Workshop Proceedings for the

State of the Science Workshop on Wildlife and Offshore Wind Energy 2020: Cumulative Impacts

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Additional Information

These proceedings are available in PDF format and may be downloaded from the workshop website at www.nyetwg.com/past-workshops. Additional workshop information may also be found at this website.

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Abbreviations

BACI- Before-after-control-impact study design

BAG- Before-after-gradient study design

BOEM – Bureau of Ocean Energy Management

CEK – Cumulative Effects Framework

CIA – Cumulative Impact Assessment

COP – Construction and Operations Plan

CRM – Collision Risk Model

CUI – Cumulative Utilization and Impact

EMF – Electromagnetic field

E-TWG – Environmental Technical Working Group

KEC – Framework for the Assessment of Ecological and Cumulative Effects

MW - Megawatt

NOAA – National Oceanic and Atmospheric Administration

NYSERDA – New York State Energy Research and Development Authority

OCS – Outer Continental Shelf

OSW – Offshore wind

PCoD – Population Consequences of Disturbance model

PCoMS – Population Consequences of Multiple Stressors model

PVA – Population Viability Analysis

RODEO – Realtime Opportunity for Development Environmental Observations

ROSA – Regional Offshore Science Alliance

RWSE – Regional Wildlife Science Entity (now the Regional Wildlife Science Collaborative)

SEIS – Supplemental Environmental Impact Statement

WinMon.Be – Belgian Offshore Wind Farm Environmental Monitoring Programme

WOZEP – Dutch Government Offshore Wind Ecological Programme

Executive Summary

Offshore wind (OSW) energy development represents a new industry in the United States. While a key strategy in reducing greenhouse gas emissions, OSW energy development poses potential negative effects to wildlife and ecosystems including: oceanographic change; seafloor disturbance; sound-related effects; collision risk; and changes to wildlife behavior and movement patterns. Potential individual and local effects form the basis of our understanding of areas of the ecosystem where there is potential for cumulative impacts to populations or communities.

The 2020 State of the Science Workshop on Wildlife and Offshore Wind was hosted by the New York Energy Research and Development Authority (NYSERDA) to explore the topic of cumulative biological impacts from OSW development. The Workshop brought together researchers, managers, and other stakeholders to assess the state of knowledge regarding potential cumulative impacts on wildlife populations and ecosystems from OSW development and to identify research that could be implemented in the next five years to position the stakeholder community to better understand cumulative biological impacts from the OSW industry as it progresses in the U.S.

The Workshop consisted of three primary components:

- Conference presentation sessions held on 16-20 November 2020
  Twenty-three plenary presentations and 20 lightning talks helped foster an exchange of information on the current state of knowledge on cumulative biological impacts from OSW development, drawing from expertise in Europe and around the U.S.

- Formation of workgroups to identify priorities
  Following plenary sessions, Conference attendees broke out into seven workgroups focused on the following topics: 1) benthos; 2) fishes and aquatic invertebrates (focusing on effects of sound); 3) birds; 4) bats; 5) marine mammals; 6) sea turtles; and 7) environmental change (focusing on potential changes in stratification).

  Over the winter/spring of 2020-2021, these workgroups met to identify priority research needs and data gaps to inform our understanding of cumulative biological impacts from OSW energy development. Each of these groups identified a list of studies that could be implemented over the next five years to position the stakeholder community to better understand potential cumulative biological impacts as the offshore wind industry develops in the U.S. Workgroup members represented a wide range of perspectives from offshore industry, government agencies, nonprofit organizations, and academia.

- Final webinar -- May 2021
  For the third component of the State of the Science Workshop, each of the workgroups

presented an overview of the recommendations from the seven workgroups in a webinar in May 2021. Each group also produced a report detailing their recommendations[1].

Several themes emerged from workshop presentations, discussions, and workgroup reports. These included: 1) the need to consider positive as well as negative effects from OSW energy development; 2) the importance of baseline data on the habitat use, demographics, resources, and energetics of populations to inform cumulative impacts studies and models; 3) the necessity of understanding sources and causes of variation in order to disentangle effects of OSW from other stressors, including climate change; 4) the benefit of large-scale thinking using a regional ecosystem-level lens to ensure we can conceptualize localized observed effects to improve our understanding of cumulative impacts; 5) the utility of building from previous knowledge and designing studies carefully to fill key data gaps; and 6) the need for a coordinated, comprehensive strategy with clear objectives, based on a holistic research framework, that is developed and executed with broad stakeholder input.

There are tools and frameworks that can be used to integrate existing knowledge about wildlife and ecosystem responses to OSW stressors and examine the potential consequences to population-level fitness or ecosystem function. However, any model or framework is only as good as the data used to populate it, and there is a need for careful consideration of study design, data transparency, and coordination to fill key knowledge gaps. While the identification of research priorities happened largely independently within each of the seven State of the Science workgroups, it became clear that priorities will need to be considered in an integrated framework across taxa and ecosystem components to appropriately prioritize and integrate future research and monitoring efforts.

[1] Webinar recording and workgroup reports are available at https://www.nyetwg.com/2020-workgroups

1 Introduction

The OSW Environmental Technical Working Group (E-TWG[2]) has recognized the importance of regional coordination, collaboration, and sharing of information among stakeholders on topics relating to wildlife impacts from OSW development in the eastern U.S. The State of the Science Workshops on Wildlife and Offshore Wind Energy Development provide an opportunity for researchers, managers, and stakeholders to share knowledge and work together towards common goals of environmentally responsible OSW development. On behalf of the E-TWG, NYSERDA hosted the second State of the Science Workshop on November 16-20, 2020. This event was followed by a series of related workgroup meetings and a final webinar in May 2021. The aim of the workshop and related efforts was to assess the state of knowledge regarding potential *cumulative biological effects* to wildlife populations and ecosystems from OSW development (see definitions in Table 1). This effort was focused on understanding effects specifically from OSW energy development; however, this focus was not intended to imply that OSW is causing greater impacts than other stressors. Cumulative impact estimates for OSW energy development will be useful in broader cumulative effects frameworks that include impacts from multiple types of anthropogenic activities.

1.1 Virtual Workshop

The virtual workshop in November 2020 included more than 430 attendees from 21 states and 20 countries. Twenty-three plenary presentations fostered an exchange of information on the current state of knowledge on cumulative biological impacts from OSW energy development, drawing from expertise in Europe and the U.S (see Appendix A for full workshop agenda). Each plenary session included presentations as well as an opportunity for questions and answers (Q&A) and panel discussion (see Appendices B-G). Twenty lightning talks on a broader range of topics were also presented.[3] The week culminated in breakout group discussions as a way to introduce workgroup efforts (see below). The plenary presentations are listed below by general session theme:

Frameworks for Understanding Cumulative Impacts from Offshore Wind Energy Development

- Cumulative Anthropogenic Impacts on the World's Oceans. Sara Maxwell, University of Washington
- Framework for Defining the Scope of Cumulative Adverse Effects Assessments for Offshore Wind. Wing Goodale, Biodiversity Research Institute
- An Ecosystem Functioning Approach for Thinking about Cumulative Impacts. Steven Degraer, Royal Belgian Institute of Natural Sciences
- Metapopulation PVA: Developing Methods for Reducing Uncertainty in Impact Assessments. Julie Miller, Marine Scotland Science
- Decision Framework to Identify Populations that are Vulnerable to Population-level Effects of Disturbance. Cormac Booth, SMRU Consulting

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[2] More information on the E-TWG can be found at nyetwg.com.

[3] Lightning talk abstracts and presentations available here: https://www.nyetwg.com/2020-lightning-talks

- Approaches to Understanding Cumulative Effects of Stressors on Marine Mammals. Peter Tyack, University of St. Andrews

European Efforts to Understand Cumulative Impacts from Offshore Wind Energy Development.

- Assessing Cumulative Effects: Challenges Faced by Offshore Wind Developers. Madeline Hodge, Ørsted
- WinMon.BE: The Belgian Countrywide Research Program to Understand Cumulative Impacts of Offshore Wind energy development. Steven Degraer, Royal Belgian Institute of Natural Sciences
- Offshore Wind Farms: Cumulative Impact Assessments in the Netherlands. Astrid Potiek, Bureau Waardenburg
- Developing a Cumulative Effects Framework (CEF) for Key Ecological Receptors in Relation to Offshore Wind in the UK. Kate Searle, UK Centre for Ecology and Hydrology

Current Knowledge on Cumulative Impacts

- Cumulative Impacts of Displacement on Seabirds. Stefan Garthe, Kiel University
- Cumulative Impacts to Birds from Collisions with Offshore Wind Farms. Aonghais Cook, British Trust for Ornithology
- Cumulative Physical Effects of Offshore Wind Energy Development on Oceanographic Processes. Jeff Carpenter, Institute of Coastal Research, Helmholtz-Zentrum Geesthacht
- Cumulative Effects of Offshore Wind on Benthic Habitats. Drew Carey, INSPIRE Environmental
- Cumulative Noise Impacts Upon Fishes (and Turtles) from Offshore Wind Construction and Operation. Arthur Popper, University of Maryland; Anthony Hawkins, Loughine Ltd.
- Cumulative Noise Impacts to Marine Mammals from Offshore Wind energy development and Operations. Brandon Southall, Southall Environmental Associates Inc.; Howard Rosenbaum, Wildlife Conservation Society
- Vessel Encounter Risk Model Tool. Mary Jo Barkaszi, CSA Ocean Sciences Inc.
- Population Impacts to Bats from Wind Energy Development. Cris Hein, National Renewable Energy Laboratory
- Synthesis of the Science: Interactions Between Offshore Wind energy development and Fisheries. Andrew Lipsky, NOAA Fisheries; Brian Hooker, Bureau of Ocean Energy Management; Annie Hawkins, Responsible Offshore Development Alliance; Lyndie Hice-Dunton, Responsible Offshore Science Alliance

Designing Studies to Assess Cumulative Impacts

- Designing Studies to Detect the Ecological Impacts of Offshore Wind energy development. Elizabeth Methratta, contractor to NOAA Northeast Fisheries Science Center
- The Vineyard Wind SEIS: Assumptions Made in the Cumulative Impact Scenario. Ian Slayton, Bureau of Ocean Energy Management
- Designing Monitoring to Detect Cumulative Impacts and Address the Confounding Variable of Climate Change. Jon Hare, NOAA Northeast Fisheries Science Center

Table 1. Definitions and Concepts. For the purposes of the 2020 State of the Science Workshop and related efforts, including this report, several concepts were defined to ensure commonality of meaning when used in plenary sessions and workgroup discussions.

