four sites within a wind farm project will be needed to ensure the spatial resolution required to address the guiding objectives, unless adjacent wind farms are able to leverage costs at their boundaries (see Deployment Configuration section above). It is recognized that the size and dimensions of a proposed wind farm will determine the appropriate number of sensors.

Table 2. Cost estimations for all instruments.

Parameter	Instrument	Cost per unit
Metocean Physics		
Met station - air temperature, pressure, humidity, solar radiation, wind speed and direction, precipitation	Thermometer, barometer, anemometer, hygrometer, pyranometer,	$10,000
Conductivity, temperature, salinity, depth	Conductivity, temp, depth (CTD) sensor	$15,000
Water velocity profile	Acoustic doppler current profiler (ADCP)	$25,000
Surface currents across lease area	HF-radar bi-static transmitter	$85,000
Sea state	Wave logger pressure sensor	$10,000
Cameras (visible and thermal)	True color and thermal camera	$4,000
Biology/Optics		
Optics (fluorescence, backscatter, CDOM, turbidity, beam attenuation, chlorophyll)	Optics sensors (fluorometer, transmissometer, radiometer)	$20,000
Underwater camera (visible)	True color camera	$5,000
Telemetry	Passive acoustic receiver	$10,000
Fish echosounder (zooplankton/fish)	Acoustic zooplankton fish profiler	$100,000
Passive acoustics (whales)	Passive acoustic sensor	$25,000
Chemical		
Dissolved oxygen	Dissolved oxygen sensor	$12,000
pH, aragonite, pCO2	Carbonate chemistry sensor	$30,000
Nitrate	Nitrate sensor	$60,000

As indicated above, autonomous platforms could also be used to support the objectives outlined in Chapter 1. The cost to purchase buoyancy-driven autonomous vehicles (e.g., ocean gliders) is approximately $250,000 to $350,000, depending on instrumentation included in the purchase. Operational costs for a 30-day deployment of a glider are approximately $75,000. The purchase cost for propeller-driven autonomous vehicles varies widely, between $50,000 and $1,000,000. Operational costs for a 1–2-day deployment are under $20,000. Operational costs for both types of vehicles are significantly less than operating a ship at sea for several weeks.

The cost to purchase gliders as the platform for data acquisition is shown in Table 3. This cost estimate includes costs for the initial purchase of three gliders and the annual costs to deploy two gliders seasonally (eight deployments per year). A single pair of gliders can be used to monitor up to four adjacent wind farms, as they are able to travel an average of 20 km per day, transiting through each wind farm twice over eight days.

Table 3. Glider costs

Glider Purchase Costs		
Autonomous gliders: Includes three gliders with spare instrument bays and parts typical with routine deployment programs.	**Data variables:** temperature, salinity, depth, oxygen, CDOM, fluorescence, chlorophyll, sediment, pH, water column currents, active acoustics (zooplankton and fish), passive acoustics (marine mammals), and fish telemetry	$1,000,000
Annual Glider Operation and Maintenance		
Autonomous gliders: Includes two gliders with spare instrument bays, pumps, and additional third glider.	Assumes four seasonal deployments for two paired gliders (eight total deployments). Maintenance costs include glider operation and maintenance (insurance, shipping, calibration, preparation, servicing, and batteries); deployment costs (travel, vessel time, piloting, iridium satellite comms); and all data support (real-time data sharing, data quality control, real-time and post-recovery data management).	$750,000

Note that all costs are approximate and intended for guidance purposes only. Actual costs will depend on the final sensors/platforms chosen and their specific operation and maintenance requirements.

Key Deployment Elements

Key elements of a deployment strategy include sensor configuration; the platform on which the sensor is placed; data transmission, storage, processing, and quality assurance/quality control (QA/QC); system maintenance requirements; and sensor integration technologies. The deployment strategy should therefore be informed by the sensor and technology providers, wind turbine manufacturers, and wind energy developers. In the context of the lifecycle of an offshore wind energy project, the timing of sensor selection and integration into infrastructure must align with production, procurement, financial, and regulatory review timelines to be feasible and cost-effective.

Health, Safety, and Environment Considerations

Deployed sensors will also have to comply with HSE considerations, including structural integrity of offshore wind energy infrastructure, potential interference with mission-critical data integration processes and/or emergency communication pathways, and risks to cybersecurity. Sensor maintenance could incur potential safety risks associated with at-sea transits for personnel. For all these reasons, effective deployment strategies will need to be designed with HSE considerations in mind.

Evolving Sensor Technologies

An important challenge when considering effective deployment strategies is determining how to accommodate constantly evolving sensor technologies. Innovations tend to improve and expand sensor capabilities but may also change the physical dimensions, power demands, maintenance needs, sampling capabilities, and data outputs of the sensor systems. If not adequately considered, these changes could hamper standardization efforts and render certain aspects of early-stage observing system planning obsolete by the time sensor technologies mature, particularly in cases where wind turbine designs have been altered to accommodate a particular sensor type or model. One way to "future-proof" this scenario could be to track historical sensor development trends to make reasonable projections about future developments, particularly regarding sensor dimensions and power needs, and build in physical and functional flexibility to accommodate these projected changes. A suggested approach for achieving this flexibility is to designate standardized areas on infrastructure with plug-and-play capability as mentioned above. This would allow future technologies to be integrated more easily while providing clear parameters for size, power supply, and allowable weight that sensor and technology providers can design toward. In addition, reliance on a variety of deployment platforms (e.g., fixed infrastructure, buoys, and AUVs) in sensor deployment plans will also maximize chances of accommodating and supporting evolving sensor technologies.

Retrofitting Considerations

While early planning and standardization are emphasized throughout this chapter, retrofitting remains an important pathway for integrating sensors into offshore wind energy projects that are already under development, constructed, or operational. Retrofitting refers to the installation of environmental or biological sensors on existing offshore infrastructure after initial design and construction phases. This approach may be necessary where monitoring requirements evolve, where early coordination was not feasible, or where pilot efforts reveal critical data gaps not previously anticipated.

Retrofitting presents unique technical, logistical, and budgetary challenges that must be addressed thoughtfully. Key considerations include:

- **Structural limitations:** Existing offshore structures may have limited space, weight tolerance, or power availability to accommodate new sensors. Detailed structural assessments are required to ensure safe and secure installation that does not interfere with wind turbine operations, emergency systems, or existing data and power conduits.

- **Power and data access:** Unlike sensors integrated during initial design stages, retrofitted sensors may not have easy access to power or communication networks. Battery-powered or self-contained units with satellite or acoustic data transmission may be needed, which can add cost and limit sampling frequency or resolution.

- **Installation and maintenance logistics:** Retrofitting requires careful planning to coordinate access to offshore infrastructure, often requiring specialized vessels and weather windows. Safety risks and associated HSE considerations must be evaluated.

- **Technology compatibility:** Not all sensors are easily adaptable to existing configurations. Retrofitting may require custom mounting brackets, enclosures, or software modifications to interface with existing control systems.
- **Permitting and legal considerations:** Depending on lease terms and applicable regulations, retrofitting may require updated permits or revisions to COPs. Coordination with BOEM and other relevant authorities is essential to ensure compliance and avoid project delays.

To support retrofitting as a complementary deployment pathway, the following recommendations are offered:

- Develop modular, compact, and low-power sensor packages specifically designed for retrofitting on wind turbines and substations.
- Identify "retrofittable" locations on wind turbines during initial infrastructure design, even if sensors are not deployed immediately.
- Pilot retrofitting on select demonstration projects to refine procedures, assess costs, and document best practices.
- Encourage sensor and technology developers to prioritize backward compatibility and minimal infrastructure modification in their designs.
- Establish a regional fund or incentive program to offset costs associated with retrofitting high-priority sensors on early-phase projects.

While not a replacement for early integration, retrofitting offers a flexible option to improve monitoring coverage and respond to evolving needs across the lifespan of offshore wind energy projects. When paired with coordinated deployment planning and future-proof design principles, retrofitting can help ensure the long-term adaptability and relevance of the regional monitoring system.

Conclusions and Recommendations

Stakeholder engagement on this topic yielded valuable insights into deployment strategies, ranging from sensor-specific guidance to broader strategic priorities. However, stakeholder feedback did have its limitations. At times, detailed guidance on optimal sensor placement, appropriate temporal or spatial sampling scales, and integration with existing regional monitoring was lacking. Feedback regarding manual sampling methods (e.g., eDNA) and certain animal-borne sensors (e.g., CTD and satellite-tracked tags) fell outside the scope of this effort, which focuses on more automated systems and sensors that can be co-located with offshore wind farm infrastructure. Additionally, stakeholders may have favored sensor types and platforms with which they were already familiar, potentially underrepresenting novel or emerging technologies with promising capabilities but limited operational history.

Additional Considerations and Next Steps

- Continued collaboration with wind energy developers, OEMs, regulators, sensor and technology providers, health and safety professionals, and stakeholders will be essential for resolving feasibility issues such as infrastructure constraints, retrofitting, sensor deployment, safety logistics, and maintenance schedules. Future forums, such as a dedicated workshop or TechSurges should be considered to provide opportunities to iterate and advance this conceptual framework.

- Possible future forums could focus on:

    1. Fisheries monitoring technologies and platform compatibility (e.g., acoustic telemetry, optical sensors, real-time catch monitoring). Active participants should include:

        - Fishing industry representatives (commercial and recreational)
        - Fish biologists/ecologists
        - Offshore wind energy developers
        - OEMs
        - Sensor innovators
        - Data managers

    2. Engagement with health and safety professionals and regulatory authorities to develop standardized procedures for safe and compliant sensor deployment, maintenance and retrofitting, particularly on operational wind turbines.

    3. Collaboration with procurement experts to refine cost estimate models, determine the return on investment for coordinated and multi-platform deployment strategies, and develop accurate and actionable regional cost-benefits.

- Enable retrofitting as a complementary strategy to integrate sensors on existing infrastructure and pilot retrofit procedures to address evolving monitoring needs and regulatory requirements.

- To maintain the relevance of this framework as technologies, regulatory needs, and costs evolve, a formal update should be scheduled every 2–3 years. In the interim, feedback from pilot deployments and emerging platform/sensor innovations should be captured and synthesized annually to inform future revisions.

CHAPTER 4: DATA QUALITY AND MANAGEMENT STANDARDS

Data collected by a regional monitoring system will require a robust governance framework to ensure that principles of quality, security, and stewardship are upheld. Establishing clear standards for how data are collected, stored, managed, and shared is critical to supporting long-term utility and ensuring that the growing volume of data can be effectively used.

Stakeholder Engagement

For detailed stakeholder engagement activities and outcomes, see Appendix B.

Input was taken from the MTS Mini TechSurge described in Chapter 2 (Appendix E), and a Virtual Data Roundtable (Appendix G) was organized to gain focused input from end users, data managers, and those with data governance expertise. This Chapter summarizes the key themes and stakeholder recommendations that emerged from these conversations.

Stakeholder input resulted in the following priorities associated with data governance:

- **Leverage existing resources:** Focus on scaling and repurposing current data management technologies/databases rather than developing entirely new archive solutions. Maximizing the potential of existing data archive resources can lead to more cost-effective and timely innovations.

- **Enhance data management systems and visualization:** Invest in improved data storage, transmission, and integration technologies. Develop tools for better integration and visualization of data and incorporate QA/QC to prevent errors in mitigation decisions.

- **AI-driven analytics and machine learning algorithms:** Advance the use of AI to efficiently process and analyze large datasets.

- **Increased security:** Prioritize cybersecurity measures to protect data integrity and prevent unauthorized access.

- **Large database repositories:** Develop large-scale repositories and promote data repository compatibility to facilitate data access, allowing for easy downloading and use by various stakeholders.

- **Case studies:** Create case studies describing specific data governance practices given the objectives, sensors, and deployment strategies described in the prior chapters. Case studies can be helpful to offshore wind energy developers because of commercial sensitivities for specific projects. In addition, during a time when offshore wind energy projects are in flux, case studies can bring focus to a discussion and remove the need to speculate on a specific project's details or viability.

Key Players in Data Management

Effective offshore wind energy data management relies on collaboration among a variety of key players, each bringing unique expertise and resources to the table. The following entities were identified as essential contributors to data collection, integration, and dissemination:

- **BOEM, National Oceanic and Atmospheric Administration (NOAA), and other federal and state agencies:** May require that certain data are managed and shared on specific timelines but often do not dictate how and where.
- **Funders of data collection:** After consideration of any requirements from agencies, funders have ultimate control of how data are managed and shared. Funders can incorporate data sharing terms and conditions into contracts with consultants and universities to ensure that data are consistently collected, managed, and shared according to RWSC and ROSA recommendations. Funders are usually states, offshore wind energy developers, and federal agencies.
- **Maintainers of data infrastructure:** Examples include the U.S. IOOS, IOOS regional associations, NOAA National Centers for Environmental Information (NCEI), Mid-Atlantic Acoustic Telemetry Observation System (MATOS), Northeast Regional Ocean Council (NROC), and Mid-Atlantic Regional Council on the Ocean (MARCO). These entities maintain existing platforms that will likely need continued support and increased capacity to handle the data generated by a regional monitoring system. These platforms have been established and funded for a variety of purposes unrelated to offshore wind energy.
- **Data users:** Decision makers at individual agencies, businesses, researchers. Data should be managed to ensure all have access and that the data produced meet as many needs as possible.
- **Regional entities:** Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS), NROC, MARCO, RWSC, ROSA, etc. help convene all groups above to plan for, support, and implement ocean data management and use.

Each of these organizations plays a crucial role in ensuring that offshore wind energy development is informed by high-quality, accessible, and collaborative data management practices.

Data Ownership

New Jersey, through the RMI, its participation in RWSC and ROSA, and in the language of its offshore wind energy solicitations, has signaled its commitment to making environmental and ecological data resulting from a regional monitoring system publicly available. RWSC and ROSA, in further support of this vision, developed a data policy that may be used or adapted by others. The policy affirms that data is legally owned by the entity(ies) collecting the data, with data owners applying a license that permits nonexclusive use by others. As planning and budgeting progress, it will be critical to clarify data ownership for certain datasets, particularly those that may be sensitive for defined periods (e.g., protected species detections) or those funded by entities other than the state. New Jersey is well-positioned to play a central role in guiding this process.

A roles and responsibilities matrix should be developed to outline data ownership and management across the data lifecycle, particularly for complicated arrangements such as cases where a state-owned sensor is deployed on private infrastructure under a permissions agreement. Ownership of all monitoring components and co-dependencies should be explicitly defined to prevent ambiguity. To address restrictions on sensitive data, data use agreements must clearly specify ownership, usability, and any limitations. If certain datasets are classified as restricted, an approval process for sharing sensitive data should be established early in the contracting phase to ensure transparency and availability while respecting proprietary concerns.

