Responsible Practices for Regional Wildlife Monitoring and Research in Relation to Offshore Wind Energy Development

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"Flying gull with offshore wind turbines in the background." Marcin Rogozinski/Shutterstock.

Disclaimer

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Contents

1.0 Executive Summary

Offshore wind energy (OSW) development activities are expanding rapidly in the eastern U.S. and regional coordination of environmental research efforts is needed to improve our understanding of OSW effects on wildlife populations and marine ecosystems. To address this need, in 2021 the Offshore Wind Environmental Technical Working Group (E-TWG) formed the Regional Synthesis Workgroup, comprised of subject matter experts, to develop recommendations for regional environmental research and monitoring related to OSW development. The Regional Synthesis Workgroup, in turn, recognized that research and monitoring efforts at multiple spatial and temporal scales can contribute to a broader understanding of the environmental effects and impacts of OSW development. Thus, the group focused on **recommendations for addressing research questions that: a) require data from a larger geographic scope than that of a single wind farm site, b) focus on methodological needs and/or implementation of mitigation to inform environmental research, risk assessments, and adaptive management decisions, and c) contribute to a mechanistic understanding of ecosystem processes, even if such studies are conducted at small spatial scales.**

The two main products from the Regional Synthesis Workgroup include:

1. **A database that compiles and synthesizes previously identified research needs related to wildlife and environmental effects of OSW energy development for the U.S. Atlantic (available at https://tethys.pnnl.gov/atlantic-offshore-wind-environmental-research-recommendations), and**
2. **High-level recommendations on how to design, implement, and communicate regional research and monitoring efforts (this document).**

Potential end users of these products include state and federal government entities, OSW developers, academics and other researchers, and groups such as the Regional Wildlife Science Collaborative (RWSC) and Responsible Offshore Science Alliance (ROSA) that are funding and/or conducting regional research to inform our understanding of the effects of OSW development on wildlife and ecosystems.

This document defines the rationale and need for regional research and monitoring (Section 2), provides background information about the Regional Synthesis Workgroup effort (Section 3), provides clarity in language around research and monitoring and OSW effects terminology (Section 4), aids in the identification of key data gaps and research needs for regional research (Section 5), identifies common considerations to help prioritize future research (Section 6), defines key components of a research framework, including study design and methodology considerations (Section 7), and provides recommendations on effective collaboration, communication, data consistency, and data transparency for regional-scale research and monitoring efforts (Section 8).

To help foster clarity of purpose and mutual understanding, there is great value in the development of a common language. This document defines *research* as any type of hypothesis-driven scientific study that improves our understanding of populations and ecosystems, and/or our ability to measure or manage these systems; this understanding may be general or in relation to the effects of OSW development. *Monitoring* (unless it is for the sole purpose of mitigation, such as the use of Protected Species Observers) is a subset of research that involves collection of repeated, systematic observations. As such, we recommend that monitoring should always be aimed at answering research questions and testing scientific hypotheses. There is also value in clearly defining a conceptual model that describes the factors contributing to effects from offshore wind energy (OSW) development on wildlife and marine ecosystems, and in clear definitions and consistent use of terms such as *receptor*, *risk*, *effect*, and *impact*.

A variety of research needs and data gaps have been identified for the offshore wind industry in recent years, many of them regional in scope. As part of workgroup efforts, these needs were compiled and synthesized into a single database to help inform the direction of future research and funding efforts. **The U.S. Atlantic Environmental Research Recommendations Database, hosted on Tethys (https://tethys.pnnl.gov/atlantic-offshore-wind-environmental-research-recommendations) allows researchers and funders to easily access, sort, and prioritize research needs relevant to understanding the effects and impacts of OSW energy development of wildlife and ecosystems.** It compiles and synthesizes research and monitoring needs and recommendations identified in a range of source documents published between 2015-2021 that are relevant to OSW and environmental research in the U.S. Atlantic. A synthesized list of 219 research recommendations is included in the database, representing a broad range of topics.

While the database does not prioritize among these data gaps and research needs, it is recommended that prioritization processes consider several aspects of potential research projects, including importance/urgency of need, achievability, and efficiency and innovation. Once regional research needs have been identified and prioritized, the design and methodologies employed in regional studies must be carefully considered to ensure they can effectively answer ecological questions of interest. Regional research efforts should have a clearly defined research plan that delineates how the proposed work will allow for a better understanding of population- or ecosystem-level effects and cumulative impacts from OSW energy development. Research plans should build from existing efforts where possible, including monitoring at the OSW site level. **Regional study plans should clearly delineate: 1) a conceptual framework, 2) study objectives, research questions and testable hypotheses, 3) a study design, data collection methods, projected samples sizes/treatment units, and analytical approaches, 4) data sharing and coordination plans, and 5) a process for evaluating effectiveness and validity of results.**

Effective planning and implementation of regional OSW research requires a degree of collaboration that may be unfamiliar to both academic researchers and OSW industry professionals. This collaboration should include, at minimum, consultation and/or cross-referencing with regional expertise including regional research entities, such as ROSA and the RWSC, and may also include more formal engagement of experts as collaborators or project investigators. Further, **collection and archiving of data should be conducted in as standardized and transparent a manner as possible, following existing standards and protocols, to help ensure that results are accessible and can be used to inform future regional and site-specific research efforts.**

2.0 Rationale for Regional Research and Monitoring

Offshore wind energy (OSW) development is a rapidly growing industry in the eastern United States. To inform our understanding of wildlife[1] populations and ecosystems, and to be able to detect changes in these systems from OSW development, research is being conducted at a range of spatial and temporal scales, and further such regional-scale research is needed to complement site-specific monitoring of lease areas as mandated by the OSW regulatory process. Coordination of these regional efforts would benefit our understanding of OSW effects, particularly around the potential consequences and cumulative impacts of these effects on wildlife populations and could help inform mitigation and adaptive management decisions. Several efforts to identify OSW energy and wildlife research needs and data gaps have occurred in recent years, including 2020 State of the Science workgroup efforts[2] (Carpenter et al. 2021, Cook et al. 2021, Degraer et al. 2021, Gitschlag et al. 2021, Hein et al. 2021, Popper et al. 2021, Southall et al. 2021, Gulka et al. 2022), scientific research framework development efforts for marine mammals and sea turtles (Kraus et al. 2019) and birds and bats (NYSERDA 2020) and various federal and state agency efforts (e.g., NYSERDA 2015, New Jersey Department of Environmental Protection 2021, State of Maine 2021, Kershaw et al. 2023). However, these research needs and data gaps are in disparate documents and may vary in scale, level of detail, and end goals.

Synthesis of research questions and data gaps, and development of guidance for studies that require regional-scale efforts, will help to inform funding allocations, encourage coordination among researchers, increase efficiency and reduce duplication of effort, and help ensure regional research and monitoring for OSW is conducted in a scientifically robust way. Several states require OSW developers to fund regional monitoring and research (e.g., as described in offshore wind procurements in 2020 and 2022 by New York[3], in 2020 and 2023 by New Jersey[4], and in 2023 by Massachusetts[5]). A range of regional research and monitoring activities are also expected to be initiated or continued due to the formation of the Regional Wildlife Science Collaborative for Offshore Wind (RWSC) and the Responsible Offshore Science Alliance (ROSA), which facilitate coordination of regional research/monitoring of wildlife and fisheries, respectively. The Regional Synthesis Workgroup's efforts are designed to support ongoing efforts by these regional entities, including the development of the RWSC Integrated Science Plan for Wildlife, Habitat, and Offshore Wind Energy in the U.S., and builds from ROSA's Offshore Wind Project Monitoring Framework and Guidelines (ROSA 2021). Identification of recommended practices for regional studies will help to guide consistent, sound science for the funding and implementation of these efforts.

3.0 Background and Purpose

The Offshore Wind Environmental Technical Working Group (E-TWG)[3] is an independent advisory body to the State of New York with a regional focus on OSW and wildlife issues from Maine to North Carolina. In

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[1] Wildlife in this context is defined as native flora and fauna of the region, including marine mammals, sea turtles, birds, bats, fishes, and invertebrates, as well as their habitat, including benthic habitat and environmental, oceanographic, and atmospheric conditions.

[2] 2020 State of the Science Workgroup Reports available at: https://www.nyetwg.com/2020-workgroups

[3] More information of New York Offshore Wind Solicitations at: https://www.nyserda.ny.gov/All-Programs/Offshore-Wind/Focus-Areas/Offshore-Wind-Solicitations

[4] More information on New Jersey Offshore Wind Solicitations at: https://www.njcleanenergy.com/renewable-energy/programs/nj-offshore-wind/solicitations

[5] More information on Massachusetts Offshore Wind Solicitations at: https://macleanenergy.files.wordpress.com/2023/05/section-83c-rfp-initial-filing-.pdf

2020, the E-TWG prioritized the development of recommendations or “responsible practices” for regional research and monitoring and formed a workgroup of subject matter experts to pursue this effort that included representatives from the RWSC and ROSA, state and federal agencies, offshore wind energy developers, academics, and environmental non-profit organizations (Appendix A).

The goal for this Regional Synthesis Workgroup was to inform and provide recommendations for regional environmental research and monitoring efforts in the eastern U.S. related to OSW development. To achieve this, the workgroup, with scientific technical support from the Biodiversity Research Institute (BRI) and funding from the New York State Energy Research and Development Authority (NYSERDA), developed two main products:

- A database that compiles and synthesizes previously identified research needs related to wildlife and environmental effects of OSW energy development for the U.S. Atlantic. This product was developed with support from the U.S. Offshore Wind Synthesis of Environmental Effects Research (SEER) team at Pacific Northwest National Laboratory and the National Renewable Energy Laboratory, who (with funding from the U.S. Department of Energy) also developed a similar database for the U.S. Pacific.
- This document, which provides high-level recommendations on how to design, implement, and communicate regional research and monitoring efforts, and is intended to complement the database.

This document seeks to provide clarity in language around research and monitoring, identify key considerations for how to define and prioritize regional research, and provide high-level recommendations on study design and methodology, data consistency, and data transparency. The geographic scope focuses on environmental topics related to OSW activities in the U.S. Atlantic, including activities in both state and federal waters, as well as any activities that may occur on land related to OSW development. However, many of the recommendations are broadly applicable and may be relevant to OSW research in other regions of the U.S. and elsewhere around the globe. “Regional” research and monitoring efforts may occur at a range of spatial and temporal scales (Section 4.2, below), but in the U.S. are generally conducted outside of the regulatory context, which is typically focuses on individual OSW projects. However, there may be benefits to drawing from these regional recommendations in the development of guidance for OSW site-level research; consistency and standardization in study design, data collection and analysis, and data sharing, regardless of study scale or funding mechanism, will add to the utility of resulting research.

Potential end users of these products are envisioned to include 1) state and federal government entities funding regional research in the next 1-3 years, with a particular need to inform the use of funding dedicated to regional research that is arising from OSW energy solicitations and research solicitations in multiple states; 2) OSW developers who are funding regional research and monitoring efforts; 3) ongoing processes at the RWSC, including the development of the Integrated Science Plan for Wildlife, Habitat, and Offshore Wind Energy in the U.S. via taxon-specific subcommittees; and 4) ROSA and other groups looking to fund and/or conduct research to inform our understanding of the effects of OSW development on wildlife and ecosystems.