Term	Definition
Attraction	When animals adjust their habitat use towards a new feature.
Avoidance	Any action taken by an individual when in proximity to an operational wind farm to prevent collision. Avoidance may occur at the scale of the wind farm (macro-avoidance), at the scale of the turbine (meso-avoidance), or at the scale of the turbine blade (micro-avoidance).
Barrier Effects	The impacts on animals due to obstacles to movement (such as increased energetic requirements to fly around, rather than through, a wind facility).
Collision	Animals may collide with turbines or other structures as a result of attraction and/or a lack of avoidance behavior.
Cumulative Impacts	Also “cumulative biological impacts.” Interacting or compounding effects across spatiotemporal scales, caused by anthropogenic activities relating to the development and operation of multiple offshore wind energy facilities, that collectively affect wildlife populations or ecosystems.
Displacement	When animals adjust their habitat use, such as foraging or breeding, due to a new feature or disturbance, causing effective habitat loss.
Effect	A change caused by an exposure to an anthropogenic activity that is a departure from a prior state, condition, or situation, which is called the “baseline” condition (after Hawkins et al. 2020).
Exposure	The extent of overlap in space and time between animals’ distribution or abundance and offshore wind energy development.
Impact	A biologically significant change whose direction, magnitude and/or duration is sufficient to have consequences for the fitness of individuals or populations (after Hawkins et al. 2020).
Oceanographic Change	Change including altered turbidity, stratification, wake effects, and others that may affect prey populations and habitats, and/or mediate behavioral, physiological, or energetic changes to predator populations.
Offshore Wind Energy Development	Activities related to preconstruction, construction, and operations of OSW facilities.
Sound	Term incorporating sound pressure, particle motion, and substrate vibration.

1.2 Workgroup Efforts

Following the plenary sessions in November, seven workgroups met throughout the winter of 2020-2021 to discuss scientific research, monitoring, and coordination needs to improve understanding of cumulative impacts. The goal for each workgroup was to identify a list of studies that could be implemented in the next five years to position the stakeholder community to better understand cumulative impacts as the OSW industry develops in the U.S.

The foci of these groups were: birds, bats, marine mammals, sea turtles, fishes and aquatic invertebrates, benthos, and environmental change (Table 2). There was substantial effort to reduce potential overlap between workgroups as well as with other ongoing efforts. In particular, the fishes and aquatic invertebrates workgroup focused exclusively on the effects of vibration and sound, while the benthos workgroup focused on artificial reef effects, seafloor disturbance, and energy introduction to avoid potential overlap between these two groups as well as with the concurrent Synthesis of the Science effort being led by the Responsible Offshore Science Alliance (ROSA). Likewise, to best apply the expertise of workgroup members, the environmental change workgroup focused primarily on effects relating to changes in stratification.

Over 240 workgroup participants offered expertise and a wide range of perspectives from offshore industry, government agencies, nonprofit organizations, and academia. Workgroup meetings were managed by group leads (Table 2) and workshop staff to identify and prioritize key topics of interest. Workgroup members also provided input on the relative priority of topics via live polls and/or online surveys. All workgroup documents were shared via a document collaboration platform (e.g., Google Drive, Microsoft Teams), and workgroup members had multiple opportunities over the course of several months to provide written input on draft reports.

Workgroup approaches—and thus resulting reports—varied substantially within this general process, with some groups aiming to develop comprehensive lists of potential research studies within an organizational framework (e.g., benthos and marine mammal groups), while others focused on a smaller number of key research needs as identified by group members (e.g., sea turtle and environmental change groups). However, all seven groups endeavored to identify a handful of top-priority short-term research needs, potential methods, and related information.

Table 2. **Workgroup technical leads and coleads and numbers of workgroup participants**. Technical leads are listed first, coleads second (the benthos workgroup had two technical leads). Full lists of workgroup participants are available in individual workgroup reports[4].

Workgroup	Workgroup Leads	Participants
Bats	Cris Hein, National Renewable Energy Laboratory	37
Benthos	Steven Degraer, Royal Belgian Institute of Natural Sciences Zoe Hutchison, University of St. Andrews Carl Lobue, The Nature Conservancy	36
Birds	Aonghais Cook, British Trust for Ornithology Jillian Liner, Audubon New York	76
Environmental Change	Jeff Carpenter, Helmholtz-Zentrum-Geesthacht	29
Fishes & Aquatic Invertebrates	Arthur N. Popper, University of Maryland & Environmental BioAcoustics LLC Lyndie Hice-Dunton, Responsible Offshore Science Alliance	42
Marine Mammals	Brandon Southall, Southall Environmental Associates, Inc Laura Morse, Ørsted	88
Sea Turtles	Gregg Gitschlag, National Oceanic and Atmospheric Administration (retired) Ruth Perry, Shell New Energies	30

The intended audience for these reports encompasses a range of stakeholders including researchers, state and federal agencies, OSW developers, regional science entities, and other potential funding entities who could potentially target these priorities for future funding.

On May 21, 2021, more than 360 people from 13 countries attended the final webinar for this effort[5], in which the technical leads from the seven workgroups presented summaries of their group outcomes and discussed common themes among groups.

1.3 Focus of this Proceedings

The remainder of this report focuses on summarizing the state of knowledge around cumulative effects of OSW energy development on wildlife from plenary presentation sessions (Section 2), and synthesizing key research and coordination needs, drawing from plenaries, workgroup discussions, and workgroup reports (Section 3). Following these syntheses, individual workgroup summaries provide more specific needs identified by each of the seven groups (Section 4).

2 Summary of Plenary Sessions

The Workshop's six plenary sessions, held the week of 16-20 November 2020, focused on assessing the state of knowledge regarding cumulative impacts of OSW energy development on wildlife populations and ecosystems (Appendix A). Individual summaries of the 23 plenary presentations and related Q&A sessions may be found in Appendices B-G. This section is a synthesis of common themes and ideas discussed during plenary presentations (**Fig 1**). Topics

[4] Workgroup reports are available at http://www.nyetwg.com/2020-workgroups

[5] Webinar recording and final workgroup reports available at http://www.nyetwg.com/2020-workgroups

from lightning talks are also included where relevant to discussions of cumulative effects. References to specific plenary presentations are noted parenthetically by presenter's last name.

2.1 State of Knowledge of the Effects of Offshore Wind Energy Development on Wildlife

Marine ecosystems are dynamic, with daily, seasonal, and annual variation in environmental conditions and wildlife distributions. These systems have many stressors acting upon them, including resource competition from fisheries, climate change, shipping and fossil fuel industries, and pollution (Maxwell). OSW development is a new industry in the eastern U.S being introduced into this highly dynamic system, and represents a key strategy in transitioning to renewable energy and reducing greenhouse gas emissions (IPCC 2021). Thus, OSW energy development has the potential to positively impact wildlife and ecosystems globally. Locally, effects for individual species can be negative, such as displacement, or positive, such as turbines supporting prey resources (Bailey et al. 2014). Specific effects at this local scale (e.g., a single wind turbine or OSW farm) may accumulate over space and time in linear, additive, or more complex ways (Renn 2008), resulting in the potential for population-level effects.

Offshore wind energy development represents several hazards, with potential direct and indirect effect pathways (Fig 2). The first steps in understanding cumulative impacts are understanding: 1) the potential effect pathways; 2) vulnerability of different species to these effects; and 3) exposure based on species' distributions in space and time (Goodale). Assessing vulnerability of any species, group, or ecosystem component requires understanding behavior, physiological constraints, and habitat use and specialization. For example, processes during construction (e.g., installation of turbine foundations) may lead to **seafloor disturbance** (Degraer et al. 2020) and **sound-related effects** (Heinis et al. 2015). While there is a body of knowledge related to the effects of sound on marine mammals, gaps remain in our understanding for fishes and sea turtles (Popper). Much less is known about the hearing sensitivity of these species, potential behavioral effects, and variation in effects across species.

Once wind farms are built, physical changes to the environment can occur, which may in turn have ecological effects. **Oceanographic change**, such as changes in turbulence, stratification, and mixing (Carpenter[6]), as well as the introduction of hard substrate (e.g., turbine foundations) in the benthic environment, can have cascading effects on marine ecosystems, including **habitat change** (e.g., expansion, suitability), enrichment via benthic-pelagic coupling, and altered connectivity (Carey). **Electromagnetic fields** from cables may affect the behavior or movements of sensitive species near the seafloor (Gill 2005). The construction and operation of wind farms may also **increase vessel traffic** (Dolman & Simmonds 2010), which has potential implications for taxa such as marine mammals and sea turtles that collide with vessels (Barkaszi), and may also influence **avoidance** and **attraction** of aquatic species including fishes, marine mammals, sea turtles, and seabirds (Dierschke et al. 2016, Brandt et al. 2018).

[6] References to plenary presentations are noted parenthetically by presenter's last name. See Appendices B-G for full summaries.