As outlined in the RWSC Science Plan (RWSC, 2024), data owners shall be responsible for ensuring that both real-time and recovered datasets are properly transmitted to public repositories. As noted in the previous section, existing databases should be leveraged and prioritized for effective data management. For all lease areas off New Jersey, the primary database to leverage for oceanographic data is the MARACOOS database. MARACOOS is certified by the federal government for meeting rigorous governance and data management standards. MARACOOS already acquires, quality controls, archives, displays and serves both real-time and recovered data for many target variables, including meteorological data, ocean temperature, salinity, oxygen, currents, waves, optical data, chlorophyll, PAM, pH, pCO_2, and visible cameras feeds, along with hundreds of other federal datasets and models for the mid-Atlantic. Through the relationship between MARACOOS and the U.S. IOOS program, each of these data streams is regularly archived at the NCEI, consistent with RWSC and ROSA recommendations.

Additional databases and repositories to be leveraged—based on the sensors and platforms described in this framework and aligned with repositories recommended by the RWSC Data Governance Subcommittee—include:

- U.S. IOOS Glider Data Assembly Center (DAC) repository
- U.S. IOOS High-Frequency Radar DAC at NCEI
- MATOS, part of the Atlantic Cooperative Telemetry Network
- NCEI Passive Acoustic Data Archive
- Environmental Data Initiative Repository, for plankton acoustic and optical profiles
- OBIS-SEAMAP for any megafauna observations
- Any others identified by New Jersey, RWSC, and ROSA

Data products, such as climatology maps of oceanographic variables, should be regularly generated from the data collected by a regional monitoring system. These outputs could be accessed and used by decision makers. They should be produced on a regular basis (e.g., annually) and provided to the following platforms:

- MARACOOS OceansMap
- Mid-Atlantic Ocean Data Portal
- Northeast Ocean Data Portal
- U.S. Marine Cadastre Hub
- Any others identified by New Jersey, RWSC, and ROSA

Data Management Planning

To ensure efficient and cost-effective data management, requirements should be established with leaseholders during the budgeting and design phase of a project. Because data management involves both financial and construction considerations, early integration of sensors and data systems is critical for long-term success. Projects are most effective when these systems are seamlessly incorporated from the outset, reducing the need for costly retrofits or adjustments later.

Each project and wind energy developer should designate a data steward—a dedicated point person responsible for navigating regulatory challenges, ensuring data interoperability, and coordinating with legal teams, contractors, and researchers. This role requires funding and should be accounted for during the planning and budgeting phase in collaboration with lease owners.

Additionally, the NJBPU and the New Jersey Department of Environmental Protection (NJDEP) should continue working closely with other states in the region to establish standardized data management protocols that will enhance consistency, accessibility, and collaboration across offshore wind energy projects.

Data Transfer

The transfer of data from and between subsurface platforms was identified as a significant challenge to consider in the buildout of the monitoring system. Similar to data management requirements, data transfer pathways should be planned and budgeted for during the budgeting and design phase of a project. Ensuring a clear and efficient process for data transmission is essential for maintaining accessibility and compliance with public data-sharing requirements. Further, it is the responsibility of the lease owner to ensure that data is made available to relevant repositories, either directly or through third-party contractors. Establishing these pathways early in the project lifecycle will help streamline data integration, reduce delays, and support broader environmental monitoring efforts.

Data Sharing and Availability

The first step to ensure agreed-upon data sharing regulations is creating a culture of data sharing fostered from the outset—beginning in the design and budgeting phase—through structured communication between state agencies, federal agencies, and the wind energy developers. Early clarity on data-sharing expectations will help inform design decisions and prevent conflicts later in the project lifecycle. However, data sharing should not be assumed, rather it must be an intentional goal set by New Jersey. Importantly, "shared" does not necessarily mean "open access"; data can remain proprietary while still being available under defined terms.

Data Standards and Formats

Consistent with the above feedback, the establishment of data standards and formats early in the process will ensure consistency, quality, and interoperability across projects. Enforcement of robust data standards should apply across wind energy developers, agencies, and academia to ensure quality in data handling and streamline data sharing and integration. The following are some important considerations:

- Account for existing data repository specifications when constructing data format requirements.
- Establish metadata needs and capture that information in a formal document (e.g. Data Management and Sharing Plan) to maintain the integrity of the data.
- Ensure the data standards support and align with scientific priorities. This will reduce costs for research funders, decrease the time needed to collect and process data, ensure standardized products, and enhance decision-making for management and policy.

By prioritizing well-defined data standards, New Jersey can facilitate collaboration, improve data availability, and support high-quality research and policy development.

Data Quality Control

- To facilitate integration across platforms and sensors, clock synchronization issues among multiple data streams should be resolved to ensure accurate and consistent datasets.
- All data should be Climate Forecast compliant. Additionally, metadata requirements defined by IOOS should be followed to maintain consistency across disciplines. Many of these requirements rely on groups external to IOOS (e.g., Climate Forecast and Darwin Core).

Data Security

Robust data security measures should be established and enforced to protect sensitive information while ensuring availability for authorized users, striking a balance between safeguarding integrity and promoting transparency. The development of guidelines and best practices should be led by parties responsible for data provision, handling, and use, including state agencies, federal entities (e.g., BOEM, NOAA, NCEI, IOOS) and wind energy developers. Regional entities like RWSC and ROSA can provide a forum for multisector dialogue on data security protocols, which should align with established cybersecurity frameworks such as the National Institute of Standards and Technology's (NIST) Cybersecurity Framework (CSF).

These guidelines should address key areas including data encryption, access control, and incident response protocols to mitigate cyber risks across the data life cycle. Clear delineation of roles and responsibilities will be essential to ensure confidentiality, integrity, and availability while enabling secure and transparent data sharing. By implementing robust data security protocols, New Jersey can protect against unauthorized access, minimize potential vulnerabilities, and support the secure, consistent sharing of environmental data among stakeholders.

Leveraging Existing Resources and Efforts in Data Governance

Numerous groups have been working on this critical issue for years, resulting in a wealth of available resources on the topic.

RWSC Data Governance Subcommittee

RWSC has taken the lead on data governance issues in the offshore wind energy space. To support this work, RWSC established a Data Governance Subcommittee tasked with identifying and recommending long-term storage solutions for the various data types outlined in its Integrated Science Plan for Offshore Wind, Wildlife, and Habitat in U.S. Atlantic Waters (RWSC, 2024). The subcommittee is open to new applicants and includes members from a diverse range of sectors, including academia, state and federal agencies, offshore wind energy developers, nongovernmental organizations (NGOs), consultants, and others. The subcommittee plays a central role in advancing data governance and is recognized as a primary coordinating body for offshore wind energy related data issues.

ROSA Data Governance Subcommittee

In February 2025, ROSA hosted the initial meeting of its Data Governance Subcommittee. This newly formed group is tasked with providing guidance on data related to fisheries, offshore wind energy, and ocean development. Its work will support future regional and cumulative impact assessments and promote interoperability with other data initiatives in the region. The subcommittee coordinates closely with RWSC to ensure the alignment of recommendations.

Public Data Portals

There are dozens of existing online data aggregation portals that host public websites for collecting and storing data. These portals are listed throughout the RWSC Science Plan (RWSC, 2024) and should be leveraged for data management. Data managers are responsible for formatting data—particularly ensuring accurate metadata—in a way that the portals can leverage to make data available to the public.

Some of the more relevant examples of these entities include but are not limited to:

- U.S. IOOS, who certifies regional associations to support their work, like MARACOOS and the Northeast Regional Association Coastal Ocean Observing System (NERACOOS).
- Data portals hosted by regional ocean partnerships, like MARCO and NROC.

- The World Ocean Database, hosted by NCEI, which is the world's largest collection of uniformly formatted, quality-controlled, publicly available ocean profile data.
- The Marine Cadastre, maintained by BOEM with support and input from several other federal agencies.
- The MATOS data portal, that archives telemetry data across the east coast of the United States.
- NOAA NCEI Passive Acoustic Data Archive and the National Marine Fisheries Service (NMFS) Passive Acoustic Cetacean Map (PACM), both of which manage and archive PAM data and derived marine mammal detections.
- Movebank, an online database of animal tracking data hosted by the Max Planck Institute of Animal Behavior.
- The U.S. Animal Telemetry Network Data Assembly Center Data Portal, hosted by U.S. IOOS.

Conclusion and Recommendations

Effective data quality and management standards are valuable to the success of offshore wind energy projects, creating an environment in which data are accurate, accessible, and usable for decision-making. Establishing a robust data governance framework, engaging stakeholders early, and leveraging existing resources will streamline data collection, sharing, and integration across various platforms. Clear ownership and data-sharing agreements, alongside early planning for data systems and security, will foster collaboration and maximize the value of collected data. By prioritizing these practices, offshore wind energy initiatives can improve environmental monitoring, enhance research capabilities, and support long-term sustainability efforts.

Additional Considerations and Next Steps

- Overall, wind energy companies embraced the idea of a third party managing both instrument operations and data. Several wind energy developers suggested creating a joint funding pool, into which they would contribute to support a third-party regional data manager in handling data acquisition and management work across multiple lease areas.
- Monitoring and evaluating the implementation of data standards and stewardship practices across projects and using a feedback loop that incorporates user satisfaction, system performance, and data usability metrics will be important as projects evolve.
- Cybersecurity professionals should be engaged to stress-test security protocols and systems.
- Continued outreach strategies should be defined to support full utilization of existing data by the stakeholders and core users, including:
    - NJBPU

- NJDEP
- NYSERDA
- WEA leaseholders
- NWS
- NMFS
- Research universities
- U.S. Geological Survey (USGS)
- BOEM
- U.S. Environmental Protection Agency (EPA)
- Bureau of Safety and Environmental Enforcement (BSEE)
- RWSC
- U.S. Navy
- USCG
- Commercial and recreational fishermen
- ROSA
- NGOs

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS FOR APPLICATION

Final Conclusions

The planning considerations outlined here provide a guidance framework for establishing a science-driven and coordinated offshore environmental and ecological monitoring system capable of serving diverse projects across the New Jersey/New York Bight, the broader Mid-Atlantic Bight, and potentially beyond. Transitioning from concept to implementation will require sustained coordination, broad collaboration, and deliberate action. Strong data governance will be essential to ensure high-quality, secure, and interoperable data systems that can adapt over time and remain reliable for long-term use.

Implementation of this system is both possible and promising, but it will require a phased, adaptive approach that balances technical feasibility, stakeholder priorities, and long-term resilience. Pilot deployments, iterative refinement, and regular plan updates will help manage risks and ensure continuous improvement.

Coordinating a system of this scope will introduce administrative burdens, particularly in managing governance and cross-sector collaboration on a regional scale. Key challenges include aligning procurement, permitting, and compliance timelines; ensuring legal and policy consistency across jurisdictions; and securing the sustained funding and organizational commitment needed for long-term operation. However, the benefits of a coordinated monitoring approach are substantial: cost efficiencies from shared platforms and infrastructure, standardized methodologies that improve data comparability, centralized data access that supports decision-making across marine users, and broader utility of the data for science and management.

Limitations and Future Needs for Stakeholder Engagement

While stakeholder input laid a strong foundation, the evolving scope of the effort and varying levels of stakeholder capacity and availability influenced both the breadth and depth of feedback received. Despite significant outreach efforts, stakeholder engagement had limitations and biases.

Groups such as small-scale fishermen and under-resourced NGOs may have faced barriers to participation, leading to input that disproportionately reflected more well-resourced or consistently engaged entities. The rapid pace of offshore wind energy development has also contributed to stakeholder fatigue, and while virtual formats make participation easier for many, it may have excluded some maritime professionals who are more willing or able to engage in person. Additionally, because few offshore wind energy projects in the U.S. and the Mid-Atlantic Bight have reached advanced development stages, stakeholder feedback, while informed, lacks the benefit of project-specific insights and lessons learned.

To address these limitations and ensure the monitoring system remains relevant and inclusive, future engagement should:

- Create formal mechanisms and feedback loops (e.g., regionally tailored workshops, forums, or working groups) for ongoing stakeholder input during pilot and operational phases to ensure the system remains responsive, inclusive, and practical.
- Involve upper management decision makers in design, procurement, and planning, securing organizational buy-in and investment.
- Consider financial compensation or travel support for entities such as small-scale fishermen, Tribal members, and under-resourced NGOs to enable more participation in stakeholder convenings.

Further input and interdisciplinary expertise are also needed to refine and operationalize the system:

Monitoring design and integration

- Define clear indicators and thresholds for long-term ecological assessment.
- Establish transparent data access mechanisms to build stakeholder trust.
- Identify data gaps and infrastructure needs, distinguishing among raw data, QA/QC data, packaged data, and data products; determine how to address gaps through data collection, models, mitigation, or other risk-based methods as appropriate.
- Align financial, procurement, engineering/design, permitting, and compliance timelines; use side-by-side comparisons to spot misalignments.
- Request bidders to demonstrate timeline alignment in their proposals.

Technical and legal expertise

- Engage legal and policy experts to create enforceable governance protocols that optimize across different applicable regulatory structures at federal, state, and local levels.
- Consult cybersecurity professionals to ensure scalable, secure data systems.

Cross-sector coordination and iteration

- Maintain collaboration among wind energy developers, OEMs, and relevant stakeholders to resolve logistical challenges.
- Use pilot deployments to test and refine sensor-platform combinations.
- Launch initiatives to standardize sensor types, placement methods, and data quality protocols.

Recommendations and Next Steps

This document provides flexible guidance for building a robust regional monitoring system that is responsive to both current and future needs. With sustained investment, inclusive engagement, and strong governance, it can deliver long-term value to the offshore wind energy industry, regulators, scientists, and the communities that depend on the health of the mid-Atlantic's ocean ecosystem.

Phased Implementation Approach

This document serves as a framework and should be used to develop a monitoring plan that is reviewed and updated on a regular schedule, ideally every 2–3 years, to reflect new insights from pilot deployments, evolving regulatory needs, and technological advancements. A structured rollout, similar to the example below, will allow for testing, refinement, and scaling:

- **Phase I:** Initiate pilot deployments in one to two priority WEAs to test sensor-platform configurations, data quality and workflows, energy demands, and maintenance and retrofitting logistics.
- **Phase II:** Synthesize "lessons learned" from pilot efforts and produce an interim progress report.
- **Phase III:** Update the conceptual framework/evolving monitoring plan to reflect pilot findings, innovative technologies, and regulatory input.
- **Ongoing:** Conduct annual reviews to track emerging technologies, adapt to regulatory needs, and incorporate stakeholder feedback.

Sensor Integration, Standardization, and Coordination

- Foster collaboration among OEMs, wind energy developers, engineers, researchers, and sensor and technology providers to design sensor systems that support innovation and standardization, identify integration opportunities, and avoid costly retrofits.
- Stay abreast of advances in sensor technology, including miniaturization, battery life, data transmission, and AI-assisted analytics.
- When retrofitting existing infrastructure, identify compact, modular sensor packages and retrofit procedures to meet evolving monitoring and regulatory needs.
- Include insurance professionals in discussions on integrating sensors into infrastructure and operating mobile platforms (e.g., AUVs) near infrastructure.
- Organize targeted forums for fisheries monitoring technology co-design (e.g., workshops, TechSurges) to ensure platform compatibility, establish aligned standards, and produce usable data products for fisheries management and community research.
- Standardize health and safety protocols for compliant sensor deployment and maintenance.
- Coordinate with RWSC/ROSA and other states on regional monitoring strategies to maximize spatial and temporal coverage while minimizing redundancy.