4.0 Terminology and Conceptual Models for Understanding OSW Effects

4.1 Key Terms and Conceptual Models

To help foster clarity of purpose and mutual understanding, there is great value in the development of a common language. This is particularly true for terms that may have multiple meanings. Appendix B provides a glossary of key terms related to environmental research and OSW energy development and defines how the terms are used in this document.

For the purposes of this document, we have defined *research* as any type of hypothesis-driven scientific study that improves our understanding of populations and ecosystems, and/or our ability to measure or manage these systems. This understanding may be general or in relation to the effects of OSW development. *Monitoring*, in this context, is a subset of research that involves collection of repeated, systematic observations. As such, monitoring should always be aimed at answering research questions and testing scientific hypotheses. For example, monitoring might be conducted to examine whether animal distributions change in response to OSW development. Given the above definitions, we use the term "research" through the remainder of the document, with the understanding that this includes monitoring efforts. We recognize that monitoring may be conducted for other purposes outside of the research context (e.g., for the sole purpose of mitigation, such as via Protected Species Observers); this type of mitigation-specific monitoring is outside of the scope of this document.

As with use of the above terms, there is also value in ensuring clarity in the connections among key terms related to OSW risk, effects, and impacts. For the purposes of this document, *risk* represents the intersection of the probability of an effect, and the consequence or severity of that effect (Copping et al 2021). We define an *effect* along similar lines, as the combination of the *conditions and stimuli* posed by an OSW-related activity (for example, sound from pile-driving), *exposure* of receptors (e.g., animals, habitats, communities, or ecosystems) to those conditions and stimuli, and *vulnerability*, which encompasses individual *sensitivity* to those OSW activities combined with population sensitivity (Figure 1). Exposure can be defined based on spatiotemporal overlap of receptor *occurrence* (distributions, abundance, and movements) with OSW activities. Sensitivity includes the expected response of receptors to OSW activity at both the individual/local and population/regional scale. Population sensitivity, in avian vulnerability frameworks (e.g., Furness et al. 2013, Robinson Wilmott et al. 2013, Kelsey et al. 2018), typically relates to the conservation status of a species or population, including factors such as population size and rate of population growth/decline, and assessments of population status such as, but not limited to, the IUCN Red List[6]. We use these terms in a similar way here, with a focus on assessing whether OSW effects affect the conservation of populations (via cumulative individual-level effects), recognizing that individual and population sensitivity are often directly linked.

While National Environmental Policy Act (NEPA) regulations consider the terms *effect* and *impact* to be synonymous, for the purposes of this effort, effect and impact are defined differently (e.g., Popper et al. 2022). Effects are defined as changes or responses linked to 1) an exposure to OSW conditions or stimuli (e.g., an OSW-related activity) and 2) sensitivity of the receptor to that activity, including both individual and population sensitivity. Effects represent a departure from a prior state, condition, or situation (called

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[6] More information on the IUCN Red List at: https://www.iucnredlist.org/

the "baseline" condition; Hawkins et al. 2020) and may be additive, synergistic, or countervailing. If the consequences of effects reach the level of biological significance to the population (e.g., causing any changes in reproduction, mortality, or survival), then they are termed to be biological *impacts* (May et al. 2019). The consideration of *cumulative impacts* includes impacts across multiple anthropogenic activities, multiple OSW-related activities, or multiple OSW farms (Figure 2). Effects that don't appear to be biologically significant at the scale of an individual OSW project, (either because of low sample sizes or actual lack of effect) could become significant or contribute to significant impacts at the cumulative/regional scale, which is part of why regional research efforts are essential for understanding OSW's effects on populations and ecosystems.

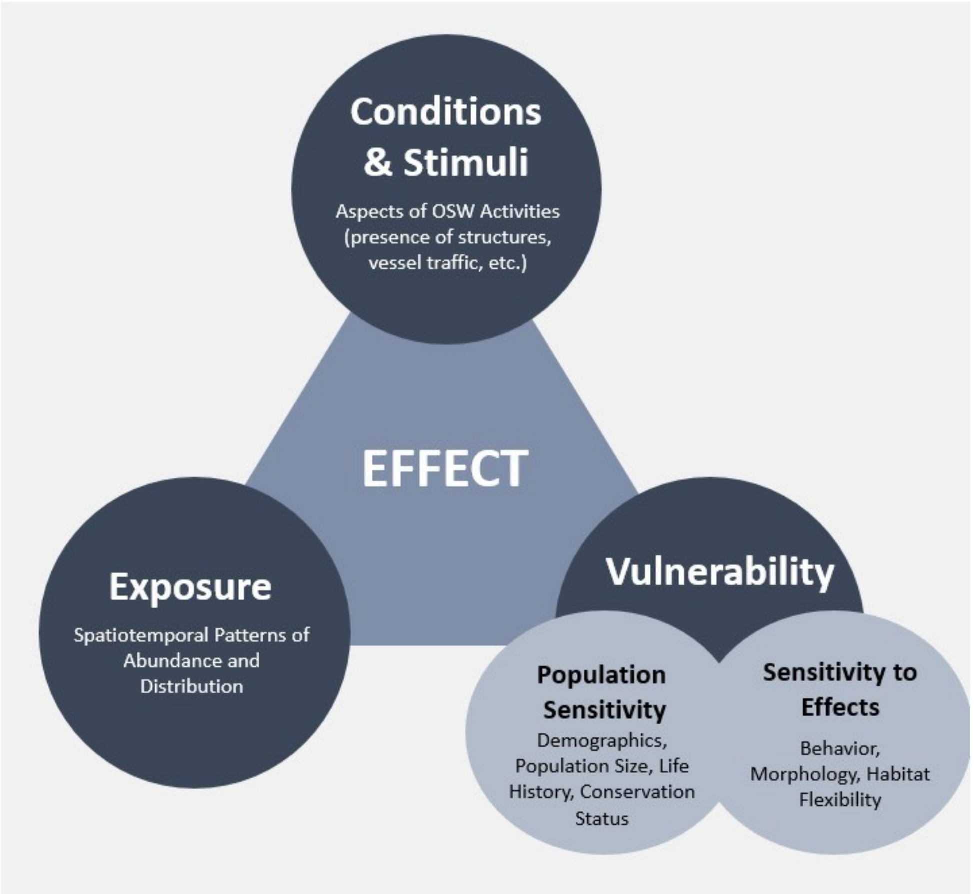

Figure 1. Factors contributing to effects from offshore wind energy (OSW) development on wildlife and marine ecosystems, including the OSW conditions and stimuli that a receptor may respond to, exposure of the receptor based on spatiotemporal patterns of occurrence/abundance, and vulnerability, which combines population sensitivity with individual sensitivity to OSW conditions and stimuli. Terminology is defined in the glossary in Appendix B.

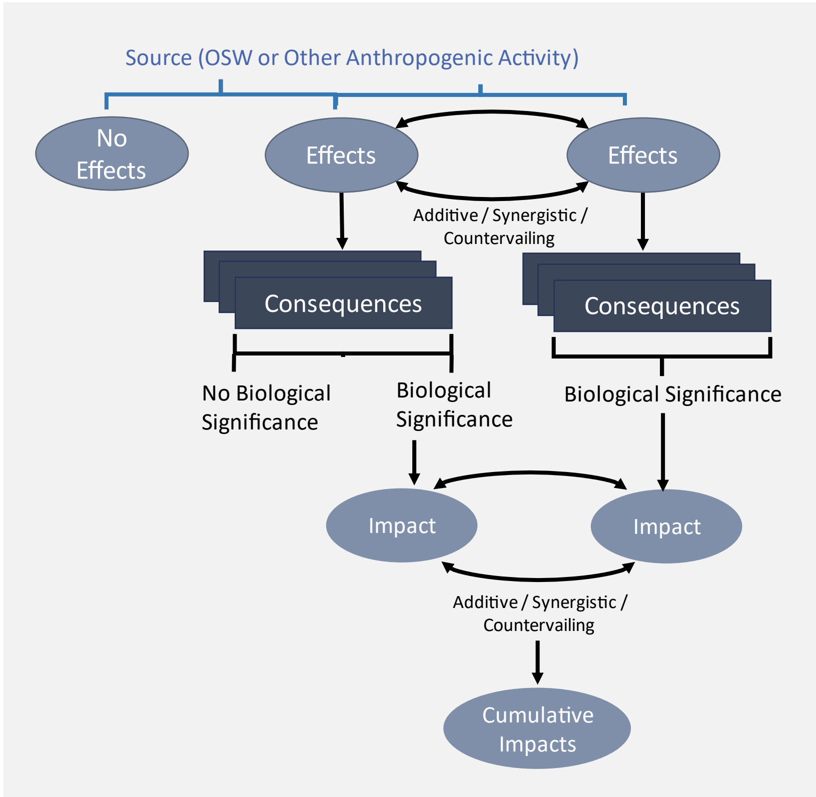

Figure 2. Differentiation between effects, impacts, and cumulative impacts from offshore wind energy development activities and other anthropogenic activities that may affect wildlife and ecosystems. Terminology is defined in the glossary in Appendix B. Effects that don't appear to be biologically significant at the site level (either because of low sample sizes or actual lack of effect) could become significant or contribute to significant impacts at the cumulative/regional scale, which is part of why regional research efforts are essential for understanding OSW's effects on populations and ecosystems. Both effects and impacts have the potential to interact in additive, synergistic, or countervailing ways.

4.2 Defining Regional Research

Research at multiple spatial and temporal scales can contribute to a broader understanding of environmental effects and impacts of OSW development and potential management approaches. As such, there are multiple ways in which studies could be considered "regional" in their implications (referred to throughout this document as "regional research"). These include situations where:

Data are required beyond a single wind farm site to answer the research question. In this context, a wind farm site is defined as the geographic space and infrastructure that comprise an OSW facility, and areas in which environmental effects from the facility occur, including areas outside the actual footprint of the facility, such as a cable corridor. Research topics that require data from beyond a single wind farm site may include those focused on:

- Examining variation in conditions or effects across a range of spatial scales, wind farm site characteristics (e.g., turbine size, distance to shore), habitats, species, or ecosystems, such that data collection would be required across these gradients for comparison, likely at multiple project sites or regions.
- Understanding phenomena such as migratory patterns and population demographics that require data collection at large spatial scales.

- Examining cumulative effects, which are regional by definition as they require data at spatial and temporal scales beyond that of individual wind farms.
- Understanding long-term temporal trends.

Study focuses on methodological needs and/or implementation of mitigation to inform environmental research, risk assessments, and/or adaptive management decisions. Methodologically focused topics are generally considered regional in scope if they can help inform understanding of, prediction of, or management of OSW effects on wildlife or ecosystems, but are unlikely to be addressed by a single developer. These include:

- Technology development, such as improved transmitters or collision-detection technologies. While technologies may be tested as individual OSW sites, the overall development and validation of a new technology would be considered regional in scope.
- Species vulnerability and sensitivity assessments and other guidance for conducting assessments.
- Development of approaches for data standardization, management, analysis, and sharing.
- Studies focused on the development and validation of mitigation approaches. *Mitigation*, in this context, includes all aspects of the mitigation hierarchy (IFC 2012) including avoidance, minimization, and compensation (further defined in Appendix B). For example, this could include a study testing the effectiveness of technology for noise reduction during pile-driving (i.e., minimization) or efficacy of offsite population management measures (i.e., compensation).