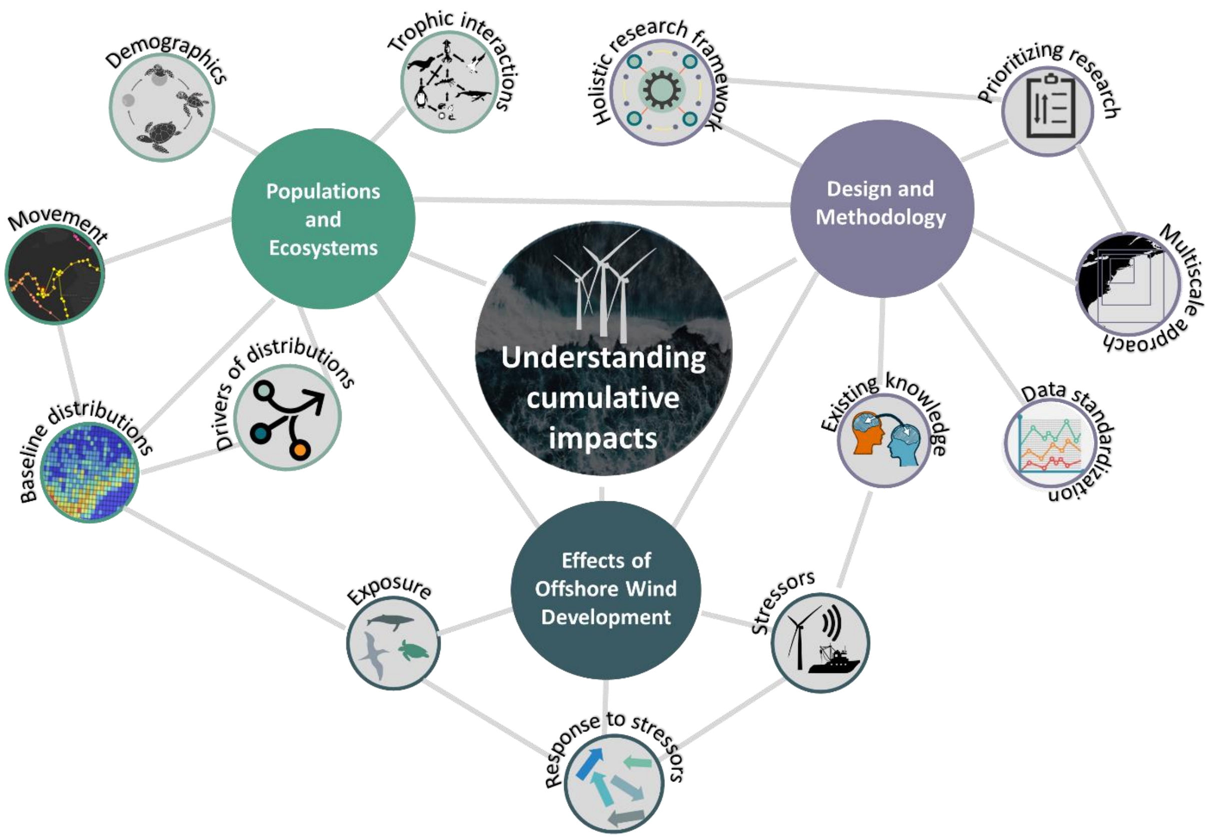


Fig 1. Information and methodological needs to inform a collective understanding of cumulative impacts from offshore wind energy development. Color-coded categories include design and methodology, populations and ecosystems, and effects of offshore wind energy development.

During the operational period, volant species may respond to the above-water structures (e.g., turbines, substations) via attraction, avoidance, or **displacement** resulting in short- or long-term changes in available habitat (Peschko et al. 2021, Vanermen & Stienen 2019). Displacement patterns have been observed in some species in Europe, including red-throated loons (Mendel et al. 2019), but much less is understood about how displacement relates to population dynamics (Garthe). Birds and bats also have the potential to collide with OSW turbines (Cook). Some bat species are substantially impacted by terrestrial wind farms, but less is known about potential **collision risk** for this taxon in the offshore environment (Hein). Due to challenges in direct measurement, understanding avian collision risk currently relies heavily on collision risk modeling (Band 2012); while current data is informative, improving predictions will require additional information on avoidance rates, behavior, flight speeds, and flight heights of species.

Combined, the above individual and local-scale effects form the basis for our understanding of areas of the ecosystem where there is the potential for cumulative impacts from OSW energy development. While we have learned a great deal to date, knowledge gaps remain, particularly regarding the applicability of knowledge from Europe for predicting effects to species and habitats in the U.S., and the potential for wind farm design factors (such as including distance from shore, turbine size, and turbine spacing) to influence the existence and degree of effects.

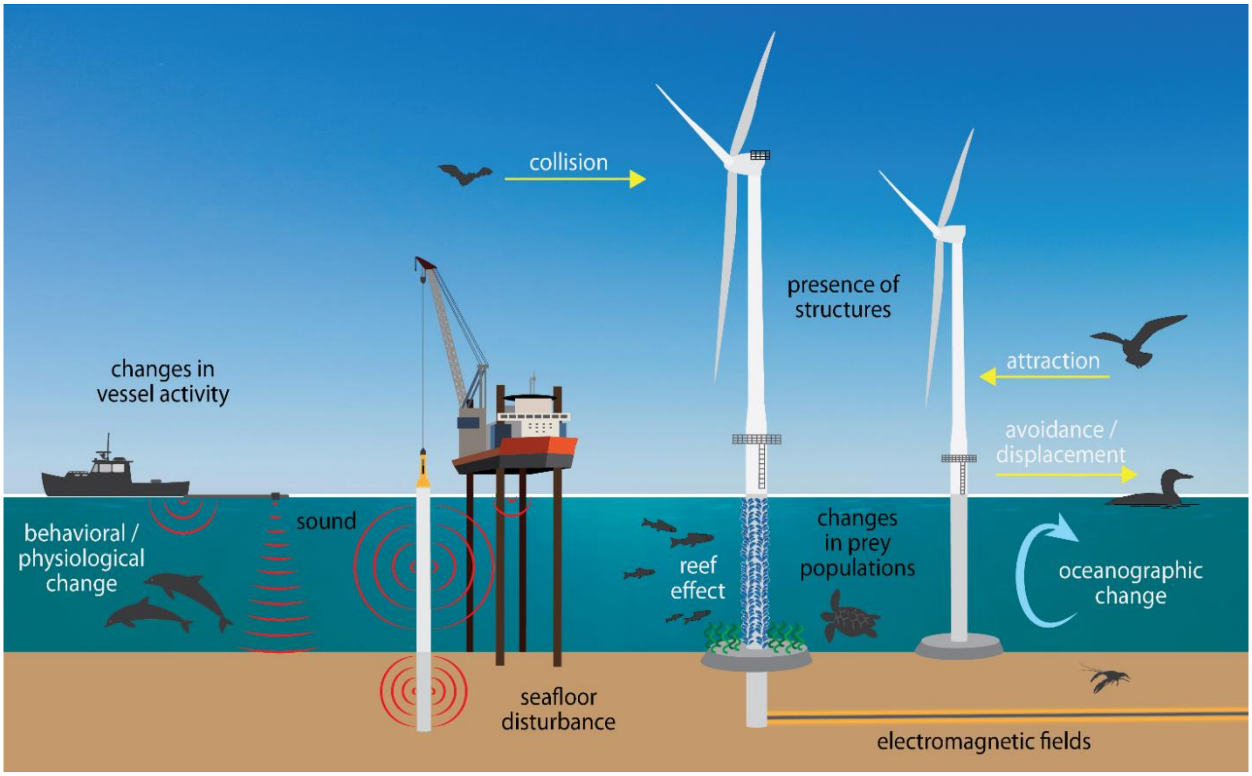


Fig 2. Potential stressors (black labels) and effects (white labels) of offshore wind energy development on wildlife. These include activities during the preconstruction period (e.g., seismic surveys), construction (e.g., pile driving, seafloor disturbance), and operations (e.g., presence of structures). Some stressors may cause oceanographic or other habitat change, which may result in further effects such as avoidance, displacement, attraction, or other behavioral and physiological changes.

2.2 Scaling from Individual Effects to Cumulative Impacts

The potential effects described above may occur locally at the turbine or wind farm scale, and can lead to cumulative impacts if they are: 1) negative effects on wildlife or ecosystems; 2) occur across multiple OSW farms; and 3) have consequences for population-level fitness or ecosystem function. There are various assessment tools and frameworks in development or currently in use that are focused on understanding effects to populations from specific stressors. **Population Viability Analysis (PVA)** uses demographic data to estimate population-level risk from a stressor that may affect fitness (Maclean et al. 2007), and recent extensions incorporate the role of population connectivity and metapopulation dynamics in understanding population viability in the face of such stressors (Miller). There are multiple models for understanding population-level risk to marine mammals from noise, including:

1) **Population Consequences of Disturbance (PCoD) models** – used to estimate impacts of noise on a population. Key sensitivities in these models include population size, impact threshold, extent and duration of disturbance, and how disturbance affects vital rates (Booth).

2) **Semi-quantitative risk assessments** – used to examine relative risk level based on magnitude of noise exposure and species vulnerability while accounting for population and environmental risk (Southall).

To assess **vessel encounter risk**, a tool has been developed for the Bureau of Ocean Energy Management (BOEM) to characterize vessel strike risk from OSW development while accounting for spatial, temporal, and species-specific parameters (Barkaszi). There are also models and frameworks to integrate the potential effects of multiple stressors, including the **Population Consequences of Multiple Stressors model**, which is designed to integrate the effects of short-term responses to multiple stressors and link them to long-term changes in survival and reproduction in marine mammals (National Academies of Science Engineering and Medicine 2017). These models and frameworks help to translate our understanding of individual- or local-scale effects into larger-scale assessments of the potential for cumulative impacts (Tyack). The **UK Cumulative Effects Framework (CEK)** estimates baseline distributions and population parameters, and uses PVA to examine effects of wind farms on demographic rates (Searle). This framework provides a good starting point, but could be improved with additional data collection, inclusion of key ecological processes (e.g., attraction, metapopulation dynamics), and additional quantification of uncertainty.