Data Management and Governance

- Invest in scalable data systems that align with MARACOOS, NROC, and BOEM frameworks.
- Leverage ROSA and RWSC data governance plans to guide implementation, data accessibility and interoperability.
- Create reusable governance templates to clarify roles, agreements, and QA/QC protocols.

Regulatory and Policy Alignment

- Work with state and federal regulators to define thresholds, indicators, and preferred data formats to support adaptive management.
- Aim to maintain alignment with broader regional ocean observing strategies and the RWSC Science Plan (RWSC, 2024).

HSE Considerations

- Incorporate HSE standards into deployment, operations, and maintenance to protect personnel and environmental resources.
- Address potential structural, cybersecurity, and emergency communication risks associated with sensor installations.

Cost and Budgeting Strategies

- Maintain a dynamic cost database informed by pilot deployments and ongoing market research.
- Develop and validate cost-benefit models that evaluate efficiencies from coordinated deployments, platform sharing, and sensor modularity.

Achieving the Monitoring Objectives

The following illustrates how the framework's design can align with and support the Monitoring Objectives.

Objective 1: Contribute local atmospheric, oceanographic, and biological data to coordinated regional monitoring efforts, helping to differentiate short-term variability and/or long-term changes in environmental conditions from potential impacts of offshore wind energy development.

- Monitoring design and data integration enables consistent long-term data collection that captures both short-term variability and multiyear trends.
- Sensor integration and standardization across fixed and mobile platforms promotes comparable datasets across projects and regions.

- Regional coordination maximizes spatial and temporal coverage.
- Phased implementation with pilot deployments allows for early validation of platform–sensor combinations and refinement of spatial coverage strategies to improve environmental change detection.

Objective 2: Provide the necessary data to address regulatory compliance, mitigation needs, and inform the management of living marine resources.

- Data governance and standardized QA/QC procedures create high-confidence datasets informing adaptive management and allowing regional bodies to respond to emerging issues or changing environmental conditions.
- Dynamic cost and budgeting strategies enable efficient allocation of resources toward the most critical monitoring activities for living marine resource protection.
- Sustained stakeholder engagement—including support for participation by management entities (federal, state, and regional), small-scale fishermen, Tribal members, and under-resourced NGOs—ensures that monitoring priorities reflect the needs of those directly affected by environmental change and regulatory decisions.

Objective 3: Contribute monitoring data to regional ocean planning and management initiatives.

- Generates standardized, high-quality datasets that are compatible with regional observing frameworks like MARACOOS, NROC, and the RWSC Science Plan, ensuring interoperability and comparability.
- Integrates data into centralized platforms for timely access by planners, managers, and researchers, reducing duplication of effort and enabling shared situational awareness.
- Provides regionally coordinated coverage across multiple WEAs, allowing agencies and planning bodies to assess cumulative and cross-boundary effects.

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Appendix A: Offshore Wind Infrastructure Monitoring Plan Requirements

Offshore Wind Infrastructure Monitoring Plan Requirements

The Applicant shall develop a plan for the use of offshore wind infrastructure including turbine arrays, foundations, and substations as environmental and ecological monitoring platforms that can contribute to relevant regional monitoring, observing, and research efforts.

- This plan for co-located monitoring equipment must identify and describe the incremental investment and implementation plan to incorporate and integrate multiple sensors, platforms, and data systems on offshore wind infrastructure. The plan must articulate how the monitoring will align with the New Jersey RMI and regional research objectives, including contributing to:
    - Environmental and ecological baseline and monitoring frameworks;
    - Understanding changes to marine resources from established baselines during the construction and operation of wind turbines; and
    - Integration of existing and novel scientific approaches and platforms.
- The plan shall consider the entire footprint of the Project including wind farm area, cable routes, landfall locations, and upland routes, and shall address how implementation of the plan will inform outstanding questions related to and reduce impacts associated with wind farm construction and operation.
- The plan shall align with the Data Management and Availability plan as described in Attachment 7.
- The plan shall describe how the applicant will work collaboratively with and leverage relevant work from federal, state, academic institutions, other ocean user groups, developers of other wind farm projects in the region, and regional science entities to develop and implement the plan.
- The Applicant is encouraged to review the following resources posted to the Solicitation documents page of the BPU's Solicitation Website in the development of their plan.[1]

[1] See BPU, Third New Jersey Offshore Wind Solicitation Documents, https://www.njoffshorewind.com/third-solicitation/solicitation-documents.

Appendix B: Stakeholder Engagement Activities and Outcomes by Chapter

The development of this framework was guided by a multi-method approach to stakeholder engagement. The CFT led the outreach efforts, conducting both virtual and in-person discussions with a wide range of stakeholders and experts to gather input, identify monitoring needs, and incorporate best practices. The team also built on existing scientific partnerships and ongoing research to ensure the integration of relevant expertise in science and technology. Stakeholders and experts included:

- **The marine user community:** The marine user community refers to the diverse groups of people, organizations, and sectors that actively use, rely on, or manage the marine environment for economic, operational, recreational, scientific, or cultural purposes. Each of these groups interacts with ocean and coastal environments in different ways and may have distinct interests, responsibilities, and data needs. Various marine users including fishing industry representatives, researchers and marine wildlife groups, and federal and state regulators, were engaged to understand specific environmental and ecological monitoring needs and to determine monitoring system objectives.

- **Technology and sensor developers:** Sensor and platform developers were engaged to inform the integration of their technologies and platforms with offshore wind energy associated infrastructure.

- **Offshore wind energy developers and wind turbine manufacturers:** Wind energy developers and wind turbine manufacturers (original equipment operators or OEMs) were engaged to understand their monitoring needs and gather technical expertise that would inform feasible deployment, health, safety, environmental (HSE) protocols, and maintenance strategies.

- **Ocean observing and data managers:** Discussions with these groups were centered around identifying robust sensing technologies, establishing data protocols, and ensuring accessibility in line with current best practices.

Chapter 1 Engagement: Identification of Monitoring System Objectives

Stakeholder Survey

The CFT developed the Research and Monitoring Initiative Ocean Observing Stakeholder Survey.). The survey was designed to gather input to define the goals and objectives of an environmental and ecological monitoring system to be deployed within offshore wind farms. The survey was distributed during Spring 2024 and complemented by two webinars to encourage participation and facilitate deeper feedback.

Participation:

A total of 112 individuals began the survey, and responses per question varied because all survey questions were optional. The most common affiliations among survey respondents were: Federal Government (19.2%), Offshore Wind Developers (15.4%), Environmental NGOs (13.5%), Academic Researchers (13.5%), Consultants (11.5%), and Other (9.6%).

Survey Feedback:

Survey participants were asked to identify key research, monitoring, and management priorities for the Mid-Atlantic Bight over the next 5–10 years. Top responses (Figure B1) included:

- **Most commonly selected research issue: "**Climate change impacts" (referred to in this document as "short-term variability and/or long-term changes in environmental conditions") — selected by **39.6%** of respondents.
- **Most commonly selected monitoring/observing need: "**Monitoring to inform regulation and management of marine resources" — selected by **64.2%** of respondents.
- **Most commonly selected management issue: "**Wind farm-specific decision-making" — selected by **41.5%** of respondents.

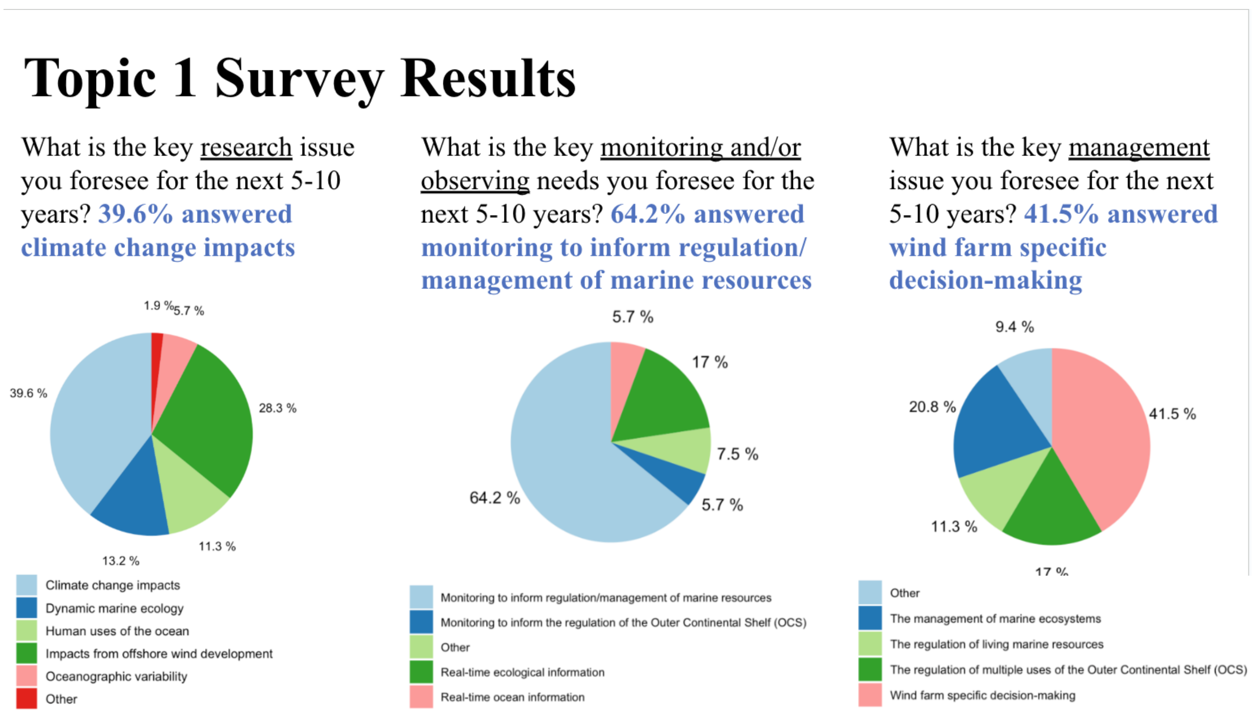


Figure B1. Results for key research, monitoring, and management priorities for the Mid-Atlantic Bight over the next 5–10 years.

Survey participants were also asked to rank candidate WEA monitoring objectives by importance on a scale from 1 (low importance) to 10 (high importance). The top four objectives identified were:

1. **Mitigating potential offshore wind impacts on protected species (Avg. 8.3).**
2. **Supporting environmental and ecological research (Avg. 8.2).**
3. **Mitigating potential offshore wind impacts on marine habitats and ecosystems, including coastal areas, oceanography, and the seafloor (Avg. 8.2).**
4. **Mitigating potential offshore wind impacts on marine mammals (Avg. 8.2).**

It is important to note that no candidate objective was rated below a 5, indicating that all objectives were considered to have at least some level of importance (Table B1). This suggests that, in addition to addressing the highest-priority objectives, a monitoring system should be multi-faceted and purpose-built to address as many objectives as possible.

Table B1 - Summary of rankings given by survey respondents (n = 48 to 52 depending on question) when asked to rate them by level of importance (0 was not rated, 1 for low importance and 10 for high importance).

Monitoring and Observing Objective	Average	Standard Deviation
Mitigate potential offshore wind impacts to protected species	8.3	1.8
Environmental and ecological research	8.2	1.9
Mitigate potential offshore wind impacts to marine habitats/ecosystems - coastal, oceanography, seafloor	8.2	2.1
Mitigate potential offshore wind impacts to marine mammals	8.2	1.8
Mitigate potential offshore wind impacts to birds and bats/collision, avoidance, or displacement	8.0	2.1
Management of coastal living resources	7.7	2.3
Mitigate potential offshore wind impacts to fishing industries/communities	7.7	2.3
Mitigate potential offshore wind impacts to sea turtles	7.6	2.2
Support regulatory processes	7.3	2.4
Mitigate potential offshore wind impacts to federal and state marine resource surveys	7.3	2.3
Real-time information for ocean community decision making	6.7	2.6
Technological innovation	6.4	2.4
Weather forecasting	6.1	2.8
Mitigate potential offshore wind impacts to coastal communities	5.9	2.3
National security	5.1	2.7

Stakeholder Discussions: Webinars and Symposium

Webinar Discussion Summaries (April 19, 2024 and May 31, 2024)

A webinar was held during the survey period to help clarify the survey's objectives and encourage participation. A follow-up webinar, held after the survey closed, provided an opportunity to discuss the results and obtain further input from stakeholders. Key themes emerged:

- **Long-term environmental change data need**: Participants emphasized the importance of distinguishing potential offshore wind energy impacts from impacts resulting from broader long-term environmental changes, including shifts in seasonal and interannual variability.
- **Monitoring versus mitigation**: A key distinction was made between monitoring (which could include short- or long-term observations or research) and mitigation (which requires specific action to lessen the intensity or duration of an impact). The discussion highlighted the importance of defining objectives clearly, because research-based monitoring provides ongoing information that can support mitigation planning, whereas mitigation is a response to specific impacts.
- **Survey focus and scope** - Participants acknowledged that the survey's focus on offshore wind energy farms would naturally emphasize concerns specifically related to offshore wind energy. However, they noted that ancillary topics like technology and weather might still be important to consider in the development of a regional environmental and ecological monitoring system.

RMI Symposium Discussion Summary (May 17, 2024)

The New Jersey Research and Monitoring Initiative for offshore wind RMI Symposium brought together scientists working on RMI research projects and provided a forum for discussions on data sharing and ways to leverage ongoing research related to offshore wind energy. At the event, the CFT presented initial stakeholder survey results and sought additional input from participants via a Q&A session. Below is a summary of the key discussion points.

Management of living marine resources: The discussion emphasized the need to broaden the considerations related to the management of living marine resources to include human communities and socio-ecological impacts.

- Ensuring socioeconomic impacts are accounted for in surveys and research.
- The role of weather forecasting in maritime safety.
- Better contextualization of whale population data, including estimating the percentage of animals struck by vessels and addressing the challenge of unseen or uncounted mortality.

Ecological and environmental research: Consistent with input from the survey and webinars, a primary concern was raised about the importance of noting the distinction between offshore wind energy specific impacts from the impacts of short-term variability and/or long-term changes in environmental conditions, recognizing that these influences are often intertwined and difficult to study in isolation. Key areas for research and additional observation included the following:

- Changes in wildlife behavior and movement, particularly in marine megafauna.
- The relationship between foraging behavior, diet composition, and offshore wind energy impacts.
- The effectiveness of foraging among species in the Mid-Atlantic Bight.
- The role of gelatinous zooplankton in marine food webs and how offshore wind energy development might influence prey availability.