Study contributes to a mechanistic understanding of ecosystem processes. This includes topics related to broader ecosystem and environmental variables as well as those focused on understanding mechanistic causes of organisms' responses to stimuli to inform our understanding at the regional level. The latter type of study may be conducted at a small spatial scale but still be considered "regional" in its implications so long as the study is focused on improving our mechanistic understanding of effects and not simply measuring those effects. As such, it is possible for research conducted at individual offshore wind projects to contribute to answering regionally relevant questions. However, for data at small spatial and temporal scales to contribute to answering larger questions, substantial coordination and planning must occur (see Section 7.0 for additional details).

A variety of research needs and data gaps have been identified for the offshore wind energy industry in recent years, many of them regional in scope. As part of the regional synthesis workgroup's efforts, these needs were compiled into a single database to help inform the direction of future research and funding efforts.

5.0 Identifying Key Data Gaps and Research Needs for Regional Research

5.1 Scope

To aid in the identification of data gaps and research needs, one of the primary products of this effort was the development of a database that compiles and synthesizes data gaps and research needs from existing sources (e.g., Hein et al. 2021, Southall et al. 2021, Cook et al. 2021, Carpenter et al. 2021, Popper et al. 2022, Degraer et al. 2021, Gitschlag et al. 2021, Kraus et al. 2019). The **U.S. Atlantic Environmental Research Recommendations Database** allows researchers and funders to easily access, sort, and prioritize research needs relevant to understanding the effects and impacts of OSW energy development of wildlife and ecosystems. It compiles and synthesizes research and monitoring needs and recommendations identified in a range of source documents published between 2015-2021 relevant to OSW and environmental topics. Needs and recommendations in the synthesized list are not prioritized, though source documents used to develop the synthesized list may contain their own internal prioritizations. Likewise, recommendations in the database are not differentiated by whether current or planned research may have already begun to address them. Prioritization, identification of interdependencies across research recommendations, and assessment of the status of recommendation topics (e.g., whether they are already being addressed), are the responsibility of the end user. High-level considerations for prioritization can be found in Section 6.0, below.

5.2 Summary of Research Recommendations

A synthesized list of 219 research recommendations is included in the database, representing a range of topics (Table 1). A further summary of the synthesized topics by taxon/receptor, category of research need, and overarching topics within each category is included in Appendix C.

Table 1. Summary of synthesized research recommendations in the U.S. Atlantic Environmental Research Recommendations Database. There are a total of 219 synthesized research recommendations categorized by one or more nonexclusive topics (the 'stressor/topic' field in the database). 'Topics' in the below summary table are keywords related to the stressors and/or topical areas of focus of the research recommendation. See Appendix C for an additional summary of research recommendations by taxon.

Topic	Number of Research Recommendations
Technology/Methods Development	63
Habitat Change	44
Baseline	40
Noise	30
Population Dynamics	22
Abundance and Distribution	20
Movement and Behavior	20
Physiology and Energetics	14
Cumulative Impacts	14
Oceanographic/Atmospheric Change	13
Avoidance (including Displacement)	13
Diet and Food Web Dynamics	12
Ecological Drivers	10
Turbine Collision	9
Attraction (including Lighting)	7
Electromagnetic Field (EMF)	7
Data Management	5
Vessel Collision	3
Entanglement	3

5.3 Access to the Database

The U.S. Atlantic Offshore Wind Environmental Research Recommendations Database and associated metadata files are hosted on Tethys at https://tethys.pnnl.gov/atlantic-offshore-wind-environmental-research-recommendations. For information on database development, including literature review methods, criteria for source inclusion, synthesis processes, and definitions of database fields, see the database ReadMe file (Regional Synthesis Workgroup 2022), downloadable from the same link.

5.4 Other Resources

In addition to the U.S. Atlantic Offshore Wind Environmental Research Recommendations Database and resources therein, additional resources for identifying research gaps are also in development, such as the RWSC's Integrated Science Plan for Wildlife, Habitat, and Offshore Wind Energy in the U.S.[7], which is currently in progress. The RWSC also hosts a database of ongoing research activities[8], which can be cross walked to lists of research needs to identify data gaps that have yet to be addressed. ROSA has developed a database of research needs focused on fishes and fisheries, the Fish FORWRD database[9], and the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS), the Bureau of Ocean Energy Management (BOEM), and the Responsible Offshore Development Alliance (RODA) recently published a technical memorandum that also synthesized data gaps and priority research questions for fishes and fisheries (Hogan et al. 2023). Project-level monitoring plans can be used to inform regional study objectives and research questions as well. Regional studies should generally be designed to fill data gaps and build off these existing efforts, or at least not duplicate site-level efforts.

6.0 Prioritizing Regional Research Topics

There are a variety of ongoing efforts to identify research needs that could help to understand the effects and impacts of OSW energy development on wildlife and marine ecosystems. While the database of research recommendations (Section 5.0) provides a first step in this process, there has been a mutual recognition among regionally focused stakeholder groups, including the Regional Synthesis Workgroup, E-TWG, ROSA, and the RWSC, that individual efforts could collectively be more effective if these groups are able to identify common criteria or considerations with which to help prioritize future work. These considerations could be part of a multi-step decision process to select research projects for funding (see Figure 4 for an example). Each funding or research entity may choose to utilize these considerations in different ways (e.g., scoping Requests for Proposals, selecting projects for funding, etc.) and each organization may augment them with their own entity-specific criteria. As such, the aim of this section is to recommend potential prioritization factors that could be considered across entities while allowing for flexibility in their use.

These recommendations were developed via extensive stakeholder community input (Appendix A). It is recommended that the use of these prioritization considerations likewise incorporate the views of researchers, scientists, managers, regulators, and other stakeholders, whether via collaborative stakeholder processes or other mechanisms. These considerations should also be periodically revisited and updated as needed.

36.1 Organization-specific Considerations

The focus and goals of a specific entity's decision-making around research funding or prioritization will always play a substantial role in its prioritization process. For example, a group may be focused on a particular taxon, geographic region (e.g., the New York Bight), or topic area (e.g., sound-related effects

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[7] Draft plan available at: https://rwsc.org/science-plan/
[8] More information available at: https://database.rwsc.org/
[9] More information on the ROSA Fish FORWARD database at: https://www.rosascience.org/resources/regional-framework-databases/

and impacts). Each entity may also have specific practical considerations relating to cost sharing, diversity of research funding recipients, or other deciding factors. This organizational lens can play a role in the initial filtering of research topics – to help narrow a long list of hundreds of topics down to a more manageable number for additional prioritization – and/or at latter stages of the process, for example by helping to select final research projects from among a short list of applicants. It is recommended that the below considerations be used in conjunction with such organization-specific considerations.

6.2 Considerations for Prioritizing Research

It is recommended that prioritization processes consider several aspects of potential research projects, including importance/urgency of need, achievability, and efficiency and innovation. Importance, urgency of need, and achievability should generally receive more weight than considerations around efficiency and innovation. However, there are always organization-specific considerations (above) as well as interdependencies among the below considerations, and it is recommended that these ideas be considered holistically rather than as independent decision factors. There may be variation in the spatial and temporal scale at which considerations are applicable, for example, depending on the geographic focus of each organization. The below considerations were drawn, in part, from existing prioritization criteria identified from previous relevant efforts (e.g., NYSERDA 2015, Rijkswaterstaat 2016, Kraus et al. 2019, NYSERDA 2020, BOEM 2020).

Importance and Urgency of Need

The importance of research in this context relates to the degree to which the objectives **contribute to understanding of key regional- and population-level effects of OSW, including disentangling OSW effects from other sources of change** (Gulka et al. 2022, BOEM 2020). Studies may either directly answer questions around regional- and population-level effects or contribute to that broader understanding in conjunction with other existing or ongoing research, but either way must have applicability to these large-scale questions. Importance should not be confused with urgency (e.g., immediacy of need), as longer-term studies may in some cases have higher utility for improving our understanding than studies that can or must be completed on a shorter time frame. Important and/or urgent research may include studies that:

- **Contribute to fundamental understanding of key regional effects and impacts to species, habitats, communities, or ecosystems. "Key" effects may be determined by their magnitude (e.g., likelihood to cause impacts) or by the specific receptors that are affected.** Such assessments should be regularly updated to incorporate the best available information on receptor distributions, status, and trends, as well as responses to OSW activities. Specific receptors of interest, including species, habitats, or communities, may be defined by a combination of:
    - **Vulnerability to OSW effects or impacts –** Vulnerable receptors could be higher priority for research. This includes species and communities that 1) may be highly exposed to OSW conditions and stimuli, 2) have high individual-level or local sensitivity to OSW effects, and 3) have high population-level or regional sensitivity to OSW impacts (see Section 4.1). Population sensitivity, in addition to the factors described in Section 4.1 and citations therein, could also be based on federal or state regulatory assessments (e.g., under the Endangered Species Act, Magnuson-Stevens Fishery Conservation and Management Act, Marine Mammal Protection Act, or state environmental protection laws) or nonregulatory assessments (e.g., Species of Greatest Conservation Need).

    - **Economic or societal value** – Species and habitats that play important societal, tribal, or economic roles, including those relevant to commercial, recreational, and for-hire fisheries could be prioritized.
    - **Importance to ecosystem stability and function** – "Foundation species" are influential in structuring communities, promoting biodiversity, and contributing to the stability of ecosystems (Lamy et al. 2020, Ansley et al. 2023).
    - **Current state of knowledge –** It may be useful in many cases to prioritize the collection of data on exposure, sensitivity, or response to OSW for species, communities, or habitats for which information is currently lacking or there are high levels of uncertainty. In some cases, it may also be valuable to focus on species or communities for which there is already substantial information available, for example to further elucidate causal mechanisms.
- **Help to understand changes in ecosystem structure and function.** If we can understand mechanistic aspects of responses, we can make sensible predictions for other regions/species without conducting research on everything everywhere.
- **Improve understanding of the drivers of change and potential interactive effects.** This includes disentangling the effects and impacts of OSW energy development from other drivers (e.g., determining what changes are caused by OSW vs. being caused by other anthropogenic influences or natural variability). It may also include efforts to improve our understanding of how OSW may interact with other anthropogenic influences (e.g., fisheries, climate change) to affect wildlife and ecosystems, or how OSW may drive multi-species interactions.
- **Inform and reduce uncertainty in decision making beyond a single OSW project or site.** This may include decisions relating to siting, permitting and other regulatory decisions, OSW project design and construction plans, and adaptive management of current and future projects. If studies are focused on informing short-term or single-site decisions, they should also have a clear application to other current OSW projects or to informing siting or permitting conditions for future projects. This also includes studies that create transparent, quantitative approaches and decision support tools to inform aspects of the OSW development and permitting process that are currently highly subjective and qualitative. Validation of model-predicted risks, for example, can help inform risk estimation processes for future projects. Data transparency is also an important consideration, as accessibility of data in a timely manner ensures that research can adequately inform decision making (see Section 7.0 for further discussion).
- **Develop monitoring techniques, technologies, methodologies, protocols, or long-term datasets to better address regional research questions**. There may be methodological limitations to understanding certain effects whereby focus on technique development could influence the ability to answer these questions at both local and regional scales. In addition to technologies and methods, this includes the maintenance of databases and other types of data-sharing and standardization efforts that contribute to our ability to utilize existing data to inform regional research questions.
- **Fulfill immediate information needs**. As OSW development progresses, the types of information considered most urgent will shift depending on the current status of the industry in a given region. Currently, given the early stage of development of the U.S. wind industry, urgent research needs include studies that:
    - Focus on broad-scale distribution, abundance, or behavior;

- Require data during the pre-construction and construction periods; and/or
- Help inform siting and OSW project design decisions.