Understanding the potential cumulative impacts from OSW energy development also requires disentangling the effects of OSW energy development from those of other stressors, including fisheries and climate change. Long-term monitoring to understand the status and trends of populations and ecosystems is a first step towards this goal, and a variety of work is being done to explore cumulative impacts from different industries (e.g., fisheries) and the potential role of climate change (Hare). However, any model or framework is only as good as the data used. As such, there is a need for careful consideration of study design, data transparency, and coordination as we work to fill key knowledge gaps.

2.3 Study Design Considerations and the Need for a Coordinated Approach

Advancing our understanding of potential effects of OSW development on wildlife and ecosystems requires thoughtful study design and data analysis. Study methods should be based on the type of predicted relationship, the hypothesis being tested, and existing knowledge of the study species and effect (Methratta). For example, the Before-After-Control-Impact (BACI) design has been commonly used to study changes in distributions and habitat use at OSW farms (Underwood 1991, Underwood 1993, Underwood 1994), but the Before-After-Gradient (BAG) design allows distance from turbines to help explain variability in the response, and thus may be a more effective design to answer some types of questions (Methratta 2020). Other critical design considerations include power analysis to ensure that the study design (including projected sample size) is adequate to detect potential effects, and the ability to transfer findings at the individual turbine scale to inform our understanding of effects at wind farm or regional scales (Degraer).

There is a general need for consistent, transparent approaches to effects studies, such that findings can inform cumulative impact assessments. A lack of coordination among cumulative impact assessments for OSW in the UK has led to the use of different parameters and methodologies between studies, reducing data transferability and scalability (Hodge). Even with a more centralized approach, variability in data collection and uncertainty can lead to assumptions that can greatly influence results (Slayton). Coordination of how data are collected and the methods and models used to scale up individual effects to cumulative impacts will be important to improve the state of knowledge. There are several examples of such coordinated efforts. The Belgian Offshore Wind Farm Environmental Monitoring Programme (WinMon.Be; Degraer) and Dutch Governmental Offshore Wind Ecological Programme (WOZEP; Potiek) exemplify the benefits of centrally managed research programs and collaborative processes to develop research goals, fill key data gaps to inform impact assessments, and inform adaptive management. The Regional Offshore Science Alliance (ROSA; focused on interactions between OSW and fisheries; Lipsky et al.) and the Regional Wildlife Science Entity (RWSE; focused on OSW and wildlife; Press) have been initiated in the U.S. in recognition of this need for coordinated regional research. The formation of these regional bodies represents a first step in ensuring regional coordination and collaboration as the industry progresses in the U.S.

2.4 Summary: Key Considerations for Assessing Cumulative Impacts

Several themes emerged from workshop presentations and discussions. Plenary speakers noted that as we work to fill knowledge gaps and improve our understanding of cumulative impacts from OSW energy development on wildlife and the physical environment, OSW industry stakeholders will need to focus on:

- **Considering positive as well as negative effects**. The focus of research is often on the negative impacts of OSW energy development. However, it is important to consider the positive effects as well, both in terms of specific or local-scale effects (e.g., increased foraging opportunities with changes in habitat) and the overall benefits of renewable energy.
- **The importance of long-term baseline data.** High quality baseline data is hugely important to understand changes and to tease apart the potential drivers of those changes. Long-term data on spatiotemporal habitat use, baseline demographic data (e.g., survival, productivity, population trends), prey dynamics, and energetics can help to improve understanding of potential effects to wildlife from OSW energy development, and distinguish these from the effects of other stressors. These types of baseline data will help make population and cumulative impacts modeling more effective, which will inform efforts to minimize or mitigate the effects of OSW energy development as well as broader conservation efforts.
- **Focusing on sublethal effects.** Many cumulative impacts are not immediately lethal (e.g., noise disturbance, avian displacement), and therefore the sublethal impacts of OSW energy development need to be better understood in order to assess their effects on individual fitness or population status.
- **Considering effects to ecosystem function.** In addition to understanding effects on species or populations, it is important to focus on understanding potential impacts to communities and ecosystem function. Many wildlife populations and food webs are already stressed by anthropogenic sources such as climate change, and the ecology of

these ecosystems need to be considered holistically in order to understand and minimize cumulative impacts from OSW energy development activities.

- **Understanding variation.** It is important to understand variation in effects in space and time. Effects observed at European wind farms may or may not be directly transferable to the eastern U.S., and smaller-scale regional differences in ecosystem dynamics may lead to variation in how species and ecosystems respond to OSW energy development. Understanding the degree of variation in species responses, and drivers of this variation, is essential in order to accurately predict wind farm or industry-wide effects based on smaller-scale studies.
- **Considering a range of scales.** In order to understand cumulative impacts, it is important to understand how results produced at a local scale inform our understanding of the larger regional ecosystem. This requires spatial conceptualization of locally observed effects and the modeling of cumulative impacts on larger scales. Studying cumulative impacts is challenging, and as such, it may be necessary to focus on filling smaller gaps in knowledge over time rather than trying to answer bigger questions all at once. Building from previous knowledge in other systems and adequately designing studies will help ensure that research conducted at all spatial and temporal scales contributes to an understanding of cumulative impacts.
- **Coordinated approaches.** The best approach to understanding cumulative impacts is to invest in a coordinated, comprehensive, and continuous monitoring strategy with clear objectives and which involves the engagement of multiple stakeholders. These types of integrated, coordinated strategies, including WinMon.BE and WOZEP, are more effective and efficient at translating localized effects into an improved understanding of cumulative impacts.

3 Workgroup Synthesis: Needs for Future Research

As with plenary presentations, several recurring themes arose from the discussions of the seven workgroups. By synthesizing these shared emergent themes, it becomes possible to visualize a coordinated research effort that strategically uses available resources to maximize efficiency and focuses on key knowledge gaps to inform understanding of cumulative effects. The four main themes include the importance of: 1) coordinating efforts via a holistic research framework; 2) carefully considering study design and methodology; 3) using transparent, logical criteria for research prioritization; and 4) understanding sources of variation.

3.1 Develop a Holistic Research Framework and Coordinate Efforts

Developing an integrated framework across taxa and ecosystem components. A holistic, long-term research framework is needed to help coordinate and direct research on the cumulative impacts of OSW energy development on the environment. Developing an integrated framework across taxa and ecosystem components would enable managers to appropriately prioritize future research and monitoring, identify interconnections between studies and protocols proposed by different groups, and maximize efficiency. There are also likely to be scientific benefits to cross-disciplinary discussions involving those who may otherwise not interact regularly, such as groups focused on specific taxa or geographic areas. Opportunities to initiate and expand collaboration among stakeholders may lead to cross-pollination of ideas and reveal previously unidentified synergies.

Using a multiscale approach. Taxa of interest, and the effects posed to these taxa by OSW energy development, occur at a wide range of scales. Research must be implemented at a range of spatiotemporal scales to link fine-scale and broad-scale studies and allow acute response data (at the scale of a turbine or wind farm) to inform our understanding of regional-scale effects, including cumulative population-level impacts.

Pooling funds for cross-disciplinary projects. Focusing research at a single, multi-instrumented site, which can support multiple teams of researchers working on cross-disciplinary studies simultaneously, can maximize effectiveness and funding. An example of such a project is available via WinMon.BE (Degraer et al. 2019), a collaborative research program, launched in 2005, for which multiple organizations supply expertise in different fields and produce scientific and public outreach reports using multiple long-term datasets.

Using existing knowledge. OSW farms have been in operation in Europe for 30 years, and a large body of research on their environmental impacts already exists. Therefore, the identification of information gaps in the context of OSW in the U.S. should build upon this existing knowledge, while acknowledging areas of potential differences between regions (e.g., in relation to characteristics such as substrate type, community composition, and ecosystem function).

3.2 Focus on Study Design and Methodologies

Careful study design. Identifying the correct methodological approach to address chosen research questions requires careful consideration, including issues of statistical power and sample size. For example, current technological limitations mean that directly measuring collisions of birds and bats with OSW infrastructure, while deemed to be an important research area during discussions, is not yet reliably feasible with sufficient sample sizes to fully understand the potential for cumulative effects. More generally, there is a need for the scientific and regulatory communities to determine the level of uncertainty in results that is considered acceptable, and use that determination to inform the choice of studies to be pursued.

Design studies to inform cumulative impact frameworks and population models. Research must be carefully designed to inform population (or other consequence) models such that study results can enhance our understanding of possible cumulative impacts on populations and ecosystems. OSW-focused studies should also be designed to feed into a broader cumulative effects framework that includes the effects of other stressors, including climate change, on populations or ecosystems of interest.

Data transparency, standardization, and sharing. As the OSW industry grows in the U.S. and more data are collected on the marine environment, there is a need to collate and standardize these data and ensure availability for future analyses, research, and decision making. Multiple stakeholders have begun pursuing this topic for particular technologies or data types, and NYSERDA recently released a report that reviews existing databases for wildlife data and makes recommendations for OSW-related data standardization and submission practices (NYSERDA

2021). Data standardization, and the consistent, long-term public availability of those data, will ensure that they can be used to inform understanding of cumulative impacts in the future.

3.3 Prioritize Urgent Research

Identifying key taxa. Recognizing the immense number of marine species and the inability to study them all, we must carefully identify focal taxa for research. Identification of key focal taxa should take multiple factors into account; suggested criteria from various workgroups included: presence at locations likely to be developed; representation of a range of life history strategies; and conservation concern and/or commercial interest. Taxa for which very little is known about OSW effects were, in some cases, noted as a possible priority; in contrast, it may be more efficient to continue focusing on well-studied species, especially if representative of others that may be affected by OSW development. Regardless of the specific criteria used, careful choice of focal taxa across taxonomic groups will promote efficiency and maximize findings applicability.

Sequencing. Efficient sequencing of new research in relation to the development phase and existing knowledge should help inform prioritization efforts. For example, due to the current lack of OSW infrastructure in U.S. waters, there is the opportunity to collect baseline preconstruction data (e.g., species abundance, habitat use, movements), which will reduce reliance on model assumptions and contribute to (and allow comparison with) future studies on the effects of stressors on species during construction and operation phases.