Knowledge gaps and data needs: To effectively separate offshore wind energy impacts from short-term variability and/or long-term changes in environmental conditions, participants identified several critical data gaps:

- The need for long-term atmospheric, oceanographic, and biological monitoring across multiple trophic levels, rather than sporadic short-term sampling.
- Improved understanding of the "cold pool" phenomenon and whether wind turbine-driven mixing could increase nutrient availability in the water column.
- Assessing the cumulative impact of individual wind turbines versus large-scale offshore wind energy development, including identifying a potential tipping point where negative impacts outweigh positive ones.
- Expanding visual and acoustic data collection on marine megafauna, reducing reliance on modeling alone.
- Enhancing data integration efforts.

Chapter 2 Engagement: Recommended Sensors And Variables

To identify robust, multi-purpose sensors, the CFT team developed an instrumentation spreadsheet intended to crowdsource recommendations from a diverse range of stakeholders, including sensor and technology providers and observing experts. Additionally, input was gathered through thought experiment exercises at the 2024 NYSERDA State of MTS Mini TechSurge session.

RMI Ocean Instrument Specifications List

Leveraging the expertise of CFT members, a spreadsheet of potential ocean sensors and instrument specifications was developed and shared with stakeholders, with an invitation to expand the sensor inventory and refine parameter data. This spreadsheet outlined key variables, including observed parameters (e.g., surface currents, waves, temperature, conductivity) as well as spatial, temporal, and vertical resolution considerations. Additionally, it detailed instrument specifications such as power requirements, dimensions, weight, maintenance frequency, and recommended data portals.

State of the Science on Offshore Wind, MTS Mini TechSurge Session

As part of the July 2024 State of the Science conference hosted by the New York State Energy Research and Development Authority (NYSERDA) and in partnership with the RWSC, the Marine Technology Society (MTS) hosted a Mini TechSurge (MTS, 2024). CFT members attended and helped to facilitate a breakout session where industry experts, researchers, government representatives, and sensor and technology providers explored innovative ways to leverage offshore infrastructure for monitoring and addressed challenges in deploying and integrating sensors into offshore wind energy infrastructure. Appendix E highlights the breakout session worksheet and questions.

The CFT synthesized the input received from over 100 people at the Mini TechSurge session and the data provided on the spreadsheet by industry experts, researchers, government representatives, and sensor and technology providers. Three broad categories of parameters were identified as essential for achieving the monitoring system objectives outlined in Chapter 1. These parameters include monitoring the temporal and spatial variation of the physical, biological/optics, and chemical characteristics within the offshore wind farms and the region.

Chapter 3 Engagement: Deployment Strategies

This engagement effort was a critical step in ensuring the framework was grounded in the practical realities, technical expertise, and operational constraints faced by those directly involved in offshore wind energy development. Sensor and platform deployment, particularly when considering HSE factors, is a highly specialized area that requires deep technical knowledge and an understanding of real-world limitations. While general recommendations from the MTS Mini TechSurge were considered, the CFT targeted this engagement specifically toward stakeholders from OEMs and wind energy developers, whose insights were most relevant to this topic.

OEM/Developer Virtual Focus Group Webinar

On October 8th 2024, a virtual focus group was convened to provide input on the draft conceptual framework and observing requirements described in previous chapters. Over 25 attendees participated, the majority representing offshore wind energy developers and equipment manufacturers.

The focus group was provided with examples of environmental sensors used in the offshore environment and existing databases detailing specific sensor technologies. Prior to and during the virtual meeting, a series of brainstorming questions were posed to the group to stimulate discussion around the placement of ocean sensors on offshore wind energy infrastructure. The goal was to better understand the technical and practical barriers to accessing offshore wind farm infrastructure for sensor deployment. Example questions included:

- *What is the typical interaction between developers and turbine suppliers regarding sensor deployment—design, engineering, etc.?*
- *When in the design process would sensor inclusion be an opportunity step?*
- *Could there be a physical placeholder on turbines as a standard space for inclusion of sensors? Dedicated communications lines? Power supply?*
- *What are the biggest impediments and limiting factors to the implementation of this type of request?*

The complete list of questions posed to the group can be found in Appendix F.

As background, the group was also provided an overview of the RMI project and timeline, examples of environmental sensors used in the offshore environment, and a review of existing databases that provide more detail about specific sensor technologies.

Wind energy developers and wind turbine manufacturers provided valuable feedback during the meeting. Two main themes that emerged were:

1. The current lack of standardization in this area, in terms of sensor and data types, physical location on infrastructure, power requirements, data transfer, and related communications between wind energy developers and wind turbine suppliers.
2. The critical importance of planning ocean sensor inclusion as early in the process as possible, preferably in the wind turbine design stage, and well before the supplier procurement and regulatory review processes begin.

Chapter 4 Engagement: Data Quality And Management Standards

Input was taken from the MTS Mini TechSurge described in Chapters 2 and 3, and a Virtual Data Roundtable was organized to gain focused input from end users, data managers, and those with data governance expertise.

Virtual Data Roundtable

On December 11, 2024 the CFT hosted a Virtual Data Roundtable to engage those closely connected to the wind energy data group and the current efforts surrounding data governance. Participants included representatives from RPS, U.S. IOOS, RWSC, MARCO, MATOS, Intertidal Agency, ROSA, National Oceanic and Atmospheric Administration (NOAA), and the BOEM. As part of the event, the CFT developed a case study to guide a structured thought experiment, prompting participants to examine key challenges and opportunities in offshore wind energy data management and collaboration. For the full case study, see Appendix G.

Appendix C: RMI Ocean Observing Stakeholder Survey

Goal of This Survey: This survey is intended to gather your input to help define initial objectives of an environmental and ecological monitoring and observing system to be deployed within and around offshore wind farms. For the purposes of this survey, please consider sensors deployed on the offshore facilities (wind turbines and substations) as well as those deployed on adjacent platforms (buoys, autonomous platforms, etc.). This system could meet the monitoring needs set in federal and state guidelines, serve the needs of the offshore wind developers constructing the wind farms by monitoring environmental and ecological conditions during the planning, deployment, and operation, and serve the needs of other marine users utilizing the same ocean spaces. Through this survey, you can provide your input on the objectives of the monitoring and observing system. We expect this survey to take approximately 15 minutes to complete. Your input through this survey will help guide the development of a more comprehensive conceptual framework of a monitoring and observing system including configuration, operation, and data sharing. We also recognize that not everyone may feel they have the requisite expertise to answer every question; for this reason, no question on this survey is mandatory, and questions can be answered in full or in part, or left blank. Please submit your survey response on or before May 17, 2024.

Target Audience: Individuals that monitor, research, and manage resources, as well as communities in the coastal waters of the MidAtlantic Bight (MAB).

Target Geography: Questions are focused on the objectives for a monitoring and observation system within existing offshore wind lease areas throughout the MAB. If you have questions or need help with the survey, please email ecosystemdata@marine.rutgers.edu, subject "RMI Survey".

Name (optional)

____

Email address (optional, both name and email would be used for future webinars or surveys)

____

What best describes your affiliation?

- ○ Resource Manager
- ○ Academic Researcher
- ○ State Government
- ○ Federal Government

- ◯ Environmental NGO
- ◯ Offshore Wind Developer
- ◯ Consultant
- ◯ Marine Transportation
- ◯ Commercial and/or Recreational Fishing
- ◯ Other ____

How long have you been involved with monitoring, researching, and/or managing marine resources in the MAB?

- ◯ Not applicable
- ◯ less than 3 years
- ◯ 3-9 years
- ◯ 10-19 years
- ◯ 20+ years

1. What is the key research issue you foresee for the next 5-10 years?

- ◯ Oceanographic variability
- ◯ Dynamic marine ecology
- ◯ Human uses of the ocean
- ◯ Climate change impacts
- ◯ Impacts from offshore wind development

◯ Other ____

2. What is the key monitoring and/or observing needs you foresee for the next 5-10 years?

◯ Real-time ocean information

◯ Real-time ecological information

◯ Monitoring to inform regulation/management of marine resources

◯ Monitoring to inform the regulation of the Outer Continental Shelf (OCS)

◯ Other ____

3. What is the key management issue you are facing for the next 5-10 years?

◯ Wind farm specific decision-making

◯ The regulation of living marine resources

◯ The regulation of multiple uses of the Outer Continental Shelf (OCS)

◯ The management of marine ecosystems

◯ Other ____

4. What decision-making scenarios should the observing system be designed to support?

____

5. What are the most relevant monitoring and observing efforts that could incorporate the local capacity of a WEA observing system?

____

6.Rate the following WEA observing objectives by level of importance (0 is for not rated, 1 is for low importance, 10 is for very important)

0	1	2	3	4	5	6	7	8	9	10

Environmental and ecological research ()	
Management of coastal living resources ()	
Technology Innovation ()	
Real-time information for ocean community decision-making ()	
Support Regulatory Processes ()	
National Security ()	
Weather Forecasting ()	
Mitigate potential offshore wind impacts to Federal and State marine resource surveys ()	
Mitigate potential offshore wind impacts to Marine Habitats/Ecosystems - coastal, oceanography, seafloor ()	
Mitigate potential offshore wind impacts to Coastal Communities ()	
Mitigate potential offshore wind impacts to Fishing Industries/Communities ()	
Mitigate potential offshore wind impacts to Marine Mammals ()	
Mitigate potential offshore wind impacts to Protected Species ()	
Mitigate potential offshore wind impacts to Sea Turtles ()	
Mitigate potential offshore wind impacts to Birds and Bats/Collision, Avoidance, or Displacement ()	
Other ()	

7. Where are the largest data gaps in monitoring and observing data in the MAB?

____

8. What are the biggest concerns with observing and monitoring data availability? Check all that apply.

- [ ] Not enough data on different topics
- [ ] Data are not taken with enough frequency
- [ ] Data are hard to find /unavailable
- [ ] Data are in too many different places
- [ ] Data are proprietary
- [ ] Confidence in historical data
- [ ] Lack of data standards and/or guidance
- [ ] Lack of governance models for data repositories
- [ ] Other ____

9. Are you engaged with any organized groups discussing environmental and ecological monitoring systems in offshore wind energy areas? If so, which? (can select more than one)

- [ ] I have not been part of any organized group discussions

- [ ] I have only discussed this with colleagues in my organization

- [ ] Regional Wildlife Science Collaborative for Offshore Wind (RWSC)

- [ ] Regional Offshore Science Alliance (ROSA)

- [ ] NYSERDA Environmental Technical Working Group (E-TWG)

- [ ] Mid Atlantic Regional Association Coastal Ocean Observing System (MARACOOS) & Northeast Regional Association Coastal Ocean Observing System (/NERACOOS)

- [ ] Mid Atlantic Regional Council on the Ocean (MARCO) or Northeast Regional Ocean Council (NROC)

- [ ] Federal, state, or interagency work group

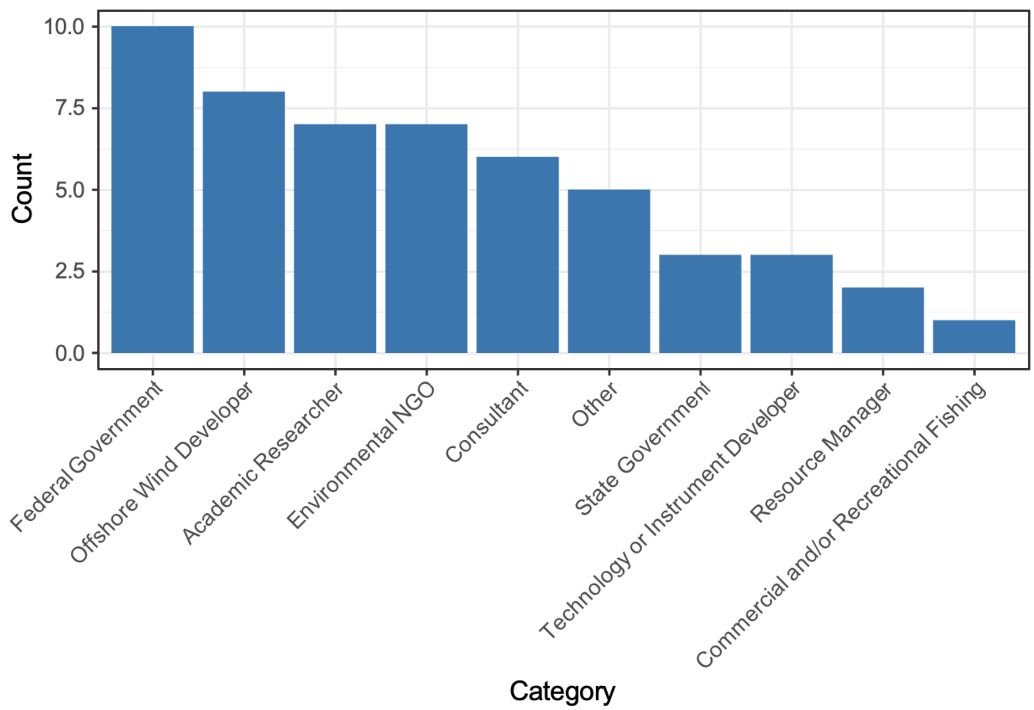
- [ ] Nongovernmental Organization(s)

- [ ] Other ____

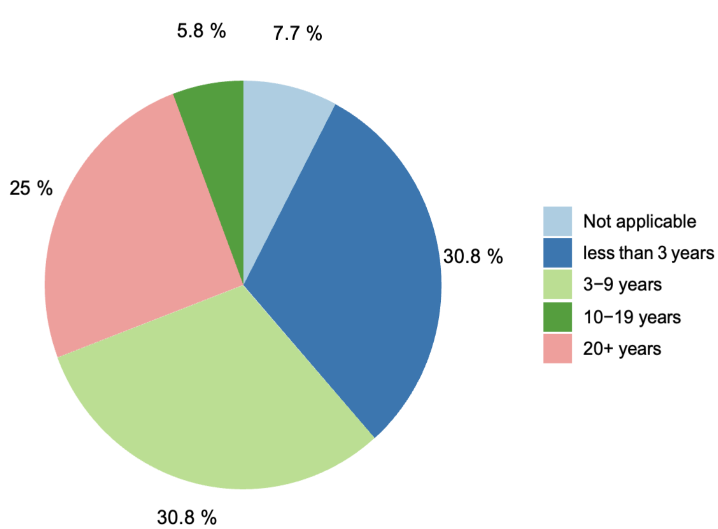
Appendix D: RMI Ocean Observing Stakeholder Survey Results

Qualtrics was used to conduct the survey. The survey was open for 36 days: April 19, 2024 to May 24, 2024. Below are the survey questions and responses.