In part, this is because the “pre-construction” window of time is rapidly closing for many locations in the U.S. Atlantic. There is substantial value in obtaining a clear view of “baseline” patterns of species distributions and behavior, as well as pairing focused pre-construction or construction data with post-construction research to compare predicted to actual effects.

Achievability

The consideration of achievability (defined as the ability to fully accomplish objectives) can help identify which research efforts will best be able to answer questions of interest. Specific considerations include whether a research study will:

- **Achieve objectives and has a well-defined scope of inference,** including having an appropriate design, a clear connection between the observed data gap and specific research objectives, and a clear pathway to statistically robust results. If applicable, this should include the identification of testable hypotheses. Power analyses or other pre-study assessments can be valuable tools to understand how much data are necessary to reduce uncertainty and effectively answer research questions (see Section 6.2).
- **Produce results that are broadly applicable.** Study results can be better leveraged if findings are applicable across multiple OSW developments, regions, or taxa. This may involve consideration of repeatability of methods in other locations, with other species groups, or at different scales.
- **Help to assess or reduce uncertainty.** There are many types of uncertainty, including spatial, temporal, process, and management-related uncertainties. If uncertainty reduction is a primary focus when selecting studies for research, the specific type of uncertainty being addressed in each study should be clearly defined. Rushing et al. (2020) defines a framework for reducing uncertainty that may be a beneficial reference, whereby hypothesis evaluation relates to 1) magnitude of uncertainty, 2) relevance of resolving uncertainty to meeting fundamental objectives, and 3) degree to which uncertainty could be reduced through research.
- **Be conducted on the necessary timeline and within the boundaries of logistical constraints.** For longer-term or more complicated efforts, breaking up topics into sub-objectives may be helpful along with consideration of long-term sustainability of funding/access. Logistical constraints are various but include compatibility with planned OSW development and operations activities in the U.S. Atlantic.

Efficiency and Innovation

Importance/urgency of need and achievability should be key considerations in any research-related decision-making. In addition, efficiency and innovation could also be considered. This may include prioritizing studies that:

- **Leverage existing resources through partnerships and collaborations.** Collaborations and partnerships among researchers, government agencies, regional groups, offshore wind developers, and others are important for multiple reasons, including cost-effectiveness and achieving buy-in from stakeholders.
- **Consider, leverage, or improve existing data.** Study designs must be compatible with existing data. Building on existing data may also lead to greater efficiency and immediacy of results,

though it must be done appropriately (e.g., overreliance on existing data may hamper ability to answer the research question). In addition, there is value in efforts that improve the accessibility, usability, quality, and integration of existing data.

- **Are innovative or work to build new partnerships and collaborations**. Not all studies can rely on existing resources or partnerships, and a lack of existing support may indicate the innovative nature of the proposed research or the need for support in forming such collaborations.

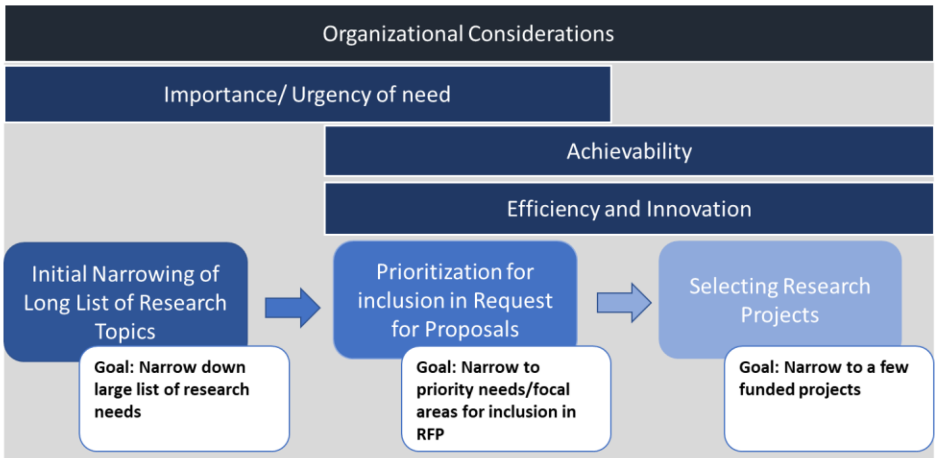

Figure 4. Hypothetical example for how to prioritize research related to offshore wind energy development and wildlife and ecosystems using the considerations defined below. Considerations including: 1) Importance/Urgency of Need, 2) Achievability, and 3) Efficiency and Innovation, can help funding organizations to identify potential topic areas on which to focus Requests for Proposals (RFPs), and/or help to determine which proposals should be selected for funding. Organization-specific considerations may also play a role in decision making throughout this process.

7.0 Study Design and Methodology Considerations for Regional Research

7.1 Defining a Research Framework

Once regional research needs have been identified and prioritized, the design and methodologies employed in regional studies must be carefully considered to ensure they can effectively answer ecological questions of interest. A framework for OSW regional environmental research can help to inform the choice of specific research questions and ensure that the effects of OSW development are placed in a broader ecosystem and cumulative context (see Section 1.0, Rationale for Regional Monitoring and Research, and Section 4.2, Defining Regional Research).

ROSA (2021) clearly defines a design structure and principles for regional research in relation to OSW development. Regional study designs and data collection methods should include the following components (adapted from ROSA 2021):

- **A conceptual framework** that describes the potential effects of OSW development on wildlife and ecosystems, and how those effects may translate into impacts (e.g., Pirotta et al. 2018). A conceptual framework should hypothesize how the ecosystem or population is regulated (e.g., factors influencing growth and stability), how OSW development may affect these systems, and how effects may translate into impacts (Reynolds et al. 2016). Specific research questions can then be defined to improve our understanding of different components of this conceptual framework.

- **Prioritization of research questions and hypotheses** on the potential effects and impacts of OSW energy development on species, communities, and ecosystems (see Section 6.0, Prioritizing Regional Research Topics).
- **Study designs to effectively answer research questions**, including selection of the appropriate metrics and indicators of change for the question of interest, to evaluate the presence and magnitude of response and how effects may translate into impacts.
- **Standardized data collection, reporting, and sharing** (see Section 7.0) to facilitate integration of data for analyses of effects and impacts at a range of spatial and temporal scales. In order for results to effectively inform our understanding of the system, data must be produced in standardized ways and shared in a timely manner.
- **Processes to assess performance of research efforts,** including the identification of metrics or performance indicators that can be used to understand whether data collection and study design are effective at addressing research questions and hypotheses. All large-scale study plans should include a review of study outcomes to assess efficacy in achieving objectives, which can serve to inform understanding of these study outcomes as well as to inform future work.

The above principles are focused specifically on detecting effects. Thus, they are more limited in scope than the definition of regional research in this document, which may include studies focused on informing our understanding of baseline occurrence and the consequences of OSW effects (e.g., cumulative effects; Southall et al. 2021) as well as the more immediate responses of wildlife and ecosystems to OSW energy development. Nevertheless, these principles represent general good practice for informing regional research plans (Reynolds et al. 2016) and are a general framework to build from.

7.2 Key Components of a Research Plan

Regional research efforts should have a clearly defined research plan that delineates how the proposed work will allow for a better understanding of population-level and cumulative effects from OSW energy development. Research plans should be compatible with existing efforts where possible, including monitoring at the site level. Components of a regional study plan should clearly delineate: 1) a conceptual framework, 2) study objectives, research questions and testable hypotheses, 3) a study design, data collection methods, projected samples sizes/treatment units, and analytical approaches, 4) data sharing and coordination plans, and 5) a process for evaluating effectiveness and validity of results. Throughout this section we will use an example assessing the regional impacts of OSW construction noise on marine mammals to demonstrate the various key components of a research plan.

Conceptual Framework

Regional research plans should be informed by a conceptual framework that includes key system components, drivers of population or ecosystem dynamics, and putative drivers of change. Such a conceptual framework helps to articulate hypotheses regarding how the system works, including how OSW energy development may affect these systems and how those effects may translate into impacts (Reynolds et al. 2016). Addressing clearly defined hypotheses on such topics can, in turn, help to inform management and regulatory decision-making. Existing information about the system is key to building an effective conceptual model. The selection of a conceptual framework and the identification of study objectives are interrelated and should be identified in tandem. An example of a conceptual framework is described in Pirotta et al. (2018), which articulates how disturbance to marine mammals caused by exposure to OSW activities might translate (via changes in health, physiology, behavior, etc.) into biological impacts (via changes in fitness and/or population dynamics).

Study Objectives and Research Questions

All regional research studies should be explicit about their objectives and intended outcomes. This includes identifying how resulting knowledge will improve our understanding of specific processes, allow for a better understanding of cumulative effects from OSW energy development, and improve decision-making. Accompanying research questions and hypotheses should be clearly defined and testable based on the proposed study design, data collection methods, and analytical approaches. Following the conceptual framework example above (Pirotta et al. 2018), one might develop the following research questions related to marine mammal noise exposure: 1) What are the exposure levels and contexts in which acute behavioral responses occur in marine mammals during offshore wind farm construction? 2) How do patterns of habitat use change across the region as different OSW projects move through the pre-construction, construction, and operational periods? 3) Does construction noise cause changes in marine mammal behavior that may affect health, physiology, or fitness?

Careful selection of a null hypothesis relative to potential implications and management outcomes is often crucial to designing effects studies; if an effect is expected, the study should be designed with this null hypothesis in mind, such that the burden of proof is higher for *not* detecting the effect (Hoenig and Heisey 2001). As Hoenig and Heisey (2001) stated (in reference to the importance of minimizing Type II error), "In matters of public health and regulation, it is often more important to be protected against erroneously concluding no difference exists when it does". Appropriate selection of null hypotheses up front can greatly strengthen study effectiveness (and simplify evaluation of study effectiveness; see “Evaluation of Study Effectiveness,” below).

There are many types of research questions that can be addressed in regionally relevant studies. Resources that can be used in the development of study objectives and research questions include the U.S. Atlantic Offshore Wind Environmental Research Recommendations Database (Section 5.0) and resources therein, as well as recommendations for prioritization of regional research efforts (Section 6.0). other resources are noted in Section 5.4 of this document.