Studying cross-cutting effects. Effects of OSW that may have impacts across food webs and ecosystems should be prioritized for research. Such studies will inform a broad range of interests and maximize the chances that results will inform future management, mitigation, siting, or other decisions. Habitat-related effects, including changes in food production and habitat creation, as well as changes to hydrodynamics and stratification, may affect all marine taxa due to connections between physical oceanographic processes and biological effects. Signals in the environment, such as sound, also may affect multiple species and trophic levels.

3.4 Understand Sources of Variation

Drivers of distributions. Workgroups consistently identified the importance of understanding the dynamic environmental variables that drive species distribution, abundance, and habitat use in OSW areas across a range of spatiotemporal scales. This includes studying variation within and among years, as well as identification of key predator-prey relationships or other trophic interactions. Such understanding can serve a range of purposes, including: 1) assess how risk of exposure may vary over time and space, and inform siting of future projects as well as current risk assessments; 2) inform estimates of how species distributions and movements may change in response to OSW effects; and 3) help to distinguish the effects of OSW from other sources of variability affecting metrics of interest.

Climate change. There is uncertainty surrounding the current distribution and abundance of many taxa, as well as how the spatiotemporal relationships between predator and prey vary over space and time. Understanding how these and other factors may change in response to changing oceanographic and environmental conditions requires long-term, broad-scale monitoring. Coordination of that long-term monitoring with site-specific studies at OSW turbine locations will help to determine the specific stressors affecting populations and habitats of interest and inform cumulative effect assessments.

4 Individual Workgroup Summaries

The below sections briefly summarize background information and key research needs identified by each of the seven individual workgroups. Full reports from each workgroup are available on the workshop website[7].

4.1 Bat Workgroup

Hundreds of thousands of bats are estimated to collide with land-based wind energy facilities each year, with migratory tree-roosting species comprising 78% of mortality (Arnett & Baerwald 2013). Apparent attraction to wind turbines is a key driver of bat mortality onshore (Horn et al. 2008). Bat presence offshore is generally thought to be lower than onshore (Sjollema et al*.* 2014), but detailed information is lacking regarding bat activity and movement patterns in the offshore environment. The potential risk of collision with OSW turbines is likewise uncertain.

Baseline data collection during the preconstruction phase of OSW facilities is important to allow comparison with post-construction data. However, due to the possibility of bat attraction to turbines, preconstruction data may not fully inform understanding of risk. As such, the bat workgroup recognized that post-construction monitoring for bats at OSW farms is essential for addressing data gaps (**Fig 3**). Workgroup discussions focused on identifying these key data gaps and potential solutions, and on outlining a process whereby outcomes of initial studies inform future steps. If initial post-construction mortality monitoring indicates generally high risk, then the group felt that additional research will be warranted to better understand the drivers of risk and how best to mitigate the impact. Alternatively, if post-construction monitoring studies find generally low risk to bats, then the group indicated that there would be a potential "exit strategy" (Ruiz-Miranda et al*.* 2020), such that further substantial monitoring and mitigation measures may be unnecessary for this taxon in the marine environment.

The workgroup identified several specific research and coordination needs in the short term, including to:

- Understand bat activity, movement and habitat use in the offshore environment to allow assessment of the degree of likely interactions with OSW facilities. This should include examination of bat activity in the rotor-swept zone during the operational phase, as well as comparison of these activity levels with other altitudes and development phases.
- Quantify bat collision risk at OSW facilities to determine whether mortality rates are high enough to be a regulatory or conservation concern.
- Integrate collision monitoring technologies with turbine manufacturing and operations.
- Assess mitigation approaches to understand the cost-benefit ratio of implementation.
- Standardize data collection, analysis, and reporting, including full data transparency.

[7] Workgroup reports are at http://www.nyetwg.com/2020-workgroups

The workgroup also identified several longer-term “conditional” priorities (e.g., topics that may become research priorities based on the outcomes of the initial shorter-term research defined above). Firstly, if bat activity levels increase with the presence of turbines and/or mortality is high, there will be a need to further explore bat and OSW turbine interactions to assess whether bat attraction to OSW turbines is similar to that observed at land-based wind energy facilities. Secondly, if OSW presents a high risk of mortality to bats, then developing, validating, and implementing cost-effective approaches to mitigate impacts will be necessary.

Fig 3. Key data gaps and potential solutions for addressing the overarching goal of understanding, and if necessary, minimizing the effects of OSW development on bats in the eastern U.S. RSZ=rotor-swept zone.

While the current understanding of the level of risk posed to bats by OSW development is incomplete, high bat mortality caused by onshore wind turbines suggests it would be appropriate to assess potential risk at offshore facilities. The technologies required to quantify mortality are still in development, and as such, monitoring bat activity during the construction phase, and more importantly (due to possible attraction), the operational phase, are recommended as highest priorities. By filling current knowledge gaps regarding bat activity in the offshore environment, as well as continuing to learn from research on bat interactions with terrestrial wind energy facilities, scientists and managers may be able to successfully assess whether OSW impacts to bats are substantial enough to require mitigation, and if so, be able to implement effective mitigation measures.

4.2 Benthos Workgroup

The benthic ecosystem is home to a wide variety of organisms living in the sediment or in proximity to the ocean floor, each of which may respond in a different way to the variety of pressures from OSW development. The effects of OSW development on the marine benthos have been examined for several decades in Europe (Dannheim et al. 2020), and more recently in the U.S. (Hutchison et al. 2020). These effects may include seafloor disturbance, artificial reef effects, the introduction of energy emissions (i.e., noise, vibrations, electromagnetic fields, and heat), and changes in nutrient cycling and commercial fish production (Degraer et al. 2020). From an anthropogenic perspective, these effects may represent both desirable and undesirable modifications. While gaps remain in European knowledge of OSW effects on benthos, this previous research is a strong foundation upon which to build U.S. research programs, though it will also be important to account for the more varied seafloor habitats in the U.S. when compared to areas of European OSW development.

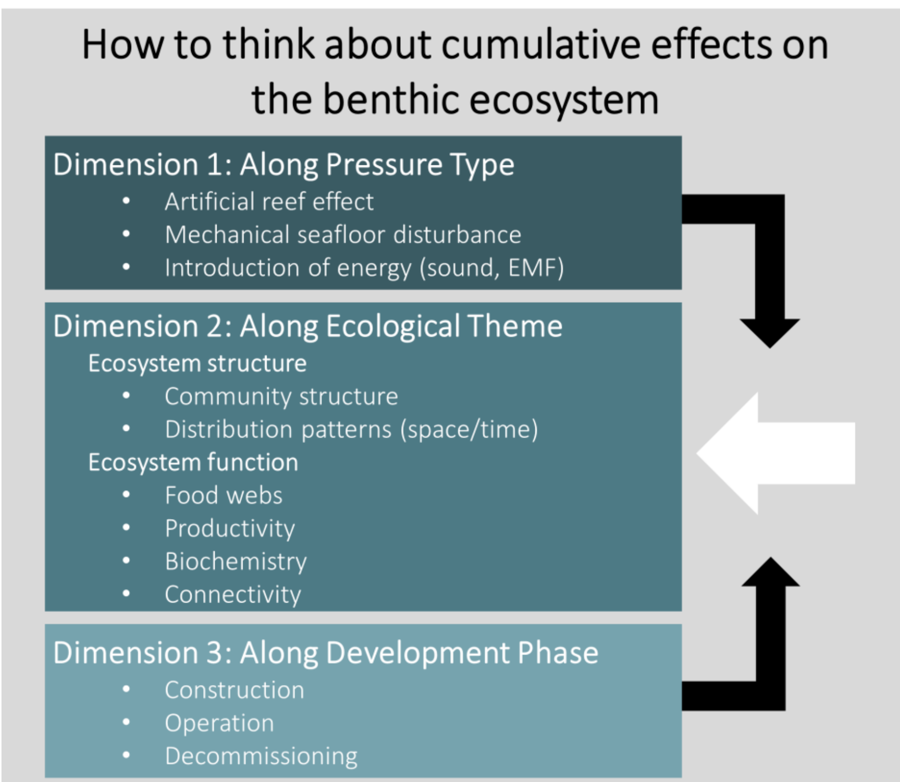


Fig 4. Three dimensions for thinking about cumulative impacts on benthic ecosystems.

In order to identify short-term research studies that can be implemented in the next five years, workgroup discussions focused on various pressure types, ecological themes, and development phases (Fig 4), followed by development of a comprehensive list of 32 potential research studies and other efforts. The effects of vibration and sound were not considered by the benthos workgroup, as they were the focus of the fishes and aquatic invertebrates group. Study topics were prioritized into three tiers (Table 3) through further discussion and online surveys. Top priorities are included in Tier 1, but topics are not ranked within each tier.

These research priorities spanned a diversity of topics in benthic ecology as well as other topics, such as disentangling the effects of OSW development from other stressors and the need for effective data collection and standardization. The majority of topics, however, related to the effects of artificial reef formation on ecosystem structure and function. Workgroup members designated fourteen topics as highest short-term priorities for funding and research (Tier 1):

Table 3. Overview of the number of first, second, and third tier priority topics identified within each pressure type and ecological theme for the benthos workgroup. Top priorities are included in Tier 1, but topics are not ranked within tiers. Some questions addressed multiple themes; additionally, five Tier 1 and four Tier 2 topics did not fit into the below themes.