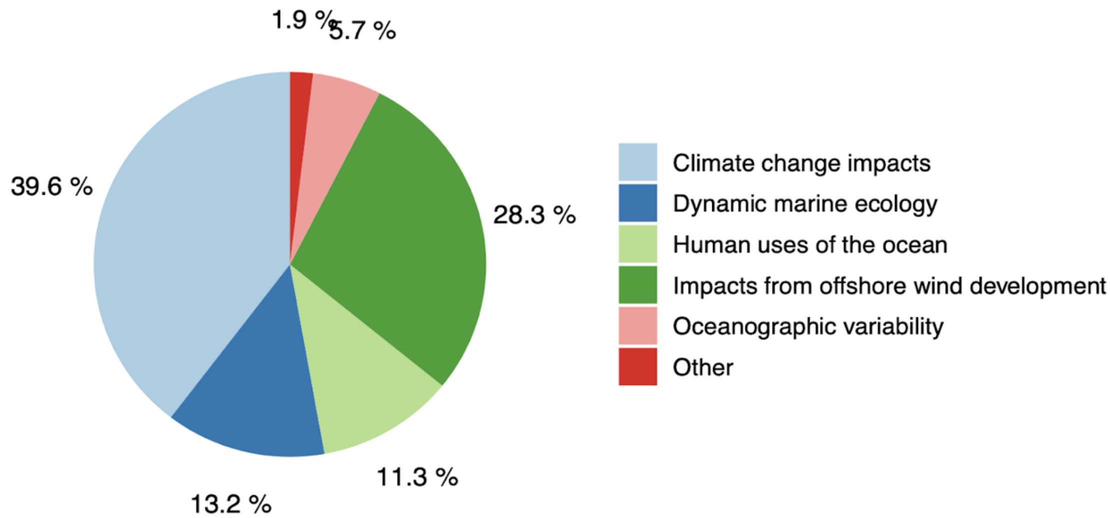
What best describes your affiliation?



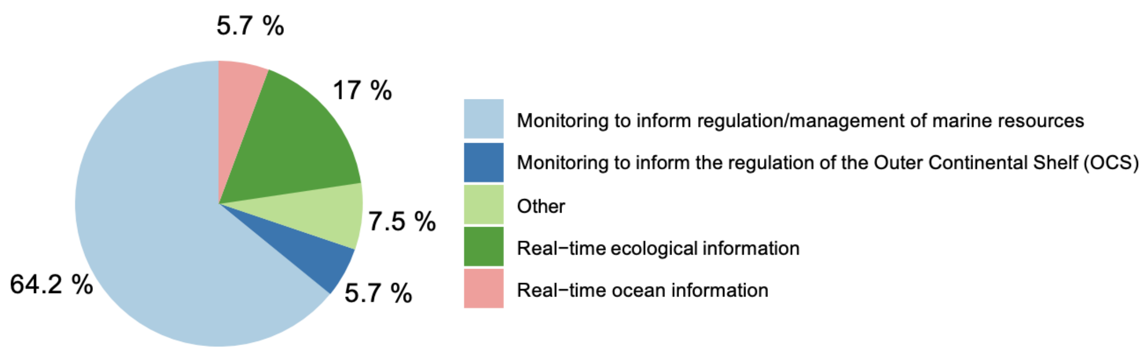
How long have you been involved with monitoring, researching, and/or managing marine resources in the Mid-Atlantic Bight?



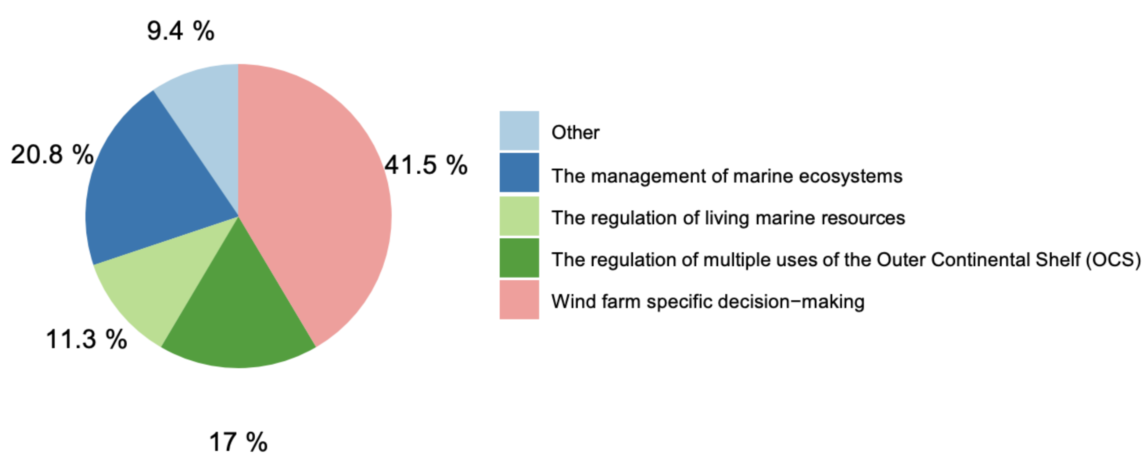
What is the key research issue you foresee for the next 5-10 years?



What is the key monitoring and/or observing issue you foresee for the next 5-10 years?

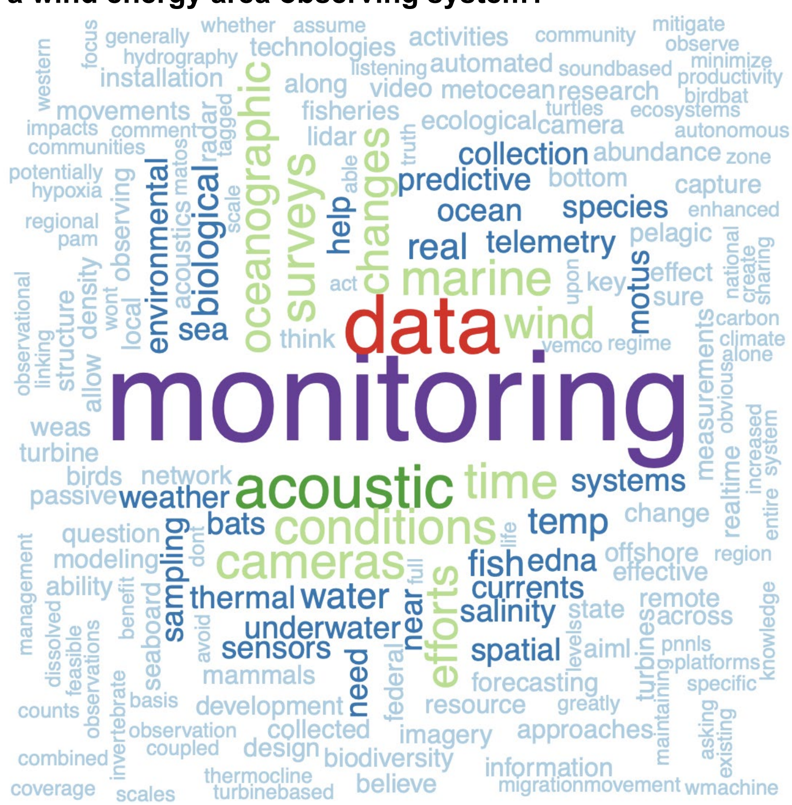


What is the key management issue you foresee for the next 5-10 years?



What decision-making scenarios should the observing system be designed to support?

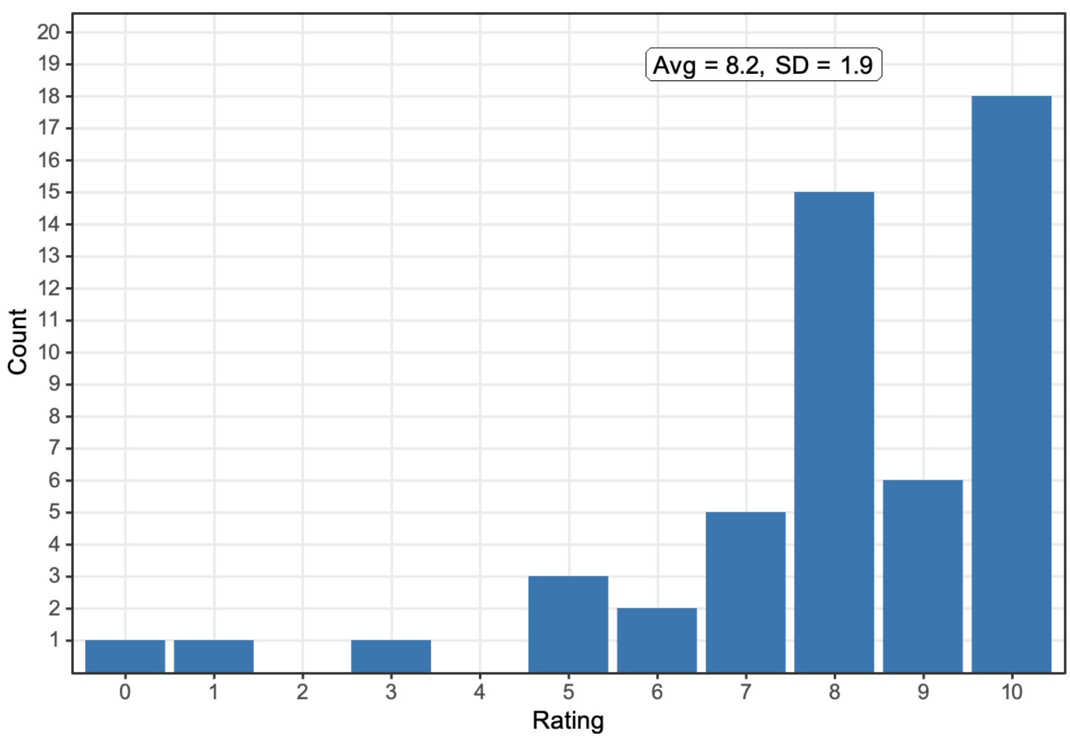
What are the most relevant monitoring and observing efforts that could incorporate the local capacity of a wind energy area observing system?



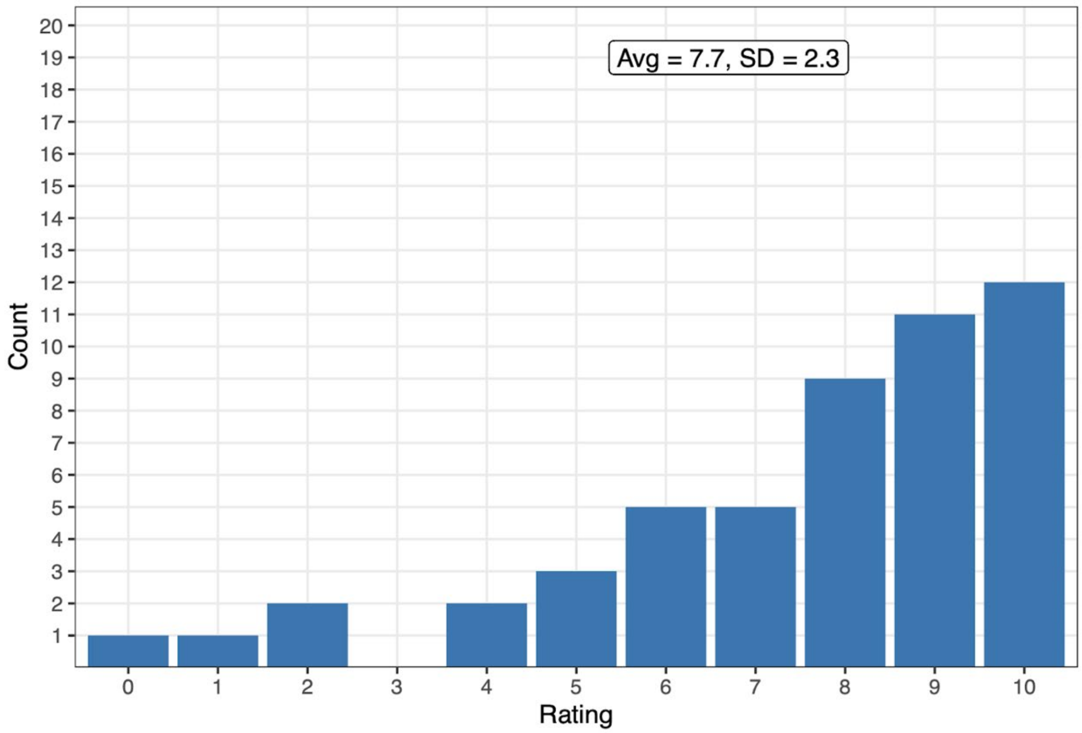
Summary table of rankings

	Average	Standard Deviation
Mitigate potential offshore wind impacts to protected species	8.3	1.8
Environmental and ecological research	8.2	1.9
Mitigate potential offshore wind impacts to marine habitats/ecosystems - coastal, oceanography, seafloor	8.2	2.1
Mitigate potential offshore wind impacts to marine mammals	8.2	1.8
Mitigate potential offshore wind impacts to birds and bats/collision, avoidance, or displacement	8.0	2.1
Management of coastal living resources	7.7	2.3
Mitigate postential offshore wind impacts to fishing industries/communities	7.7	2.3
Mitigate potential offshore wind impacts to sea turtles	7.6	2.2
Support regulatory processes	7.3	2.4
Mitigate potential offshore wind impacts to federal and state marine resource surveys	7.3	2.3
Real-time information for ocean community decision making	6.7	2.6
Technological innovation	6.4	2.4
Weather forecasting	6.1	2.8
Mitigate potential offshore wind impacts to coastal communities	5.9	2.3
National security	5.1	2.7