Study Design, Data Collection, and Analysis Methods

Careful study design is important for conducting good-quality science regardless of scale. However, this is particularly true for studies that aim to address regional research objectives, as studies conducted at regional spatial scales typically encompass large amounts of spatial and temporal variability. It is also essential for studies that are local in spatial scale but regional in their implications; such studies must be conducted in a scientifically rigorous and consistent way to ensure that results can be combined or accurately extrapolated to other locations and across the broader ecosystem. Specific considerations for study design and methodology for regional research studies include: integration of research at different scales; issues of statistical power; collection of baseline and covariate data to ensure that observed effects can be attributed to specific causes; compatibility with other data collection efforts; robust analytical methods and treatment of uncertainty in results; and use of existing guidance, recommendations, and standards. A hypothetical example related to marine mammal noise exposure that walks through each of these considerations is presented in the callout box below (Figure 5).

Integration of research at different spatial and temporal scales – The spatial and temporal scale of the study must be appropriate for the question of interest. For example, broad-scale regional data collection on wildlife distributions or oceanographic conditions is often not designed appropriately to detect changes at smaller geographic scales. Studies that are focused on detecting effects at smaller spatial scales can still be regional in their implications if they are designed to facilitate integration with similar studies at other locations, as well as broader regional efforts. This integration requires coordination, the use of established methods and protocols, publicly available research plans, data sharing, and reporting of detailed methodologies. Study design must be rigorously targeted to specific questions of interest, but researchers should also be thinking broadly to produce data that could have multiple applications and be integrated with other relevant datasets as appropriate.

Statistical power and effect size – The study design process should include an evaluation of whether sample sizes are sufficient to detect a reasonable level of observable change, and when possible, to ensure that research is conducted to adequately address a question or hypothesis of regional importance (or if local in focus, to effectively contribute to the power of regional analyses). Sample sizes should be based on power analysis that incorporates existing data on expected variation in metrics of interest as well as information from the literature on potential effect size and associated uncertainty. The choice of metric for effect size should be informed by the specific study question as well as a broader conceptual ecological model of the system or population of interest (Osenberg et al. 1997). Insofar as existing data allow, the choice of effect size value (e.g., for power analysis) should take into consideration taxonomy, sources of variability including temporal variability (e.g., seasonal, annual, and longer-term fluctuations) and spatial variability (ROSA 2021), and the biological relevance of the selected value (Osenberg et al. 1997). Power analyses for studies to detect effects from OSW energy development should also consider their ability to reduce Type I vs. Type II error (Leirness and Kinlan 2018) as well as the relative impact of Type I vs. Type II error on resource management and decision making; the risk of committing a Type I error (e.g., false alarm) may have a higher or lower environmental management consequence than Type II error (e.g., not detecting an effect when there is indeed one; Fairweather 1991). Data are not always available to inform these decisions, unfortunately, but we recommend considering the above factors as much as possible given available information on the taxon, effect, or system of interest.

Data collection and integration – The methods of data collection, as well as the metrics, precision, and format of the data that are collected, should be clearly articulated and connected to the regional-level research questions and hypotheses. Data collection should include environmental covariate data and other factors that may affect the detection of effects or interpretation of results at local or regional spatial scales. Specifically, data should be collected that can improve the ability to disentangle the effects of OSW from the effects of other anthropogenic activities and natural variability. This typically involves the integration of a range of datasets to inform interpretation. For example, data on **environmental conditions** should be collected simultaneously with biological sampling (when feasible) and may include a range of oceanographic, weather, and other relevant environmental variables for use in analysis. For studies of effects, **baseline data collection** prior to exposure is important to ensure sufficient statistical power to assign any effects that are detected to the hypothesized causal mechanism. High levels of temporal variability in marine systems suggest that a minimum of 2-3 years of baseline data are generally needed to characterize systems prior to perturbation (Brodie et al. 2021, ROSA 2021), though this can be highly species- and situation-specific. Data on the **biological parameters** of species or habitats being sampled are also important; for wildlife being observed or sampled, for example, this may include factors such as body condition and other morphometrics, age, and sex that may be sources of variation in potential responses. And finally, studies should be designed to include explicit consideration of **external factors** that may affect data collection and interpretation of results. This might include OSW project information such as turbine size or spacing, and exposure to non-OSW activities or conditions that may influence response.

Compatibility with long-term data collection – New data collection for regional research should consider compatibility with other large-scale and/or long-term monitoring, such as ongoing trawl surveys conducted by the National Marine Fisheries Service (NMFS; Hare et al. 2022), whether via the use of similar methods, via calibration between methods, and/or via analytical integration. Studies should also consider how to integrate or harmonize with data from previous research efforts that may have used different study designs. It is important to maintain high standards of scientific data quality and use best available practice; as methods and technologies naturally evolve, this should include application of appropriate methods of calibration and standardization (e.g., designing comparison studies for calibration purposes or utilizing analytical integration methods, as reviewed in Zipkin et al. 2021) to ensure compatibility among older and newer datasets or methods wherever possible (Hare et al. 2022).

Analytical methods and uncertainty – Analytical plans, including applicable modeling approaches, should be statistically robust, clearly articulated, and repeatable, and follow established approaches (when applicable) that incorporate and assess spatial and temporal uncertainty. Repeatability should be achieved by providing both highly detailed descriptions of modeling approaches and sharing of computer code from analyses. Analytical results, including uncertainty, should be clearly reported to maximize utility and assist with incorporation of local-scale research into regional assessments and interpretation (ROSA 2021). For studies that are focused on detecting effects at smaller spatial scales (but that have a goal of addressing questions with regional implications), there is often value in meta-analysis and other types of data synthesis to assess evidence in support of a hypothesis and determine effect size across studies. For these types of analyses, the reporting of effect sizes and associated uncertainty is critical.

Use of existing standards, protocols, and documents. Reference to established, scientifically rigorous methods and study designs can help to ensure that new studies can effectively answer questions and facilitate integration across studies to meet regional research objectives. A range of resources are available for different types of studies and taxa of interest. The Ocean Best Practices Repository[10], for example, documents a variety of standards with varying applicability to OSW. We also refer the reader to resources listed in Table 2 (as well as to the citations therein). Not all of these resources are explicitly regional in focus, but all can help to develop study designs that will inform a broader regional understanding of wildlife populations and ecosystems and/or OSW effects to those systems.

[10] More information on the Ocean Best Practices Repository available at: https://search.oceanbestpractices.org/

Hypothetical Research Question: Understanding changes in marine mammal habitat use in response to turbine installation noise

(Note: this example is entirely hypothetical. Specifics such as distance of expected displacement are not drawn from the scientific literature)

Hypothesis 1: Marine mammals will be displaced up to 10 km from OSW pile-driving activities during OSW construction.
Hypothesis 2: Marine mammal habitat use will return to pre-construction levels within 6 months of the completion of pile-driving activities.

Key Aspects of Study Design, Data Collection, and Analysis Methods

Spatiotemporal scale: Information on the abundance and distribution of marine mammals (via aerial observational survey) will be collected monthly for at least four years (two years prior to construction, during construction activities, and one year during operations) using a before-after gradient study design (Methratta 2020). Spatial scale is defined by a polygon that includes all offshore wind farms in a specific region of interest plus a 20 km buffer, selected based on existing information on response distances of the species of interest and in order to adequately detect changes of 10 km or greater (based on H1). Spatial and temporal scale were defined based on a power analysis (see next section).
Statistical power and effect size: Existing survey data of marine mammals in the region was used to conduct a power analysis to determine that number and spacing of surveys needed to have a high probability of detecting an effect at 10 km given known levels of variability in distribution and regional abundance. This led to determination of monthly surveys for two years pre-construction, throughout construction (timed in relation to pile-driving activities), and for one year post-construction, with spatial coverage of 10% with a 20 km buffer.
Collection of data: Via visual observational surveys, the location, species, number, age, and behavior of individuals will be recorded continuously for each transect on each survey in addition to associations (e.g., mother calf pairs) and body condition following existing protocols (BOEM 2019). Survey conditions (e.g., weather, visibility) and observer variables will also be recorded. In addition, sound levels will be measured in proximity to pile-driving during construction, and other external factors for consideration will include offshore wind project information (e.g., turbine size), the use and type of noise attenuating devices (if any), location and size of vessels in the survey area, and time since last pile-driving event.
Compatibility with long-term data collection: There are multiple existing regional observational surveys for marine mammals conducted in the region (e.g., Atlantic Marine Assessment Program for Protected Species surveys). As such, careful consideration was given to the survey methods to follow similar protocols and ensure compatibility with these datasets for larger-scale studies.
Analytical plans and uncertainty: Observational data will be analyzed using Generalized Linear Mixed-effects Models (GLMM) with the interaction of development phase and distance as an explanatory variable, and a range of random and fixed effects, including turbine and sound level information, and time since last pile-driving event, to determine changes in abundance and distribution in relation to construction and operations and at finer scales post-construction to assess potential habituation. Effect sizes and distance and associated uncertainty will be reported for each marine mammal species and phase of development.
Use of existing standards, protocols, and documents: Following a search in the Ocean Best Practices Repository and Table 2, existing standards relating to marine mammal survey design, gradient study design, power analysis, and existing survey data were used to inform the study design.

Figure 5. Key aspects of study design, data collection, and analysis methods for a hypothetical regional study focused on understanding changes in marine mammal habitat use in response to offshore wind turbine installation noise (e.g., pile-driving). Note: all information is hypothetical and for exemplary purposes only.

Table 2. Examples of research protocols and guidance related to environmental research and offshore wind energy development.

Category	Specific Topic	Source
Study design	Gradient versus control-impact study design	Methratta 2020
Study design	Distance-based sampling methods	Methratta 2021
Population monitoring	Operational protocols for the use of drones in marine animal research	Raoult et al. 2020
Population monitoring	Monitoring marine populations: Review of methods and tools dealing with imperfect detectability	Katsanewakis et al. 2012
Bats	North American Bat Monitoring Program (NABat)	Loeb et al. 2015
Bats	Guidance for Conducting Acoustic Surveys for Bats	NPS 2016
Benthic resources	Benthic and Fish Monitoring Protocols for the Atlantic/Caribbean Biological Team	Roberson et al. 2014
Benthic resources	Research recommendations for habitat monitoring	In progress (Methratta)
Benthic resources	Guidelines for Providing Benthic Habitat Survey Information for Renewable Energy Development	BOEM 2019a
Birds	Overall research framework for examining OSW effects	Croll et al. 2022
Birds	A framework for mapping the distribution of seabirds with integrated methods	Carneiro et al. 2020
Birds	Seabird observational surveys	Maclean et al. 2013
Birds	Offshore Motus guidance	Loring et al. 2023
Birds	Power analysis for Motus tracking	Lamb et al. 2023
Birds	Guidelines for Providing Avian Survey Information for Renewable Energy Development	BOEM 2020a
Birds	Statistical Analyses to Support Guidelines for Marine Avian Sampling	Kinlan 2012
Birds	Recommendations for studies of bird displacement	Marques et al. 2021
Fisheries	Framework for offshore wind and fisheries monitoring	ROSA 2021
Fisheries	NOAA Fisheries and BOEM Federal Survey Mitigation Implementation Strategy	Hare et al. 2022
Fisheries	Guidelines for Providing Information on Fisheries for Renewable Energy Development	BOEM 2019b
Fishes	Monitoring guidance for underwater noise in European seas	Dekeling et al. 2014
Fishes	Standards for measuring underwater noise	Ainslie 2011
Fishes	How to set sound exposure criteria for fishes	Hawkins et al. 2020
Fishes	Best practice guide of underwater particle motion measurement for biological applications	Nedelec et al. 2021
Fishes, Sea turtles	Sound exposure guidelines for fishes and sea turtles	Popper et al. 2014
Marine mammals	Underwater Passive Acoustic Monitoring (PAM) Systems	RWSE 2022
Marine mammals	Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing	NMFS 2018
Marine mammals, Sea turtles	Guidelines for providing Information on marine mammals and sea turtles for renewable energy development	BOEM 2019c
Marine mammals, Fishes	Underwater Passive Acoustic Monitoring (PAM) Systems	Van Parijs et al. 2021
Sea turtles	Guidelines for long-term monitoring for marine turtles nesting beaches, feeding, and wintering areas	UNEP 2016
Sea turtles	Controlling for perception and availability bias in marine turtle abundance estimates	Fuentes et al. 2015
Sea turtles	Process for telemetry attachment on sea turtles	USFWS 2013

Data Sharing and Coordination Plans

Data sharing and coordination is an essential component of regional research efforts and is further addressed in detail in Section 8.0, below. Regional research plans should include a clearly delineated process and timeline for sharing study results and conclusions, including publication of scientific papers and reports, sharing of raw and processed data, and stakeholder outreach (e.g., public websites, webinars, and conference presentations), as appropriate (Reynolds et al. 2016). Data sharing and coordination plans should detail with whom, how, and when stakeholder outreach will occur. For example, this might include the formation of an external committee for technical review of the study plan, engagement with OSW developers, and involvement with collaborative groups such as the RWSC.