			Pressure Type								
			Artificial Reef Effect			Seafloor Disturbance			Energy Introduction		
		Prioritization Tier:	Tier 1	Tier 2	Tier 3	Tier 1	Tier 2	Tier 3	Tier 1	Tier 2	Tier 3
Ecological Theme	Ecosystem Structure	Community Structure	1		2		1				1
		Distribution	2	2					1		1
	Ecosystem Function	Food Webs	2						1		
		Productivity	3	1	2					1	1
		Biogeochemistry	1	1	1					1	1
		Connectivity	2	1	1						

Artificial reef effects

- Differences between natural and artificial substrata in their structural and functional ecology
- Degree and spatial scale of organic enrichment and increased productivity in OSW farms
- Changes in the use of habitat by fishes and crustaceans in OSW farms, including possible changes in juvenile habitat use, nursery function and use of spawning grounds
- Alteration of bioenergetics and trophic interactions in relation to OSW installation, including feeding opportunities for fishes
- Influence of changes in recruitment, connectivity, and settlement around OSW areas
- The degree to which OSW energy areas provide spawning habitat for different species

Energy introduction

- The influence of electromagnetic fields (EMF) emitted by OSW farm components on energy acquisition (predators) and survival (prey) due to changes in predator-prey interactions
- The effect of EMF on the ability of species to derive locational cues for homing and migration

Organizational challenges

- Creation of an integrated survey design that allows for trawl surveys and stock assessment practices both inside and outside of wind farms, and allows for comparison of biases and limitations of different survey methods
- Integration of monitoring by developers with cause-and effect-studies and regional-scale monitoring
- Development of quality assurance and quality control practices for new data collection, and identification of approaches for housing benthic data and making them accessible across projects

Cross-cutting topics

- The effect of OSW farms on the distribution and connectivity of mobile species
- Disentangling changes due to OSW farms from those due to climate change

Workgroup members identified several key considerations for implementing these research priorities, including:

1. Putting the effects of OSW energy development in the context of a changing ocean;
2. Building from existing knowledge from Europe and elsewhere, but also considering when comparisons between regions may not be appropriate;
3. Selection of appropriate methods to answer research questions, and the importance of standards for data collection and transparency; and
4. A focus on integrated research to maximize resources and knowledge gain.

Finally, workgroup members stressed the need to consider the research priorities within a broader framework. Productivity in the benthos cascades up to higher trophic levels, and also links to ecosystem services. As such, characteristics of the benthos and how the benthos are affected by OSW development can strongly influence other aspects of marine ecosystems.

4.3 Bird Workgroup

OSW development has the potential to interact with seabird species throughout their annual cycle as well as migrating terrestrial bird species (e.g., passerines, shorebirds). Potential effects include collision with turbines (Masden & Cook 2016), displacement from, or attraction to, wind farm areas at a range of spatial scales (Dierschke et al*.* 2016, Mendel et al*.* 2019), and changes to habitat and prey resources (Degraer et al*.* 2020), among others. Initial workgroup discussions resulted in a comprehensive list of 44 potential studies. Further discussion and online surveys led to the identification of 19 short-term research needs that could be addressed in the next five years, organized by theme and ranked into three prioritization tiers (Fig 5).

Of the 19 research topics initially identified as priorities, seven topics were designated as highest short-term priorities (Tier 1):

- Topic 1. Establish site-specific focal taxa for research and monitoring, in order to focus funding and research towards species of highest concern and improve the chances of designing effective studies to detect effects. The development of an exposure and vulnerability risk matrix, using known distribution data for a given location of interest and information on known/suspected sensitivities to OSW impacts, can help identify species at greatest potential risk at each proposed development area. This will ensure that further research studies (including #3-4, below) are focused on species of greatest potential risk in the lease area or region.

- **Topic 2. Focus on habitat and prey drivers of seabird distributions and behaviors**. Habitat use and foraging patterns are dynamic and may shift over time, particularly in relation to climate change. Understanding linkages between seabird populations, prey populations, and other environmental drivers is fundamental to inform strategic siting of future projects and understand the potential for OSW interactions given the "shifting baseline" posed by climate change. Identifying the prey and habitat drivers of seabird distributions and movements can help us to better understand potential consequences of displacement and habitat loss.
- **Topics 3 and 4. Data compilation and standardization.** Two topics were identified as priorities: 1) a review of available tracking data to determine possible data compilation and analytical approaches for using these data collectively to inform future siting and risk assessments and to identify gaps in data for priority species; and 2) the development of standardized survey data collection and storage protocols, such that data can be used collectively to quantify displacement or other cumulative impacts as the industry develops, and so that data remain accessible and comparable in the longer term.

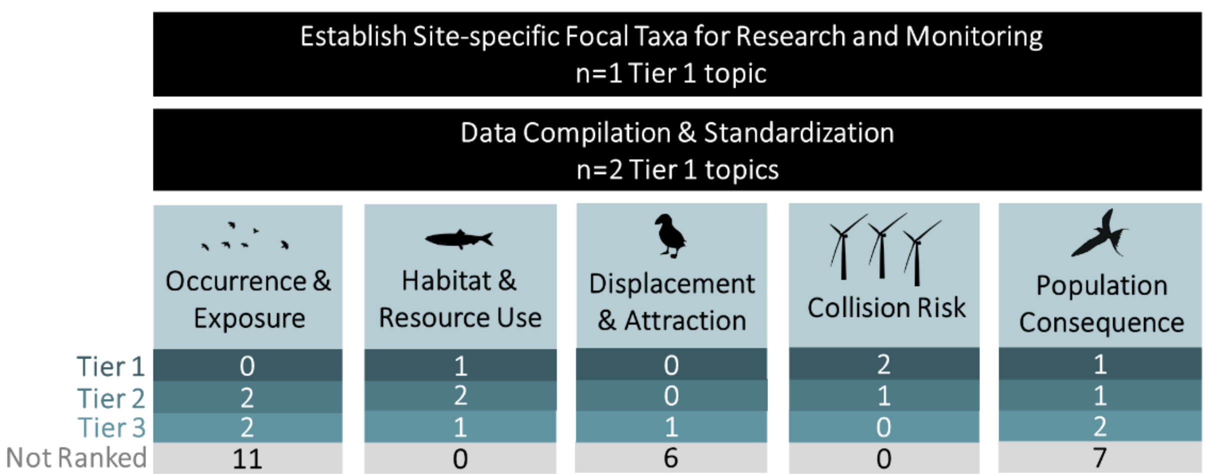


Fig 5. Forty-four research topics, organized into thematic categories, were identified by the bird workgroup with the aim of better understanding and minimizing the effects of OSW development on birds in the eastern U.S. The top nineteen topics were identified and prioritized into three tiers. Several topics (at top) transcended thematic categories and were intended to inform further studies within these categories. Occurrence and exposure studies focused on understanding offshore use and distributions of species and the factors influencing these patterns. Habitat and resource use studies focused on key prey and habitat resources, and how those resources may be affected by OSW development and in turn affect bird populations. Displacement and attraction included topics related to avoidance and attraction at different scales. Collision risk studies include those related to improving collision risk model parameters. And population consequences studies focus on potential cumulative population-level impacts to birds from OSW development.

- **Topics 5 and 6. Develop reliable estimates of collision risk.** Collisions, due to their clear effect on individual fitness, were a substantial concern for some workgroup members. Two studies were identified as priorities to support the development of collision risk models by examining seabird flight height and speed around OSW turbines and under different environmental/weather conditions.
- **Topic 7. Assess the potential for population-level effects to key taxa of concern via population modeling**. Understanding cumulative population impacts was generally felt to be a longer-term goal, but workgroup members agreed that population models and sensitivity analyses should provide a framework for guiding the focus of immediate research. It was felt that preliminary models to quantify population-level consequences of OSW impacts should be developed. As more demographic data will likely be needed for many species, development of models was recommended to initially focus on 1) developing robust estimates of baseline demographic parameters, and 2) conducting sensitivity analyses and other gap analyses to identify where additional data are most needed.

While desktop studies were prioritized in the selection of the above top seven short-term priorities, this was largely related to sequencing. Workgroup members emphasized that a mix of short-term and long-term research and monitoring efforts should be initiated in the next five years, and that field efforts should be developed and implemented in coordination with desktop analyses to maximize resources and efficiency. Technology and analytical advancements were also identified as a key need in some areas (e.g., relating to obtaining detailed three-dimensional movement data and to reliably predict and monitor collisions).

As with several other workgroups (benthos, environmental change, sea turtles), the effect of climate change on the distribution of seabirds and prey was also highlighted in discussions. However, understanding the effects of climate change is considered a longer-term research priority given current uncertainty around the spatiotemporal distributions of seabirds and their prey, as well as uncertainty in how these relationships may respond to changing conditions.

4.4 Environmental Stratification Workgroup

Research from Europe has demonstrated that OSW structures affect physical and oceanographic processes in their surroundings, which may have knock-on effects on wildlife and other aspects of the marine environment. Predicted effects of OSW energy development on the local physical environment include changes to stratification (Carpenter et al. 2016), turbulence (Schultze et al. 2020), suspended sediment (Vanhellemont & Ruddick 2014), and wind- and ocean-wake effects (Platis et al. 2018). Of these potential effects, workgroup discussion focused particularly on stratification. The group identified six priorities for improving understanding of OSW effects on physical and oceanographic conditions in the eastern U.S. in the coming years. These included: guidance and coordination needs; physical effects of OSW development on stratification; and the knock-on biological effects of those physical changes to local ecosystems (numbered below in priority order, with Topic #1 the highest priority but grouped by theme).

Guidance and coordination needs

- **Topic 1. Develop a methods and metrics document to define what monitoring should be done and how.** This includes developing a strategy for short- and long-term monitoring that can span a range of spatial and temporal scales and differentiate OSW effects from natural and climate variability.
- **Topic 3. Coordinate existing efforts to maximize the utility of available resources and expand the scale of inference.** Formalized coordination and collaboration among small-scale efforts could greatly maximize the utility of datasets and funding, help bring together different ideas, and develop standardized methods and new techniques.
- **Topic 4. Conduct feasibility studies to identify the types and scale of potential effects and focus research in the eastern U.S.** Existing oceanographic data coupled with OSW-related studies in different regions could help determine the variables, parameters, and scales on which to focus U.S. research.