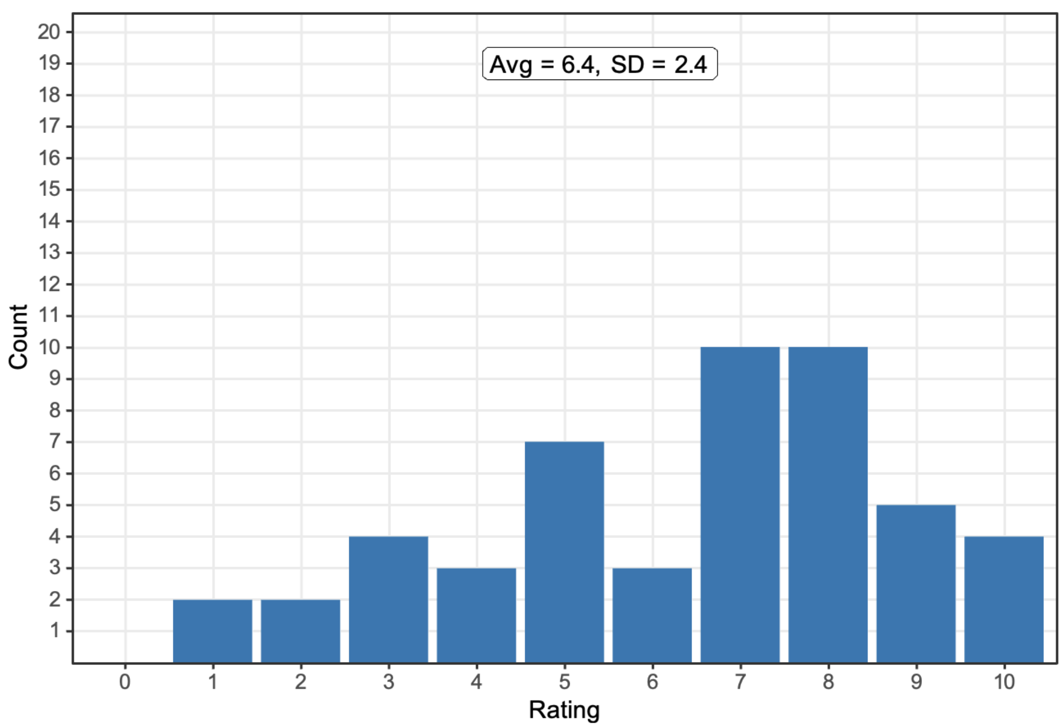
Environmental and ecological research



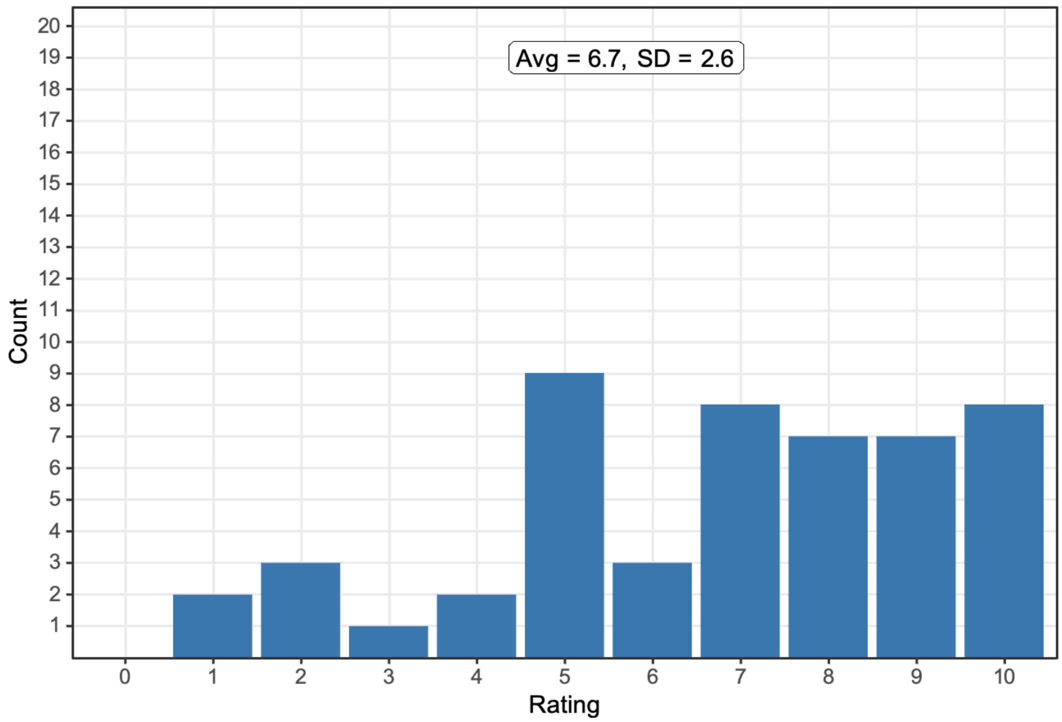
Management of coastal living resources



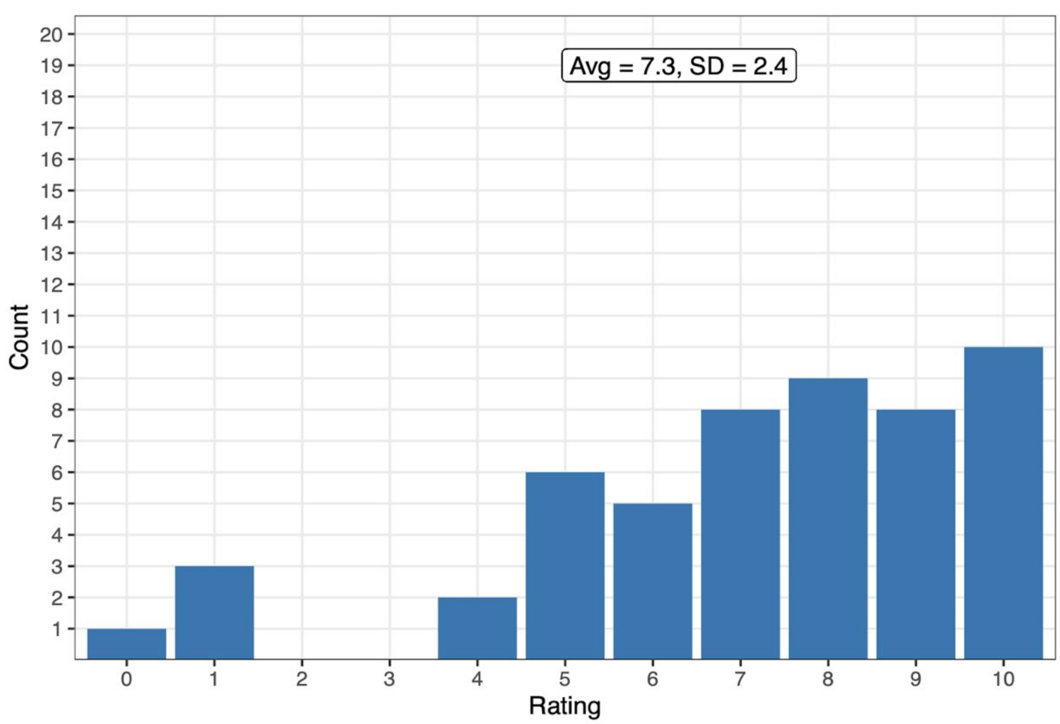
Technological innovation



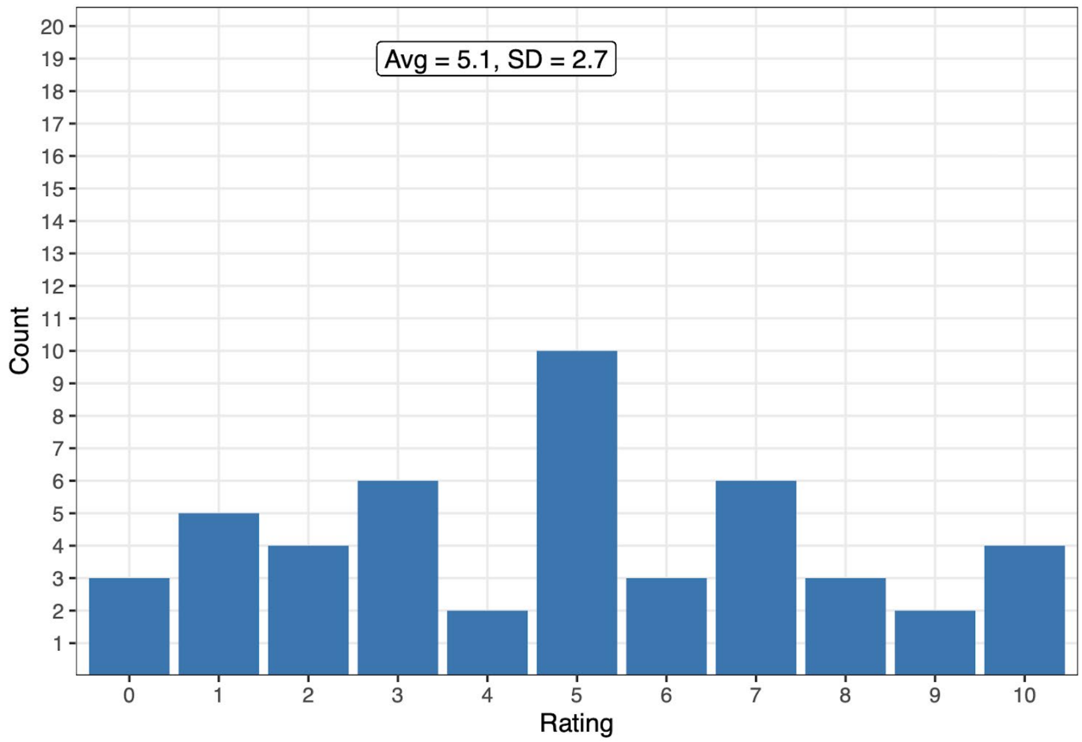
Real-time information for ocean community decision making