Evaluation of Study Effectiveness

Research plans should include measures that can be used to evaluate performance, which is particularly important for longer-term monitoring efforts. This should include identifying, calculating, and reviewing a set of performance indicators or metrics to inform an understanding of whether data collection and study design are effective at addressing research questions and hypotheses (ROSA 2021). *Post hoc* power analysis, for example, has been suggested as an approach to help determine whether an already-collected dataset allowed for effective testing of the chosen hypothesis (Fairweather 1991). While *post hoc* power analysis should not be used as an alternate method to suggest evidence for/against the null hypothesis, it can be useful to help assess whether the study design was effective in addressing the chosen question (e.g., to inform the design of future work; Hoenig and Heisey 2001). Uncertainty information such as that provided by confidence intervals can also be used to assess the power of the available data to support a given hypothesis. Use of Bayesian statistical approaches, in which posterior distributions can be calculated (and which lack some of the limitations of frequentist statistics), can also be helpful for evaluating study effectiveness. More generally, this feedback loop should involve the update of conceptual and/or quantitative models to improve system understanding and inform future decision making (Reynolds et al. 2016); one performance indicator for research programs could be whether research results adequately update these models. Performance metrics can be applied internally within a regional research collaboration or via external (independent) review of research programs. Regardless of process, these findings should then be used to modify study design as needed and inform the design of future studies.

8.0 Collaboration and Communication, Data Consistency, and Data Transparency

Effective planning and implementation of regional OSW research requires a degree of collaboration that may be unfamiliar to both academic researchers and OSW industry professionals. This collaboration should include, at minimum, consultation and/or cross-referencing with regional expertise, and may also include more formal engagement of experts as collaborators or project investigators. Further, data collection and archiving during regional research should be conducted in as standardized and transparent a manner as possible; existing recommendations on this topic are available in a variety of other sources, including NYSERDA (2021), ROSA (2021), and van Parijs et al. (2021).

8.1 Collaboration and Communication

Regional research often includes multiple collaborators and funding sources, so collaboration/coordination should generally occur at all stages of the research process, including planning and study design, data collection, public access to the raw data and data products, and reporting of results. Collaborative efforts should:

- **Ensure consistent and transparent communication with regional research entities and other relevant groups, including state and federal agencies.** Regional research entities including the RWSC and ROSA provide a forum through which to communicate research plans, obtain feedback from relevant stakeholder groups (including state, federal, industry, and environmental non-profit caucuses), and form collaborations with other researchers. Consistent communication with groups that are coordinating OSW and wildlife studies on a large scale (e.g., the RWSC science subcommittees, ROSA) and groups conducting regional research (for example, Project WOW[11]) will help to reduce duplication of effort, identify opportunities for collaboration, and focus research and monitoring efforts on areas of greatest need. Such coordination may also help to support education and capacity-building across sectors.
- **Consider coordination with other geographies.** In addition to coordination at the regional level, international coordination is important for taxa and research questions that are relevant across multiple regions, especially given the breadth of knowledge that has been produced on the environmental effects of offshore wind energy development in Europe to date, as well as the scale of development planned elsewhere around the globe.
- **Engage in early planning and collaboration for study design development.** Engagement of project collaborators, as well as state and federal agencies and other experts in the field, is important to inform development of research plans, avoid duplication of effort, ensure awareness of existing data, and help to ensure that smaller-scale studies can be integrated to inform regional research questions. Coordination efforts should include other relevant research studies in the region, including OSW project site-level research, which can be facilitated by regional groups such as the RWSC, as well as regional states, federal agencies, and other stakeholders. The RWSC database of current research studies and the OSW Metadata Tool in development by Tethys[12] are also useful resources.

8.2 Data Standardization

Regional research efforts should:

- **Ensure consistency of data collection,** where possible, by following existing guidelines and established protocols from federal agencies, regional science entities, and others collecting similar data at site-level, regional, and national/international scales (Section 6.2). If there are no publicly available protocols for a specific study type, then a protocol should ideally be developed with expert support (which can be done in coordination with regional science groups like RWSC and ROSA) to inform study plans. At the very least, reporting of data collection methods and project metadata should be detailed enough to enable repeatability. Publication of methods (below) is also essential so that others can reference them for future studies.
- **Follow appropriate metadata standards** for newly collected data, such as standards from the Federal Geographic Data Committee[13], to the degree possible based on the data type. This

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[11] More information on Project WOW at: https://offshorewind.env.duke.edu/
[12] Offshore Wind Metadata Tool forthcoming. More information at: https://tethys.pnnl.gov/about-oes-environmental
[13] More information on the Federal Geographic Data Committee at: https://www.fgdc.gov/

includes development of comprehensive metadata for both spatial and non-spatial data types (NYSERDA 2021), with clearly defined formats, units, precision, etc.

8.3 Data Sharing and Transparency

The following recommendations relate to data accessibility, archiving, and publication of results. While these processes often occur in the latter stages of a research project, planning and clear delineation of these processes up front can help to ensure that budgetary and other logistical constraints do not hinder the dissemination of wildlife data and research findings. Specific recommendations include:

- **Encourage development and implementation of formal data sharing agreements** among data funders, operators, and those analyzing results, if applicable, during the planning stages of the project (NYSERDA 2021) to ensure that expectations for data availability and intellectual property rights are clearly defined, data are effectively shared as required for regional analysis, and data are made available to the public in a timely manner (see below). It is recommended that this includes minimum data standards, where relevant. Data sharing agreements should clearly define the period of agreement, intended use of the data, constraints on the use of the data, data confidentiality (where relevant), data security (e.g., to ensure data are not lost due to file corruption or drive deterioration), and methods of data sharing.
- **Make data publicly available in a timely manner via common data portals**. Raw wildlife datasets (following Quality Assurance/Quality Control, or QA/QC procedures in which erroneous data are identified, corrected, or removed to the extent possible), co-collected environmental covariate and effort data (where relevant), and comprehensive metadata should be made publicly available in a consistent manner (NYSERDA 2021). A single database would ideally be chosen for each data type (e.g., OBIS-SEAMAP for survey data), informed by federal guidelines and recommendations (e.g., BOEM 2020), and in collaboration with the RWSC and other relevant research efforts. Available databases and their strengths and limitations are discussed in the NYSERDA 2021 report "*Wildlife Data Standardization and Sharing: Environmental Data Transparency for New York State Offshore Wind Energy.*" Regardless, newly collected wildlife data should be made publicly available as soon as possible based on the QA/QC and other requirements for each data type, and within two years regardless of data type (NYSERDA 2021). For multi-year data collection, it is recommended to release subsets of data (once they are completed and QA/QC'd) to ensure that data can be incorporated into broader efforts in a timely manner. In certain cases, there are potential limitations for OSW developers to share certain types of data that may be considered proprietary; this issue is likely to less often be relevant for regional research studies than for site-specific monitoring, but in these cases, it is encouraged that such data be released as soon as is feasible.
- **Report results clearly and consistently,** particularly key methodological and summary data, to support consistency in methods between studies and facilitate meta-analysis and other large-scale analysis efforts. Information such as the size of the sampled area relative to the geographic area of inference, for example, is important to retroactively assess effect size and inform meta-analysis efforts. Key data to report will likely be method-specific, but standardized reporting templates and frameworks do exist for certain data types, and for the remainder should be developed in consultation with subject matter experts and the RWSC. Clarity of reporting can be achieved by ensuring that, at minimum, the methods are replicable with the provided level of detail, and results can be interpreted by researchers in the field. Ideally results should also be

reported such that they can easily be understood by OSW industry, stakeholder, and public audiences.

- **Encourage independent peer-review and public accessibility of results.** Peer-review processes and publication of results should be a key aspect of any research plan. Peer-review by independent researchers helps to ensure scientific rigor of study methodologies and results. This can include peer-review of scientific journal articles or other processes that utilize subject matter expertise more informally to review results in a scientifically robust manner (e.g., federal agency review processes). While ideally findings should be published in the scientific literature, reports should, at a minimum, be made publicly available via existing public repositories such as Tethys (including the OSW Metadata Tool, currently in development[14]) to facilitate transparency (NYSERDA 2021) and to help ensure that results remain accessible for future large-scale analysis efforts.

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10.0 Appendices

Appendix A. Process for Development of this Document

E-TWG Specialist Committees

The Environmental Technical Working Group (E-TWG; http://nyetwg.com) was convened by the New York State Energy Research and Development Authority (NYSERDA) in 2018 to provide input to the state on environmental topics and advance common understanding among offshore wind stakeholders. The E-TWG assists the State to improve understanding of, and ability to manage for, potential effects of offshore wind energy development on wildlife. This involves the development of transparent, collaborative processes for identifying and addressing priority issues relating to wildlife monitoring and mitigation, with the goals of both improving outcomes for wildlife and reducing permitting risk and uncertainty for developers.

E-TWG "Specialist Committees," which are comprised of subject matter experts and a subset of E-TWG members, advance technical work supporting this mission. These committees are made up of volunteers, with technical and facilitation support from E-TWG support staff (Biodiversity Research Institute, the Cadmus Group, and the Consensus Building Institute). The committees develop collaborative, science-based products focused on priority issues, which are presented to the State of New York and the E-TWG, who provide review and comment.