Physical and biological effects of stratification

- **Topic 2. Link the physical effects of OSW energy development to biological effects.** This would involve an interdisciplinary approach to examine biological effects at all trophic levels, including consideration of direct and indirect effects (e.g., prey production, distribution, and availability).
- **Topic 5. Examine effects of OSW energy development on ocean stratification.** Effects from OSW structures on stratification, including turbulence and wind stress alterations, can affect both mixing and upwelling/downwelling ocean responses (Carpenter et al. 2016). Understanding these physical effects can inform potential biological effects (Topic 2 above).
- **Topic 6. Assess changes in light conditions** due to the suspension of sediment, which can alter primary production within OSW areas. The degree of potential effects will be highly dependent on sediment class; sediment resuspension has been observed at OSW farms in the North Sea, but the BOEM RODEO project at Block Island did not find it to be a major issue (HDR 2020). Workgroup members varied in their opinions of the importance of this topic, but overall ranked it by far the lowest of the six priorities.

Workgroup members felt strongly that coordination of existing long-term, broad-scale monitoring efforts with site-specific studies at OSW development locations will be essential to understand changes in physical oceanographic processes in relation to both OSW energy development and climate change. The highest priority topics identified in this report included a mix of efforts that were felt to address issues of key ecological importance and those that would serve to set the stage for needed research (e.g., developing appropriate methods and metrics). Coordination of research and data collection at a range of spatiotemporal scales will allow for an improved understanding of how OSW energy structures affect physical processes and in turn may affect wildlife and their habitats.

4.5 Sound and Vibration Effects on Fishes and Aquatic Invertebrates Workgroup

Sound is an essential communication channel for many aquatic vertebrates and invertebrates (Hawkins et al. 2015), and anything that interferes with the ability of those animals to detect sounds has the potential to impair survival of individuals and populations (Slabbekoorn et al. 2018). Most existing data on underwater sound and fishes has been based on studies focused on the pressure component of the sound field, but there is a growing understanding that other aspects of sound such as particle motion and substrate vibration are equally or more important for both fishes and invertebrates (Popper & Hawkins 2019). The lack of understanding of bioacoustics, as well as animal responses to sound sources associated with OSW activities, represent gaps that need to be addressed via multiple approaches. The workgroup identified

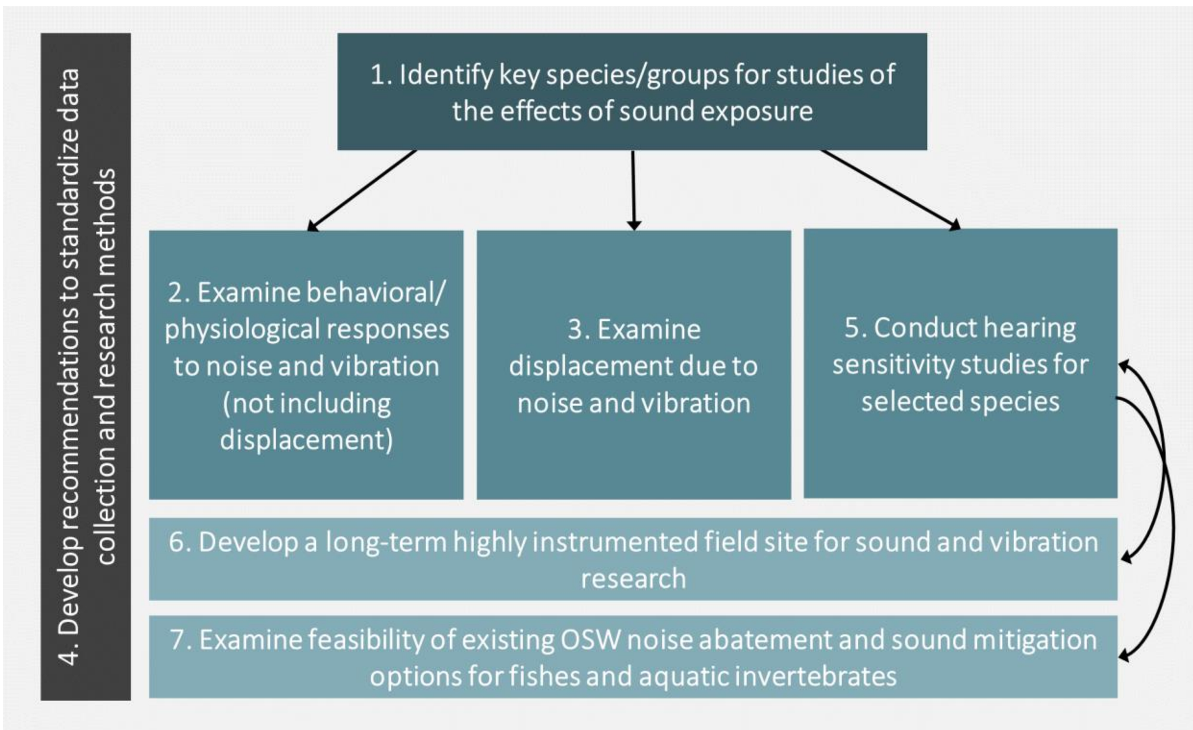


Fig 6. Seven research priorities identified by the workgroup with the aim of better understanding the effects of sound and vibration from offshore wind energy development on fishes and aquatic invertebrates in the eastern U.S. Topics are numbered in order of relative priority as determined by the workgroup (#1 = highest priority).

seven short-term priorities that could be initiated in the next five years including a mix of primary research and other types of coordination efforts (Fig 6). Following the main effort, this workgroup report was published in a peer-reviewed journal (see Popper et al. 2022).[8]

Topics are presented in order of descending priority, as assessed by workgroup members (e.g., with #1 being the top priority); however, workgroup members agreed that some studies could and should be pursued simultaneously to best inform OSW development.

[8] Paper available at: https://asa.scitation.org/doi/full/10.1121/10.0009237?via=site

- **Topic 1. Identify key species/groups for studies of effects of sound exposure of fishes and invertebrates.** The number of fish and invertebrate species located in the vicinity of OSW lease areas are too numerous to study individually. Thus, it is necessary to prioritize the most important species based on relevance, representativeness of potential species of interest, and other criteria (Popper et al. 2022).
- **Topics 2 and 3. Conduct behavioral response studies to examine changes in relation to sound exposure and substrate vibration.** Two research topics were identified in relation to understanding displacement and other behavioral and physiological changes of fishes and aquatic invertebrates in response to sound from OSW development. A focus on changes with survival or reproductive implications (e.g., changes in spawning behavior, displacement during spawning periods, or other changes with fitness implications) was recommended.
- **Topic 4. Develop recommendations for methods standardization.** It is important that studies use comparable methods to record, analyze, and present on the effects of OSW sounds and vibrations on fishes and aquatic invertebrates such that data can be aggregated for larger-scale analyses.
- **Topic 5. Conduct hearing sensitivity studies for selected species, including particle motion, vibration, and sound pressure.** Very little is known about sound detection capabilities of fishes, and far less is known about hearing in aquatic invertebrates. Data on hearing is imperative to extrapolate results across sites, species, or research questions, and to inform models including those to predict spatial scales of effects.
- **Topic 6. Develop a long-term, highly instrumented field site for research on responses of animals to sound and vibration**. Given the complexity and expense of developing an acoustically defined environment, there would be substantial value in developing a collaborative, long-term, year-round field research site with well-defined acoustics. Such a site would ideally allow: 1) control or full characterization of the sounds being added to the ambient soundscape; 2) tests on various authentic substrates and focal species; 3) examination of particle motion and substrate vibration (in addition to sound pressure); and 4) behavioral and physiological response studies.
- **Topic 7. Feasibility study to examine sound mitigation options for fishes and invertebrates.** To date, OSW noise mitigation has focused heavily on marine mammals, but these approaches may target different sound frequencies than those of importance to (and detectable by) fishes and aquatic invertebrates. It is therefore important to explore the effectiveness of existing noise abatement and mitigation methods for fish and invertebrates, in case substantial impacts are detected that should be mitigated. Such a feasibility study could identify gaps in knowledge to be filled to develop effective mitigation measures.

In addition to the seven specific research topics identified above, the workgroup also recommended:

- Assessing the extent of existing data and prioritizing knowledge gaps.
- Balancing the need for small-scale lab studies, controlled field studies, and studies at OSW sites. Due to the difficulties associated with recreating a real-world marine sound environment in a laboratory setting, field or field-relevant research on the behavior and

responses of fishes and invertebrates to OSW sound sources was recommended where possible.

- Focusing on animal behavioral responses, e.g., assessing how animals respond to sounds, not just whether they can hear those sounds.
- Focusing on potential behavioral effects of particle motion and substrate vibration, in addition to sound pressure, at all life stages for species of concern.

The workgroup indicated that there are substantial gaps in our understanding of the potential effects of sound (including sound pressure and particle motion) and substrate vibration on fishes and aquatic invertebrates, and that these gaps currently preclude assessment of potential cumulative impacts from OSW development. In particular, there is a dearth of data from field studies conducted under real-world conditions that examine behavioral and/or other effects with possible fitness consequences. The workgroup suggested focusing OSW-related research over the next five years on filling some of the most critical gaps in knowledge. Rather than studying a random selection of species, workgroup members felt that it would be more efficient to carefully select a group of species for study that represent the range of hearing capabilities and mechanisms for taxa present in OSW areas. In the long term, the aim of research should be to inform cumulative impact models, thereby substantially enhancing our understanding of possible impacts to populations and ecosystems.

4.6 Marine Mammal Workgroup

Along the U.S. east coast, a variety of marine mammals are expected to interact with OSW development. While studies of distributions (Roberts et al*.* 2016) and some aspects of behavior (Salisbury et al. 2018) have been conducted for some species in OSW lease areas, many knowledge gaps remain. Potential stressors posed by OSW include increased vessel traffic, altered noise conditions, and changing ecosystem and prey conditions, among others.