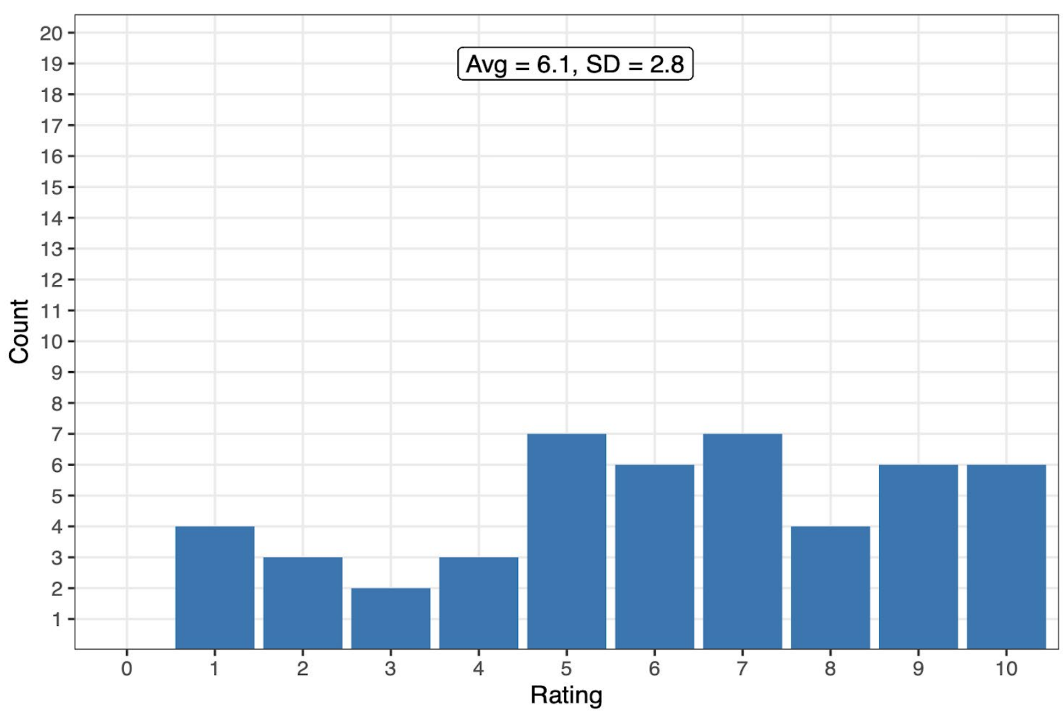
Support regulatory processes



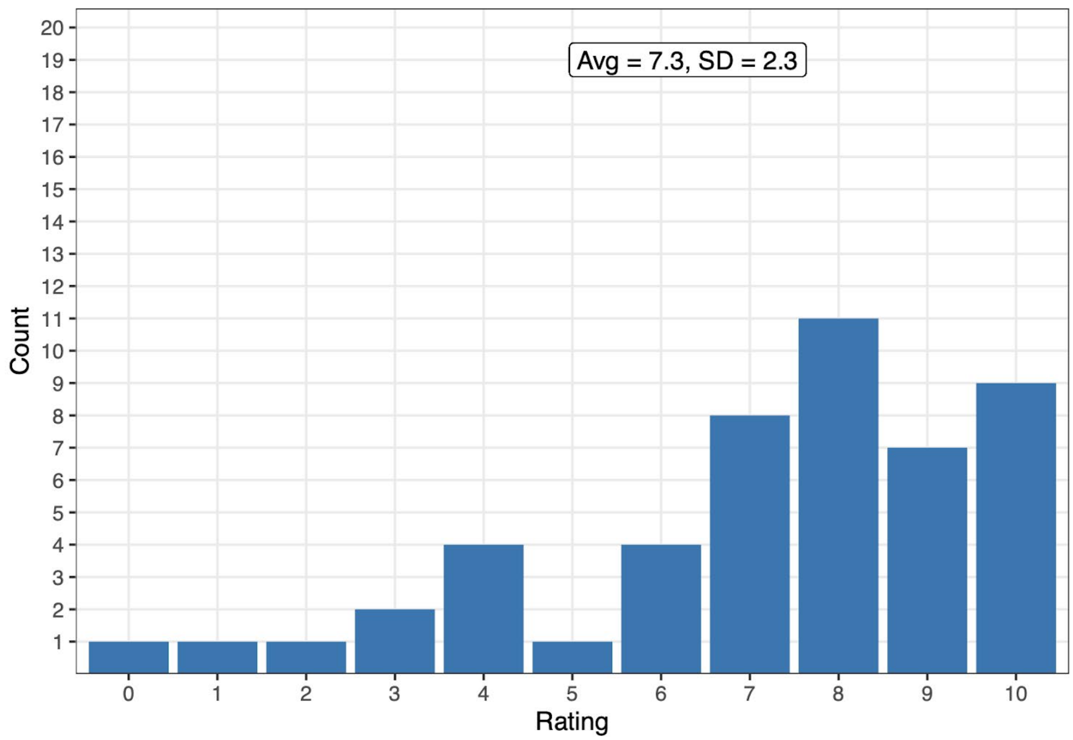
National security



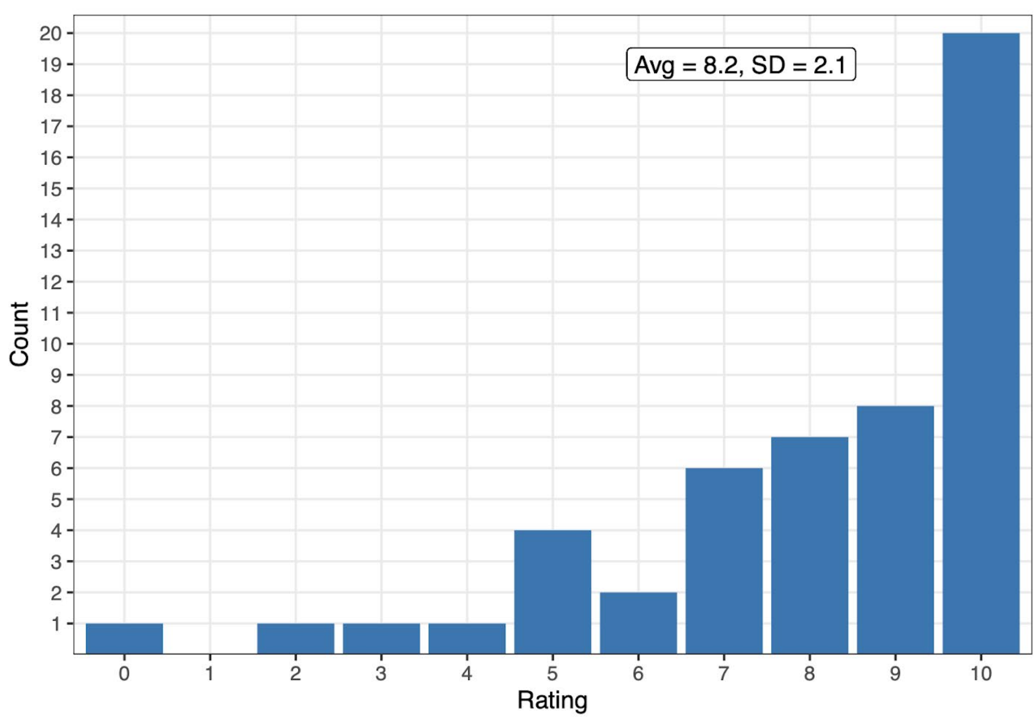
Weather forecasting



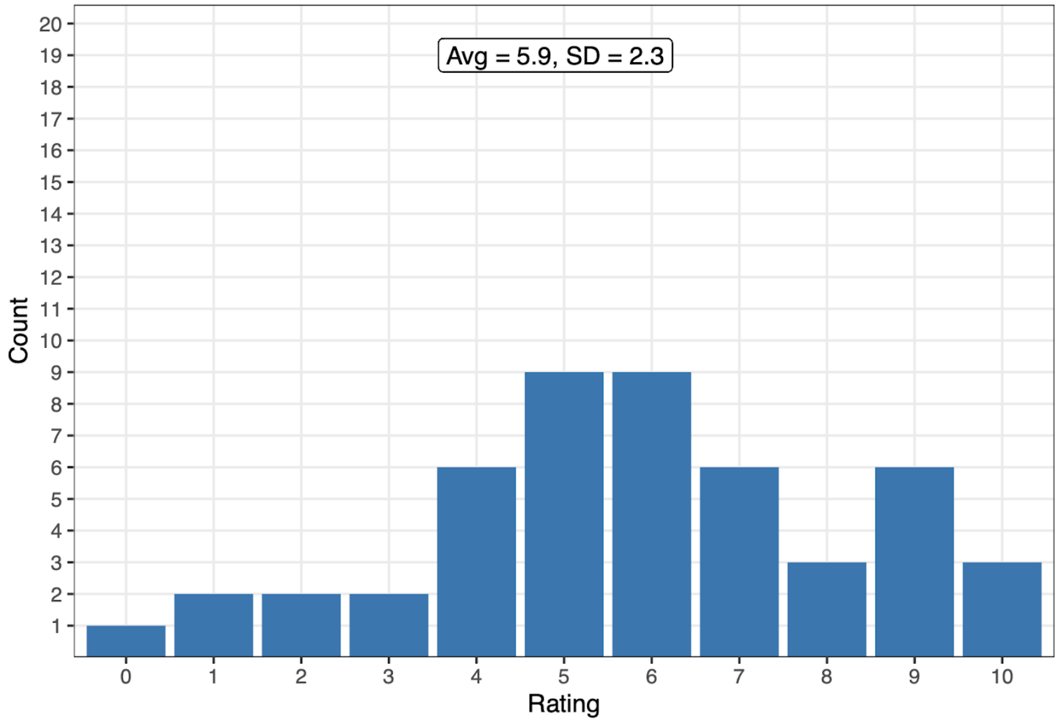
Mitigate potential offshore wind impacts to federal and state marine resource surveys



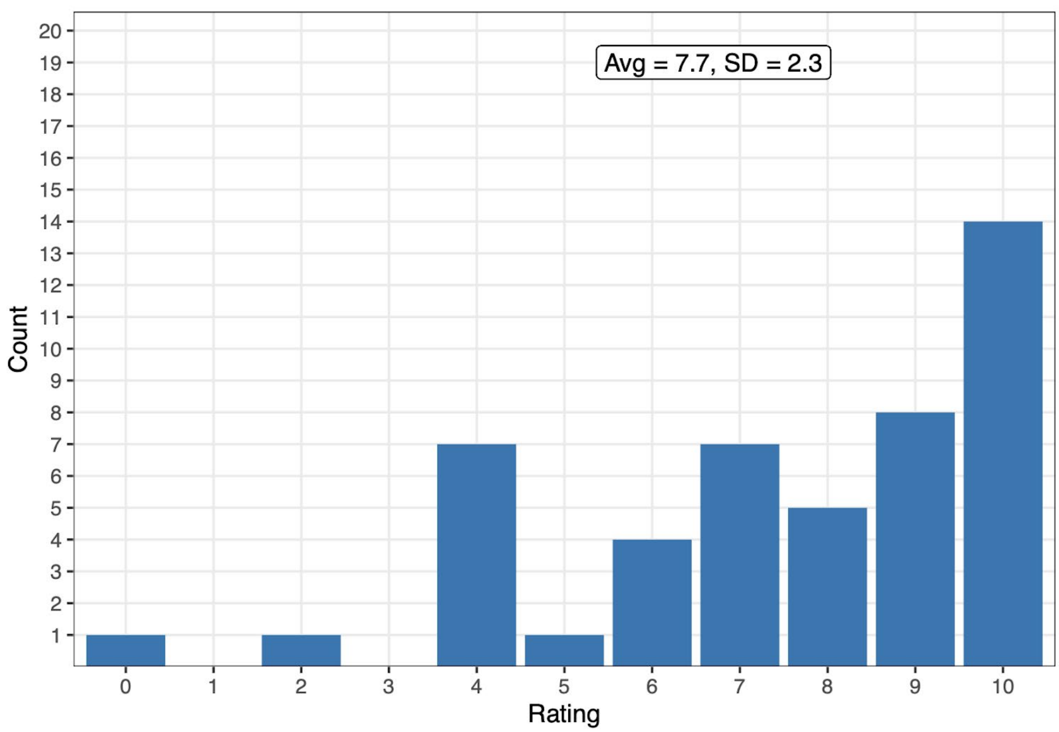
Mitigate potential offshore wind impacts to marine habitats/ecosystems - costal, oceanography, seafloor



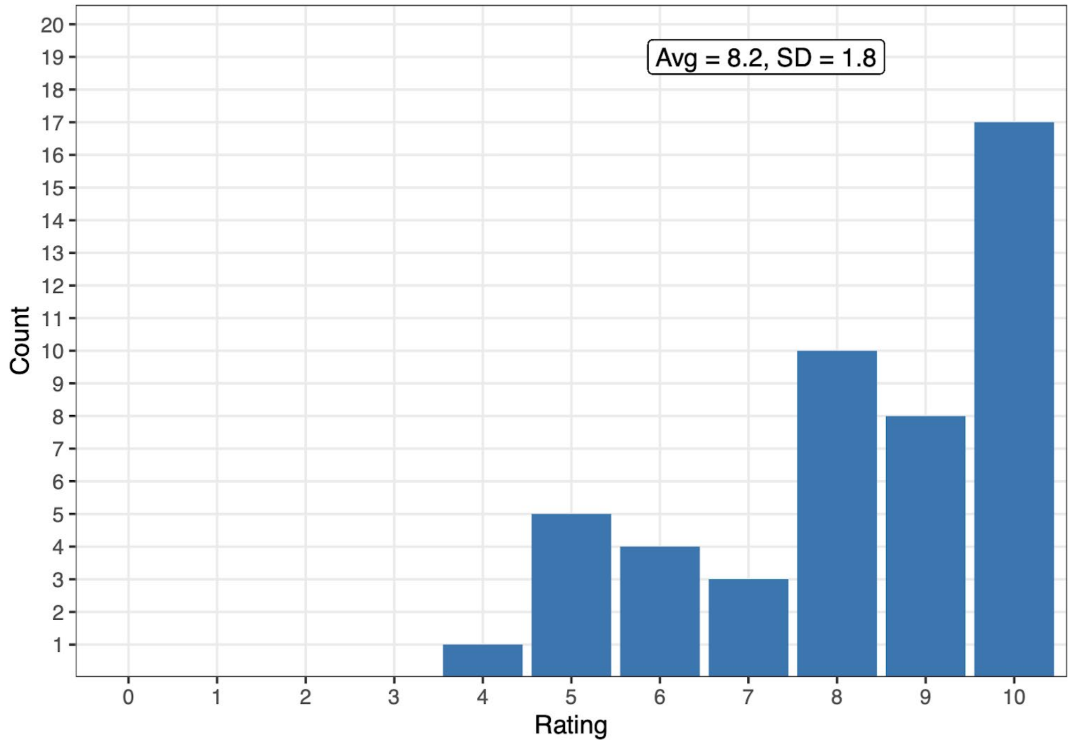
Mitigate potential offshore wind impacts to coastal communities



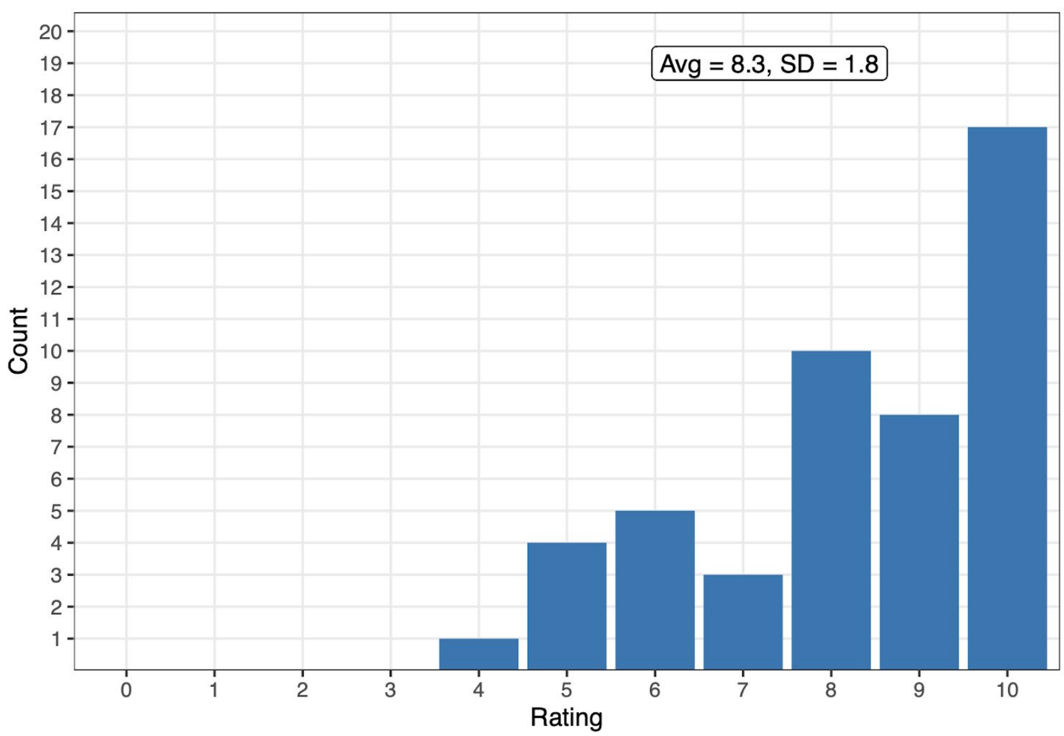
Mitigate potential offshore wind impacts to fishing industries/communities



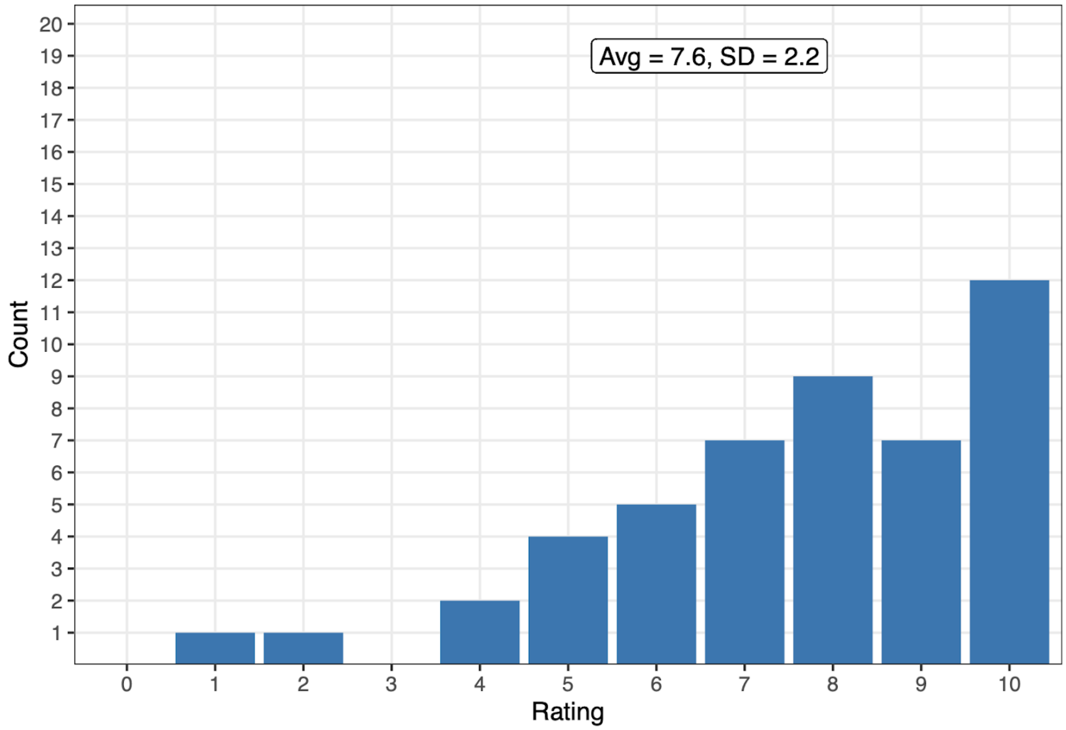
Mitigate potential offshore wind impacts to marine mammals



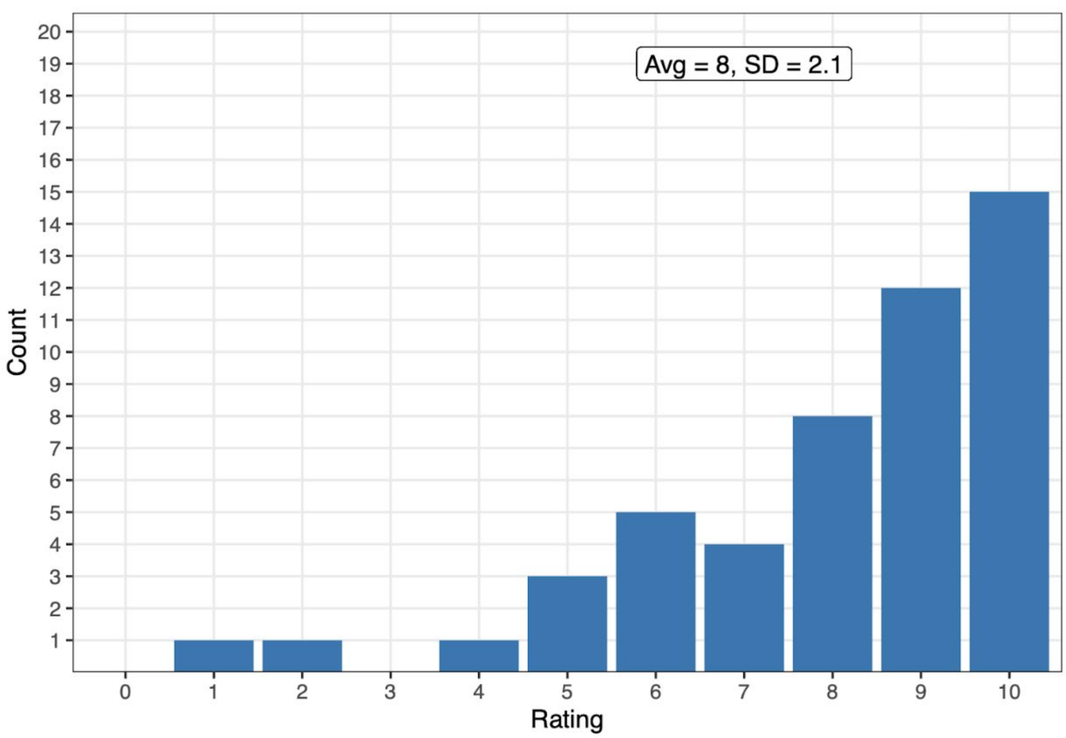
Mitigate potential offshore wind impacts to protected species