Committee Formation

This document and the associated database of research recommendations were developed in response to a need identified by the E-TWG in 2021 to provide guidance for regional research in relation to understanding the effects and impacts of offshore wind development on wildlife and ecosystems. The workplan for the regional synthesis committee was developed with input from NYSERDA, the E-TWG, members of the (newly formed, at the time) Regional Wildlife Science Collaborative (RWSC), and the Responsible Offshore since Alliance (ROSA), as well as other regional science efforts such as the Offshore Wind Synthesis of Environmental Effects (SEER) effort funded by the U.S. Department of Energy, to ensure the committee's efforts would contribute to the goals of the broader OSW environmental community and avoid duplication of effort. Following these discussions, members of RWSC, ROSA, and SEER agreed to join the committee (Table C1). Additionally, the SEER team (including scientists from the National Renewable Energy Laboratory and Pacific Northwest National Lab) joined the committee's technical support team to support the development of the research recommendations database. The regional synthesis committee members (Table C1) were selected for their scientific expertise on study design, regional monitoring frameworks, and offshore wind development, as well as for representation across key wildlife taxa and ecosystem components.

Process

As the scientific technical support for the committee, BRI and the SEER group developed the two products (the database of research needs and this document) with substantial guidance and input from the workgroup. The workgroup met approximately monthly from December 2021 to April 2023 to discuss different aspects of the development of this document and that of the research recommendations database. In addition to extensive stakeholder feedback on draft products (below), the E-TWG reviews and provides input on committee products prior to finalization.

Stakeholder Feedback

Committee products were developed with extensive stakeholder community input. This process involved specific input and collaboration from regional science entities as well as feedback from a broad group of >200 stakeholders at public meetings and during designated periods for written feedback in 2022-2023. Three public meetings were held, along with requests for written feedback, to solicit input on committee products. The focus of these three stakeholder feedback periods were:

- Prioritization of regional research (cohosted by ROSA, July 2022), which largely shaped the development of Section 6 of this document.
- The draft U.S. Atlantic Offshore Wind Environmental Research Recommendations Database (September 2022).
- The complete draft of this document (May-June 2023).

A summary of the July 2022 meeting and recordings of the September 2022 and May 2023 meetings are available at https://www.nyetwg.com/regional-synthesis-workgroup.

Table C1. Participants in the Regional Synthesis Workgroup of the Environmental Technical Working Group. Participants are listed in alphabetical order (first name) by role.

Name	Organization	Role
Kate McClellan Press	NYSERDA	Committee Chair
Ally Sullivan	TotalEnergies	Workgroup member
Annie Murphy	INSPIRE Environmental	Workgroup member
Doug Nowacek	Duke University	Workgroup member
Emily Shumchenia	Regional Wildlife Science Collaborative	Workgroup member
Francine Kershaw	Natural Resources Defense Council	Workgroup member
Jennifer DuPont	Equinor Wind US	Workgroup member
Josh Kohut	Rutgers University	Workgroup member
Juliet Lamb	The Nature Conservancy	Workgroup member
Kyle Baker	Bureau of Ocean Energy Management	Workgroup member
Lesley Thorne	Stony Brook University	Workgroup member
Lisa Methratta	National Marine Fisheries Service (contractor)	Workgroup member
Mike Pol	Responsible Offshore Science Alliance	Workgroup member
Pam Loring	US Fish and Wildlife Service	Workgroup member
Peter Auster	U. of Connecticut/Mystic Aquarium	Workgroup member
Rebecca Green	National Renewable Energy Laboratory	Workgroup member, Support Staff
Renee Riley	NJ Dept. of Environmental Protection/Responsible Offshore Science Alliance	Workgroup member
Sofie van Parijs	Northeast Fisheries Science Center	Workgroup member
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Tim White	Bureau of Ocean Energy Management	Workgroup member
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Appendix B. Glossary of Terms

For purposes of this document, the below terms are defined specifically in relation to assessment of environmental effects from offshore wind development.

Abundance – The number of individuals from a biological population that are present in a geographic area of interest.

Atmospheric – Conditions and factors related to weather, climate, gas circulation, air quality, and other processes related to the Earth's atmosphere.

Attraction – The process by which individuals are drawn towards another object. In the offshore wind context, this includes individual attraction to structures for perceived food, shelter, or other resources, as well as attraction to features of offshore wind infrastructure such as artificial lighting.

Avoidance – Changes in directed movements such as migration or daily movements, in which an individual takes evasive action when in proximity to a wind farm to prevent collisions (for volant animals) or maintain a certain distance/separation from a wind farm or its components (for both aquatic and volant animals). Avoidance may occur at the scale of the wind farm (macro-avoidance) or at the scale of the turbine, cable, or other structure (meso-avoidance). For volant animals, micro-avoidance may also occur at the scale of the turbine blade, e.g., a last-minute evasion to prevent collision (NYSERDA 2020). See also "Displacement."

Baseline – Characterization of the existing environment, including the states, situations, or conditions in the absence of the conditions and stimuli from a particular activity that can be used as a reference when determining effects (ROSA 2021). In the U.S. Atlantic Offshore Wind Environmental Research Recommendations Database, baseline is used to distinguish recommendations related to understanding conditions prior to offshore wind development, in order to detect responses to the development and/or help disentangle the effects of OSW development from other anthropogenic activities.

Behavior – The responses (action or inaction) of an individual or group in response to internal or external stimuli (Levitis et al. 2009). In the context of effects, behavioral change may indicate response to OSW activities.

Collision – The instance of an individual striking or being struck by an object, causing potential injury or mortality. In the context of offshore wind energy development, this includes collisions of volant animals with offshore wind infrastructure (including turbine blades and other structures) and collisions of aquatic animals with vessels.

Conditions and Stimuli – Characteristics of a particular activity that may affect the receptor of interest (e.g., noise, changes in habitat, physical structures). Also known as "hazards" (Crichton 1999), "impact-producing factors" (BOEM 2021), and *"stressors"*.

Consequences – The short- and long-term individual or population-level effects of exposures and responses to offshore wind-related conditions and stimuli. Understanding of population-level cumulative consequences requires an understanding of demographic effects of individual responses. Consequences may include how responses to offshore wind development affect fitness through changes in reproduction, growth, or survival (Southall et al. 2021).

Control – Selected reference site or condition that is isolated from, but similar to, an affected offshore wind site or condition with regard to biological, physical, and environmental characteristics, as well as other anthropogenic uses (e.g., fishing, shipping activities; ROSA 2021).

Cumulative Impacts – The net effect of multiple activities associated with offshore wind development, which may be additive, synergistic, or countervailing to populations, communities, or ecosystems across spatiotemporal scales (Popper et al. 2022; Burton et al. 2020; Goodale and Milman 2016). Cumulative impacts may refer to impacts across multiple anthropogenic activities or specifically related to offshore wind development, either across effects from a particular project or across spatiotemporal scales.

Data Management – The process of gathering, organizing, vetting/reviewing, storing, modeling, interpreting, and sharing data. This includes topics related to data transparency and standardization.

Data Transparency – Sharing data or otherwise making it available to other users, whether publicly or on request. May include sharing of summary information and/or derived data products such as model outputs as well as sharing of original datasets.

Development Phase – Phase(s) of the development of an offshore wind energy project, including pre-construction activities such as seismic surveys, construction activities, operations and maintenance activities, and decommissioning.

Diet – The combination of foods typically consumed by a species or group of organisms. May vary by age class, sex, breeding stage, location, etc.

Distribution – The pattern by which species, taxon, or individuals are spatially arranged (NYSERDA 2020).

Disturbance – A physical force, agent, or process, either biotic or abiotic, that disrupts, perturbs, or stresses components of the ecosystem, community, population, or individual organism, causing changes to the physical environment, resources/habitat, physiology, behavior, or life history (White and Picket 1985; Beever et al. 2019).

Displacement – When animals temporarily or permanently adjust their habitat use, such as foraging or breeding, due to a new feature or disturbance, causing effective habitat loss (NYSERDA 2020). Includes avoidance behavior during directed movements (see "Avoidance").

Ecological Drivers – The natural or human-induced factors that directly or indirectly induce changes individuals, communities, or ecosystems. Often used to refer to environmental and oceanographic conditions that may directly or indirectly influence distributions, movements or behaviors.

Ecosystem – A biological community of interacting organisms and their physical environment (Chapin 2011).

Energetics – The energy-related properties of animals. Animals have energy "budgets," in which they must take in sufficient energy to perform necessary activities, such as foraging, reproducing, and migrating. Energetic impacts, or disruptions to these energy budgets, may have short-or long-term influences on individual survival or reproductive success (NYSERDA 2020).

Entanglement – The wrapping of lines, netting, or other materials of anthropogenic origin around the body of an animal. Entanglement in commercial fishing and aquaculture gear (both active and derelict) and certain types of marine debris can cause significant injuries and energetic consequences to marine species, affecting their ability to swim and feed.

Electromagnetic Field (EMF) – A force field consisting of both electric and magnetic components that can be generated by both natural and anthropogenic sources (in the latter case, emanating from human-made equipment that uses or carries electricity). In the offshore wind context, EMF primarily emanates from underwater cables, and may cause behavioral or other responses in species on or near the seabed (Hutchison et al. 2020).

Effect – A change or response that is linked to 1) an exposure to OSW conditions or stimuli (e.g., an offshore wind-related activity) and 2) sensitivity of the receptor to that activity, including both individual and population sensitivity. Effects represent a departure from a prior state, condition, or situation (called the "baseline" condition; Hawkins et al. 2020). Effects may be additive, synergistic, or countervailing. While National Environmental Protection Act (NEPA) regulations consider effect and impact synonymous, for the purposes of this effort, effect and impact are defined differently (see *Impact*), unless in reference to an "Environmental Impact Assessment."

Effect Size – Statistically determined direction and strength of a receptor's response to conditions and stimuli.

Exposure – Frequency and duration of contact or co-occurrence between an offshore wind activity and an environmental receptor that may result in a change or response of the receptor (Goodale and Milman 2016).

Food Web – The interconnected feeding relationships within an ecological community. It also implies the transfer of food energy from its source in plants through herbivores to carnivores.

[Project] Footprint – The project footprint includes areas of offshore wind projects containing turbine and substation structures. The project footprint represents part of the project site (see "Site-specific Scale").

Habitat – The array of physical factors (e.g., temperature, light) and biotic factors (e.g., presence of predators, availability of food) present in an area that support the survival of a particular individual or species.

Hypothesis – An explanation for an observable phenomenon, usually expressed in a testable manner. In the context of offshore wind development, a hypothesis represents a potential explanation for a receptor's response or a relationship between variables.

Impact – An effect that results in a change whose direction, magnitude and/or duration is sufficient to have biologically significant consequences for the fitness of individuals or populations (Hawkins et al. 2020). Impacts may be additive, synergistic, or countervailing. While National Environmental Protection Act (NEPA) regulations consider effect and impact synonymous, for the purposes of this effort, effect and impact are defined differently (see *Effect*).

Importance - In relation to prioritization of regional scale research topics, importance is defined by the degree that a study's objectives contribute to understanding of key regional and population-level effects of OSW, including disentangling OSW effects from other sources of change. Studies may either directly answer questions around regional- and population-level effects or contribute to that broader understanding in conjunction with other existing or ongoing research, but either way must have applicability to large-scale questions.

Lighting – The use of artificial lights to illuminate infrastructure, vessels, planes, and other objects, with the potential to cause attraction in some animals (see "Attraction").

Mitigation – Based on the mitigation hierarchy framework (see "Mitigation Hierarchy"), mitigation in the context of offshore wind energy development and wildlife relates to actions taken to avoid, minimize, or compensate for the negative effects of development. "Avoid" generally relates to siting and construction decisions, "minimization" includes measures that can be taken to reduce likelihood of effects, and "compensation" can include restoration and offsetting that could occur either in the area of development or offsite.

Mitigation Hierarchy - A framework to address the negative impacts of development on wildlife and ecosystems. It is applicable to projects in any sector, including renewable energy, and is based on the sequential and iterative application of three actions: avoid, minimize, and compensate. The latter includes both restoration and offsetting (Bennun et al. 2021).

Monitoring – A subset of research that involves collecting repeated systematic observations using the same methods and approaches in an area over time.

Movement – A change in the spatial location of an individual organism over time.

Multi-site Scale – See "Spatial Scale."

Noise – Sounds that are considered loud, disruptive, or unpleasant and can hinder the ability of individuals to detect signals or perform behaviors (Popper and Hawkins 2019). In the U.S. Atlantic Offshore Wind Environmental Research Recommendations Database, the terms "noise" and "sound" are at times used synonymously.

Occurrence – Basic information on the distribution, abundance, and temporal habitat use of receptors, including seasonal and interannual variability and elements of behavioral, movement, and acoustical ecology, among other characteristics (Southall et al. 2021). Used to inform understanding of exposure (above).

Oceanography – A science that includes the geological, chemical, and physical properties of the ocean and the processes that govern species' spread and development, including productivity and nutrient cycling (NYSERDA 2020; MIT-WHOI Joint Program 2022).

Physiology – The functions and activities of a living organism or its body parts; includes physical, biological, and chemical phenomena (NYSERDA 2020).

Population Dynamics – How a population of a species (i.e., a group of individuals of the same species that occupy a specific area over a certain period of time) changes in abundance or density over time. In an ecological context, often used specifically to refer to factors influencing reproductive success, survival, and/or immigration/emigration.

Population Sensitivity – Relates to the conservation status of a species or population, including factors such as population size and rate of population growth/decline, and assessments of population status such as the IUCN Red List (Furness et al. 2013, Robinson Wilmott et al. 2013, Kelsey et al. 2018, Goodale and

Stenhouse 2016). Assessments of population sensitivity may also be based on federal or state regulatory assessments (e.g., under the Endangered Species Act, Magnuson-Stevens Fishery Conservation and Management Act, Marine Mammal Protection Act, or state environmental protection laws) or nonregulatory assessments (e.g., Species of Greatest Conservation Need).

Power Analysis – Statistical methods that estimate the minimum sample size required to detect a specified amplitude of change with a given degree of confidence, which generally occurs *a priori* (NYSERDA 2020). *Post-hoc* analysis can also be used under certain circumstances to help inform the design of future work (Hoenig and Heisey 2001).

Project (also "Offshore Wind Project") – Geographic space and infrastructure that comprise an offshore wind energy facility, includes areas in which environmental effects from the facility occur, including areas outside the actual footprint of the facility, such as a cable corridor.

Receptor – Ecological entity, such as an individual, group, population, species, community, or ecosystem, which may be exposed to and/or affected by conditions and stimuli. For the purposes of the database, receptors include taxonomic groups (birds, bats, marine mammals, sea turtles, fishes, invertebrates) as well as ecological communities (benthos), and oceanographic and ecosystem dynamics.

Recommendation – Data gap and/or research need identified in the existing literature and synthesized in the Environmental Research Recommendations Database. Duplicative recommendations were synthesized within the database but were not further ranked or prioritized.

Regional Scale – See "Spatial Scale."

Research – Any type of hypothesis-driven scientific study that improves our understanding of populations and ecosystems, either generally or in relation to the effects of offshore wind development. Monitoring is considered a subset of research.

Response – How receptors may be influenced by or react to exposure to an activity, on either acute or long-term time scales. Responses can include measurable changes in physiological condition or behavior (e.g., communication, navigation, movements, habitat use) of an individual, group, population, or community (Southall et al. 2021).

Risk – The intersection of the probability of an effect, and the consequence or severity of that effect (Copping et al 2021). See "Effect."

Sensitivity – Properties of an organism or system that influence relative susceptibility to respond to conditions and stimuli. This encompasses sensitivity related to intrinsic and response behavior, physical tolerance, and habitat specialization. Population sensitivity relates to conservation status – See "Population Sensitivity."

Site-specific Scale – See "Spatial Scale."

Sound – Vibrations traveling through air, water, or other media that can be perceived by animals using the sense of hearing. Hearing capacities of species depend on the frequency and magnitude of sound as well as the degree to which sound is detected via pressure or particle motion (Popper and Hawkins 2019). In the U.S. Atlantic Offshore Wind Environmental Research Recommendations Database, the terms "noise" and "sound" are at times used synonymously.

Spatial Scale – The spatial extent at which an offshore wind-focused research study is conducted. While multi-site and regional-scale geographic extents more directly may be considered "regional research," studies at smaller spatial scales can also be considered regional in their implications if they contribute to a mechanistic understanding of ecosystem processes and/or focuses on methodological needs to inform assessment. The three main spatial scales of interest for research and monitoring studies include:

- **Site-specific Scale** – Geographic extent within which effects and responses occur in relation to individual turbines or a single offshore wind project footprint. May also include immediately adjacent areas outside a project footprint.
- **Multi-site Scale** – Geographic extent that is comprised of multiple offshore wind projects. Studies may be required to occur at this scale due to the need for larger sample sizes than can be achieved at a single wind farm, or because the research question of interest includes the examination of variation in effects between locations, time periods, or other characteristics.
- **Regional Scale** – Geographic extent that includes data collection focused outside of offshore wind project areas, instead of (or in addition to) focusing on wind project areas alone. Examples of regional-scale research include examination of broad-scale population characteristics such as demography or range-wide distributions, or the examination of interactive effects across multiple industries.

Study Design – a well-structured plan for implementing research, including topic, purpose, scope, questions and hypotheses, type of study best suited to answer the research question, study methods, and expected outcomes (De Vaus 2001).

Study Methods – set of tools, procedures, and approaches used to collect and analyze data to test a specific hypothesis (De Vaus 2001).

Technology – Human-made methods, systems, or devices. In the context of offshore wind energy environmental research needs and data gaps, technologies are generally machines or other devices that allow for or improve the data collection, analysis, and storage of data, or that aim to mitigate the effects of offshore wind energy activities on wildlife or ecosystems.

Topic – See "Recommendation."

Urgency – Immediacy of need.

Variable – A measured attribute associated with research. Includes independent or "explanatory" variables, dependent or "response" variables, and confounding variables (extraneous variables that relate to the study's independent and dependent variables and ideally should be controlled for in study design and post-hoc analyses to constrain variance and potential bias of results).

Vulnerability – Combination of individual sensitivity to a particular effect and population sensitivity to that effect, to encompass the degree to which a receptor or system will respond to exposure to conditions and stimuli.

Wildlife – Native flora and fauna, including marine mammals, sea turtles, birds, bats, fishes, and invertebrates, as well as their habitat, including benthic habitat and environmental, oceanographic, and atmospheric conditions.

Appendix C. Summary of Database Topics by Taxon, Category, and Overarching Topic

Table B1. Numbers of synthesized topics in the Atlantic Offshore Wind Environmental Research Recommendations Database by taxon/receptor, category of research need, and overarching topic. Overarching topics are defined as general ideas, concepts, or major principles related to offshore wind effects on wildlife, oceanography and ecosystems, defined based on existing effects and consequences frameworks. Overarching topics are nested within categories. This is intended to be a high-level summary of topic areas included in the database; for more information, including definitions of categories and overarching topics, please refer to the database ReadMe file at: https://tethys.pnnl.gov/atlantic-offshore-wind-environmental-research-recommendations.

Category	Overarching Topic	Bats	Birds	Benthos	Ecosystem/ Oceanographic	Fishes	Inverte-brates	Marine mammals	Sea turtles	Total
Occurrence	Baseline environmental conditions			1	2	2	2	2		4
	Behavior		2					3	1	5
	Diet	1	1	1	1	1	1	1	1	1
	Distribution and Abundance	1	1	2		2	3	1	1	4
	Ecological Drivers	1	3	1	2	3	2	2	2	5
	Food web dynamics	1	2	1	1	2	1			3
	Habitat use	1	1	1	1	2	2	2	1	3
	Health and Energetics		1					1	1	3
	Movement patterns	2	2	1		1		1	1	2
	Physiology and stress	1	1	1		2	2	3	2	4
	Population dynamics		3	1		2	1	1		3
	Presence	1	1	1		1	1	1	1	2
	Occurrence Subtotal	*9*	*18*	*11*	*7*	*18*	*15*	*18*	*11*	*39*
Conditions & Stimuli	Changes in biological characteristics of ecosystem			5	2	2	1			5
	Changes in physical and chemical characteristics of ecosystem			3	6	1	1	1		8
	Changes in sound characteristics of ecosystem			1	1	1	1	2	1	2
	Conditions/Stimuli Subtotal			*9*	*9*	*4*	*3*	*3*	*1*	*15*
Exposure and Vulnerability	Exposure to changes in sound/vibration			1		1	1	1	1	1
	Exposure to changes in vessel traffic							1	1	1
	Exposure to wind turbine structures	1				1		1	1	3
	Exposure/Vulnerability Subtotal	*1*		*1*		*2*	*1*	*3*	*3*	*5*

Category	Overarching Topic	Bats	Birds	Benthos	Ecosystem/ Oceanographic	Fishes	Inverte-brates	Marine mammals	Sea turtles	Total
Response	Acoustic response			1		2	2	4		5
	Behavioral response		1	4		4	3	5	3	8
	Changes in food web dynamics		1	3	2	2	2	1		5
	Changes in habitat and resources		4	4		4	3	3	2	9
	Changes in hydrodynamics			2	2	2	1			2
	Distribution change	4	8	9	3	11	7	6	3	19
	Energetic/Body condition response			1		2	2	1		3
	Injury and Mortality	4	3	1		3	1	3		7
	Seafloor disturbance			8	4	2	2			9
	Stress/Physiological/Developmental response			2		3	3	2	1	3
	Response Subtotal	*8*	*17*	*35*	*11*	*35*	*26*	*27*	*9*	*70*
Consequences	Changes in ecosystem structure or function			9	3	5	1	1	1	9
	Changes in habitat use or structure			1		1				2
	Health and Energetics		1	1		2	1	2		3
	Population dynamics		1	2		2	1	3	1	5
	Vital rates	1	1	1	1	1	1	2		2
	Consequences Subtotal	*1*	*3*	*14*	*4*	*11*	*4*	*8*	*2*	*21*
Methodological	Data standardization/transparency	4	6	4	4	3	3	5	4	6
	Mitigation	8	8	5	4	8	6	7	2	13
	Monitoring/analytical approaches	12	21	10	11	12	10	24	6	42
	Risk assessment processes	1	6	1		3	1	3	1	8
	Methodological Subtotal	*25*	*42*	*20*	*19*	*26*	*20*	*39*	*13*	*69*
TOTAL		44	79	90	50	96	69	96	39	219