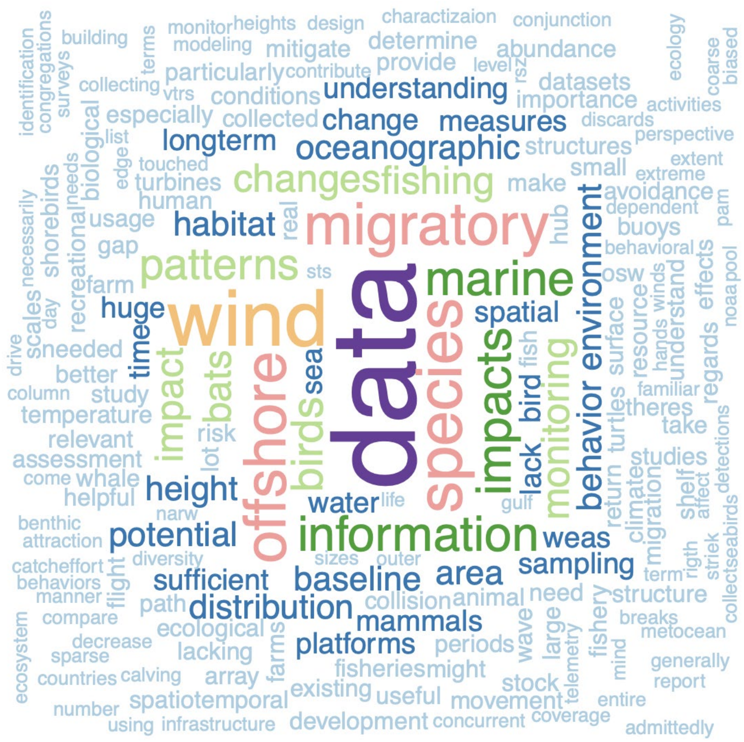
Mitigate potential offshore wind impacts to sea turtles



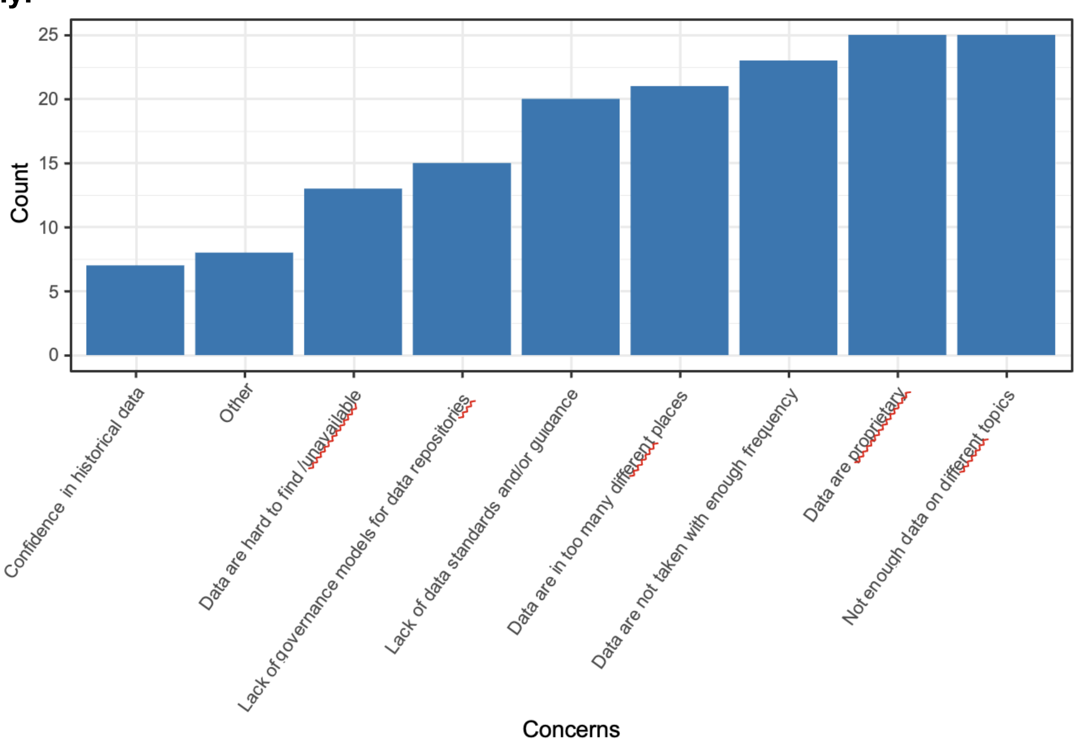
Mitigate potential offshore wind impacts to birds and bats/collision, avoidance, or displacement



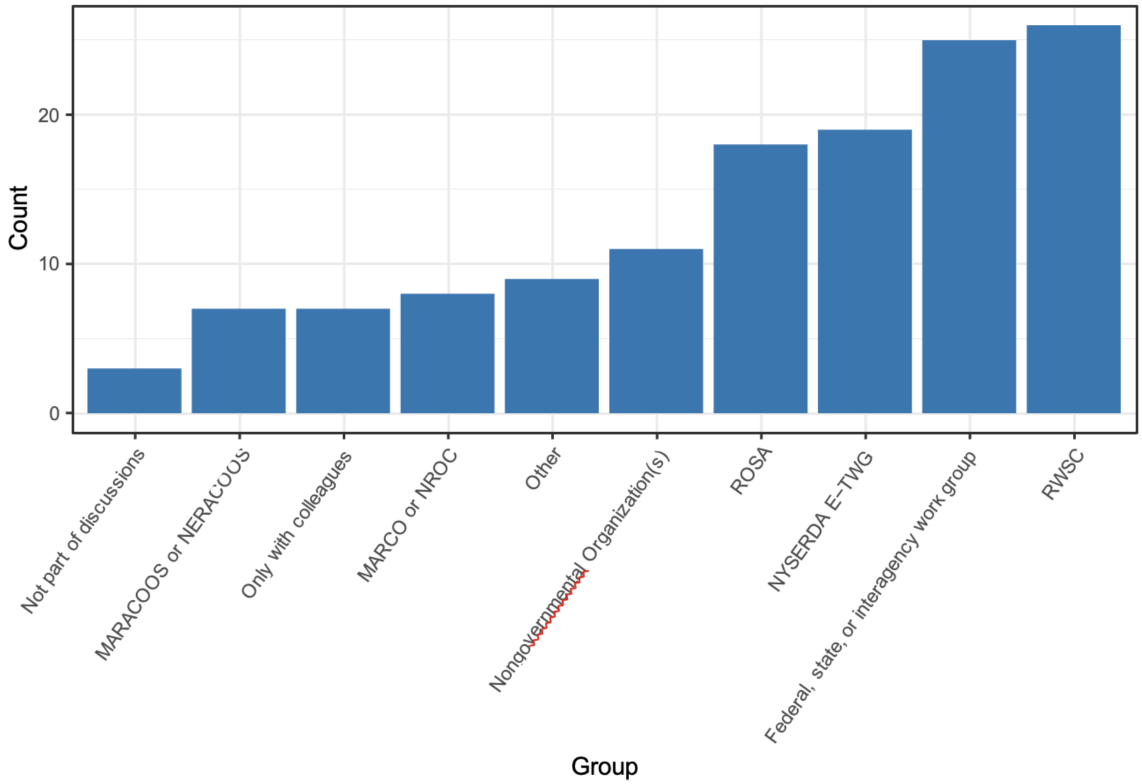
Where are the largest data gaps in monitoring and observing data in the Mid-Atlantic Bight?



What are the biggest concerns with observing and monitoring data availability? Check all that apply.



Are you engaged with any organized groups discussing environ- mental and ecological monitoring systems in offshore wind energy areas? Can select more than one.



Appendix E: Mini TechSurge Breakout Session Worksheet

Mini TechSurge: Advancing Collaboration and Inspiring Innovation for Offshore Wind Monitoring and Mitigation | Website
NYSERDA State of Science Meeting | Stony Brook University
July 18, 2024 | 1:30 – 5:15 PM | Ballroom

MTS marine technology society Opportunity runs deep
RWSC Regional Wildlife Science Collaborative for Offshore Wind

Breakout Session Worksheet

Purpose: Participants will engage in discussions to pinpoint specific bottlenecks, assess the adequacy of data collection and sensor deployment, and explore technological and partnership solutions for enhancing workflow.

Topics:

- Science & Monitoring - Anticipated data needs for research, potential impact assessment, and mitigation
- Technology - Current capabilities and potential applications of future innovation

Sticker Color	Facilitator
Green	Facilitator 1: Ruth Perry
Blue	Facilitator 2: Emily Shumchenia
Red	Facilitator 3: Josh Kohut
Yellow	Facilitator 4: Joe Brodie

Breakout Session 1

Participants will be divided into four groups, each identified by colored stickers: green stickers with Facilitator 1, blue stickers with Facilitator 2, red stickers with Facilitator 3, and yellow stickers with Facilitator 4. In Session 1, attendees will move to their designated areas based on their color sticker. They will discuss the questions under the guidance of their assigned facilitator, addressing Science & Monitoring and Technology perspectives. Attendees will be randomly distributed. Facilitators will ensure that all questions are addressed and encourage active participation.

Data and Sensor Deployment (15 minutes)

- What specific types of data and real-time monitoring sensors/platforms can be utilized for real-time decision-making and monitoring, and what are the optimal deployment methods, locations, and technological innovations needed to address challenges like local data storage and transmission?

Future Data Needs (15 minutes)

- What data requirements and technological advancements are anticipated for offshore wind ecological impact research and monitoring over the next two years?

Identifying Roadblocks and Solutions (15 minutes)

- What are the current bottlenecks in science interpretation workflows, and what technological advancements are needed to address these challenges?

Session 2

For session 2, facilitators and notetakers will switch groups with their flipchart: Facilitator 1 will move to the group initially with Facilitator 2, Facilitator 2 will move to the group initially with Facilitator 3, and so on. This ensures comprehensive capture of discussions.

- Green stickers with Facilitator 4: Joe Brodie
- Blue stickers with Facilitator 1: Ruth Perry
- Red stickers with Facilitator 2: Emily Shumchenia
- Yellow stickers with Facilitator 3: Josh Kohut

1

Appendix F: OEM/Developer Virtual Focus Group Discussion Questions

On October 8, 2024, a virtual focus group was convened to provide feedback on the draft NJ RMI Observing and Monitoring Framework. Over 25 attendees participated, the majority representing offshore wind energy developers and equipment manufacturers. The goals of the meeting were to:

1. Better understand the technical and practical barriers to accessing offshore wind farm infrastructure for placement of ocean sensors
2. Define an initial strategy for inclusion in the conceptual framework, a final project deliverable to NJBPU.

Prior to, and during, the virtual meeting, the following series of brainstorming questions were posed to the group to stimulate discussion around the placement of ocean sensors on offshore wind infrastructure.

- What is the typical interaction between developers and turbine suppliers regarding sensor deployment—design, engineering, etc.?
- When in the design process would sensor inclusion be an opportunity step?
- Discuss the dynamic between regulators recommending versus requiring sensors.
- Could there be a physical placeholder on turbines as a standard space for inclusion of sensors? Dedicated communications lines? Power supply?
- What are the biggest impediments and limiting factors to the implementation of this type of request?
- Is it preferable to have a baseline required/recommended set of sensors for all East Coast projects? Or to require on a project-by-project basis?
- Other areas for discussion: legal, HSE, logistics, etc.

Appendix G: Data Round Table Thought Experiment: Building a Data Framework for Jersey Breeze Offshore Wind

Farm <u>Scenario:</u>

You are an advisor for Jersey Breeze, a fictional offshore wind farm investing in advanced underwater sensors for ecological and environmental monitoring within their lease area off the coast of New Jersey. You are tasked with designing a comprehensive framework for data quality and management standards that ensure the data are Findable, Accessible, Interoperable, and Reusable (FAIR).

<u>Guiding Question:</u>

➢ What steps should Jersey Breeze take to ensure they are incorporating best practices for management of the project generated data?

- Case 1: A data repository currently exists
- Case 2: A data repository does not exist

Jersey Breeze Data Framework:
a Pathway for Data Sharing

As part of the framework, you develop a "Pathway for Data Sharing", which is a roadmap of the who, what, where, when, and how of data management; including, quality control, access, key players, roles, responsibilities, and decision points along the path. Below is a first draft of the Pathway you are developing.

Guiding Questions:

➢ What aspects of data management are missing from the categories considered in the Pathway for Data Sharing?

➢ How would you **edit, expand, and improve** on the below draft?

<u>Key Players:</u>
What entities are key players in this space?

- RWSC
- BOEM
- NCCOS
- IOOS
- ROSA

- **OTHER (Please Specify)**

Roles and Responsibilities:
What are the roles and responsibilities of the different key players?

- Data transfer
- Data Management
- Funding
- Users
- QA/QC
- **OTHER (Please Specify)**

Guidance and Best Practices:
What existing frameworks can be consulted?

- **NCCOS/BOEM Workshops** - identifying data needs and implementing best practices in data collection and processing.
- **RWSC** https://rwsc.org/research-data/ - Recommendations for regional coordination, data management, standardization, and sharing by data type.
- **ROSA** FishFORWRD is a catalog of all East Coast research, monitoring efforts, and stated research needs for offshore wind, fish, and fisheries. https://www.rosascience.org/fishforwrd/
- **OTHER (Please Specify)**

Key Decision Points Along the Path:
The who, what, where, when, and how of assuring data are Findable, Accessible, Interoperable, and Reusable (FAIR). This ensures that it is possible to find data, gain access to them, that data are comparable across wind energy farms, and it is possible to reuse data for different analyses.

1. **Data Standards:**
    - Clear standards for data sets and integration.
    - Compatibility across platforms and organizations.

2. **Data Accessibility:**
    - Key data sets and sharing opportunities.

3. **Data Transparency:**
    - Transparency policies and mechanisms to ensure policy adherence.

4. **Data Sensitivity:**
    - Approval process for sharing sensitive data.
    - Balancing accessibility with privacy concerns.

5. **Data Repositories:**
    - Repository depth and storage limitations.
    - Long-term data preservation needs.

6. Data Security:

○ Security measures necessary to protect data while ensuring accessibility. ○ Guidelines to mitigate cyber risks.

7. Funding:

○ Funding opportunities to support data consistency and interoperability.

8. User Engagement:

○ Outreach strategies to ensure existing data is fully utilized.

9. Other Resources and Partnerships