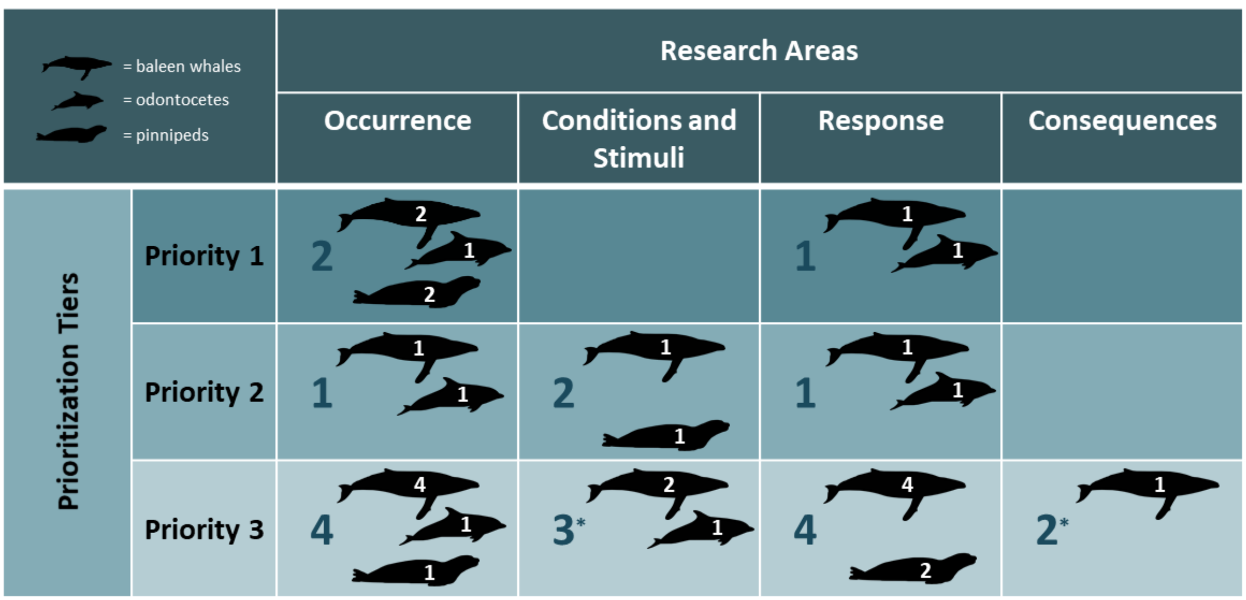
After discussing relevant conceptual frameworks and previous research efforts, workgroup members identified four overarching research areas: occurrence, conditions and stimuli, response, and consequences (Fig 7). Within these categories, the group identified 20 research studies that could feasibly be conducted in the next five years to improve understanding of cumulative impacts from OSW as the industry progresses in the U.S. These topics were prioritized through a series of surveys and polls into three tiers (Fig 7). Baleen whales were overwhelmingly considered the highest priority for research, due in part to concerns regarding potential interactions between the endangered North Atlantic right whale (*Eubalaena glacialis*) and OSW development. However, priorities were identified for each of the three major taxonomic groups of baleen whales, odontocetes, and pinnipeds, indicated for each topic in parentheses.

Workgroup members indicated three topics as the highest immediate priority (Tier 1) and an additional four were high priority (Tier 2; listed below).

Tier 1 Topics

- **Estimate habitat use, distribution, and abundance in OSW development areas by season and explore the environmental variables driving these patterns (baleen whales,** odontocetes, and pinnipeds).** Understanding seasonal differences and environmental drivers of offshore habitat use for all marine mammals can provide important information on exposure to potential effects from OSW development, while helping inform sources of variation and improve consequence models.

- **Establish individual baseline movements and behavior patterns (e.g., foraging, diving, reproduction) in OSW development areas (baleen whales, pinnipeds).** Examining baseline patterns during pre-construction periods can help to estimate exposure and inform a variety of movement and noise propagation models to better understand potential consequences of OSW energy development.
- **Identify acoustic exposure and contextual conditions associated with potential acute response to OSW stressors (baleen whales, odontocetes).** This includes examining potential acute individual or discrete group responses in relation to noise exposure as well as relevant contextual variables such as ambient noise levels and individual covariates. Results would help support the development and refinement of risk and consequence assessments.



* Includes one topic that was not-taxon-specific

Fig 7. Twenty marine mammal research topics organized by research area and prioritized for each major taxonomic group (baleen whales, odontocetes, and pinnipeds). The four research areas are: **occurrence**, which includes basic information on the distribution, abundance, and temporal habitat use of species; **conditions and stimuli**, which includes information on characteristics of OSW activities that may affect marine mammals; **response**, which includes how animals may be influenced or react to exposure to a stressor; and **consequences**, which includes the short- and long-term individual or population-level effects of multiple types of exposures and responses. Some topics are prioritized for multiple taxonomic groups, and therefore the number of taxon-specific priorities in each category may be larger than the sum total number of topics.

Tier 2 Topics

- **Determine spatially and temporally explicit species presence in OSW development areas (baleen whales, odontocetes).** A large-scale regional approach to determine species presence/absence in space and time using a gradient design could help improve understanding of exposure to OSW stressors, inform consequence models, and help target further research.
- **Evaluate ambient sound levels in OSW development areas prior to development activities, as well as during all development phases (baleen whales).** A gap analysis of expected sound ranges paired with a gradient study design to examine power spectral density across a wide frequency range would improve knowledge of potential exposure conditions to inform consequence models.
- **Evaluate changes in ecosystem and prey conditions in OSW development areas from the preconstruction to operational periods (pinnipeds).** Examine species composition, distribution, and abundance of forage fish in relation to the movements of pinnipeds, in order to improve understanding of the potential for indirect effects to this taxon from OSW development via effects on prey populations and habitats.
- **Evaluate relative threat of mortality/injury from vessel strikes associated with OSW (and non-OSW) activities (baleen whales).** Combining information on localized changes in habitat use related to OSW development, changes in vessel patterns, and factors contributing to collision risk would improve understanding of potential risk of vessel strikes and inform consequence models.

In addition to specific research priorities, the workgroup noted several other needs, including: 1) identify vulnerable species by region and lease area to prioritize for research; 2) examine changes more holistically across taxa and stressors; and 3) standardize data collection and coordinate across research projects. Marine mammals are some of the most studied taxa in the marine environment of the U.S., but key gaps remain in our understanding of their distributions, populations, and other relevant characteristics. Additionally, little is known about the effects of OSW development on taxa other than harbor porpoises and some seal species (primarily based on studies outside the U.S.). These gaps indicate that assessment of consequence (e.g., cumulative impacts to populations) will be a longer-term effort, however, addressing the group's shorter-term research priorities will produce new data to feed into consequence models and situate the OSW industry, regulatory, and research communities to better understand the potential for cumulative impacts as the industry progresses.

4.7 Sea Turtles Workgroup

Sea turtles are rare in areas where OSW buildout has occurred to date. However, data from offshore oil and gas exploration and production in the Gulf of Mexico can inform our understanding of potential interactions (Renaud & Carpenter 1994, Gitschlag & Herczeg 1994). Possible short-term effects of OSW energy development on sea turtles include displacement, behavioral disruption, stress, temporary hearing impairment, vessel interactions, and changes to prey availability, while longer-term effects may include changes in the distributions of sea turtles and their prey, changes in vessel traffic, and ecosystem enhancement (Bonacci-Sullivan 2018).

Workgroup members identified eight research studies that could feasibly be conducted in the next five years, and three that were considered longer-term priorities. Studies are organized into one of three overarching categories (baseline understanding, direct effects of OSW development, and interactions among stressors). Topics are listed below (Fig 8) in order by priority (as determined by an online survey), with top-priority topics listed first. The first two topics were by far the highest priority recommendations from the workgroup, and address similar gaps in our knowledge of sea turtle distributions, movements, and habitat use.

- **Topic 1. Improve understanding of sea turtle movements, distributions, and habitat use patterns, including changes in habitat use in relation to OSW development.** Determining fine-scale patterns of sea turtle movement and habitat use, as well as possible changes in these patterns over time can help better understand potential risk of interactions with OSW development and inform models of abundance and vessel strike risk.
- **Topic 2. Update density/abundance estimates and characterize baseline habitat use patterns.** Compiling existing tracking and survey data across sea turtle species in the U.S. Atlantic region can help fill data gaps in relation to the environmental factors driving distribution and habitat use patterns, improve modeled abundance estimates, and inform decision making.
- **Topic 3. Assess sea turtle use of OSW structures and potential reef effects.** This study would assess sea turtle foraging opportunities and habitat use around OSW structures once built.
- **Topic 4. Examine physiological and behavioral responses of sea turtles to offshore wind-related sound.** A behavioral response study that includes pre, during, and post-construction assessments would provide insight into sea turtle behavioral responses to sound. Coupled with lab-based physiological effects studies, this research could inform our understanding of the potential for individual and/or population-level effects. Results would also have the potential to inform potential mitigation approaches (e.g., by helping to define appropriate sound exposure thresholds).
- **Topic 5. Improve scientific understanding of sea turtle hearing and morphology**. Examining the mechanisms by which sea turtles hear and their hearing capabilities and morphology across species and life stages would improve understanding of the potential sound-related impacts from OSW development.
- **Topic 6. Assess potential vessel strike risk posed by OSW development.** OSW development will likely increase and change vessel traffic patterns. Evaluating the threat of sea turtle mortality or injury from vessel strikes associated with OSW activities, and assessing the spatiotemporal patterns of risk, can help to inform potential mitigation approaches. This priority will require integration of distribution and abundance data on sea turtle populations (Topics 1-2, above) with vessel information.
- **Topic 7. Assess risk to sea turtles from entanglement with fishing gear on or around OSW structures.** Evaluating the potential risk posed to sea turtles from the interaction of OSW development with commercial and recreational fishing will improve understanding of potential impacts. This could broadly include active fishing gear (e.g., gear used in new locations or different types of gear within OSW areas) and aggregation of derelict gear that could entangle OSW structures.

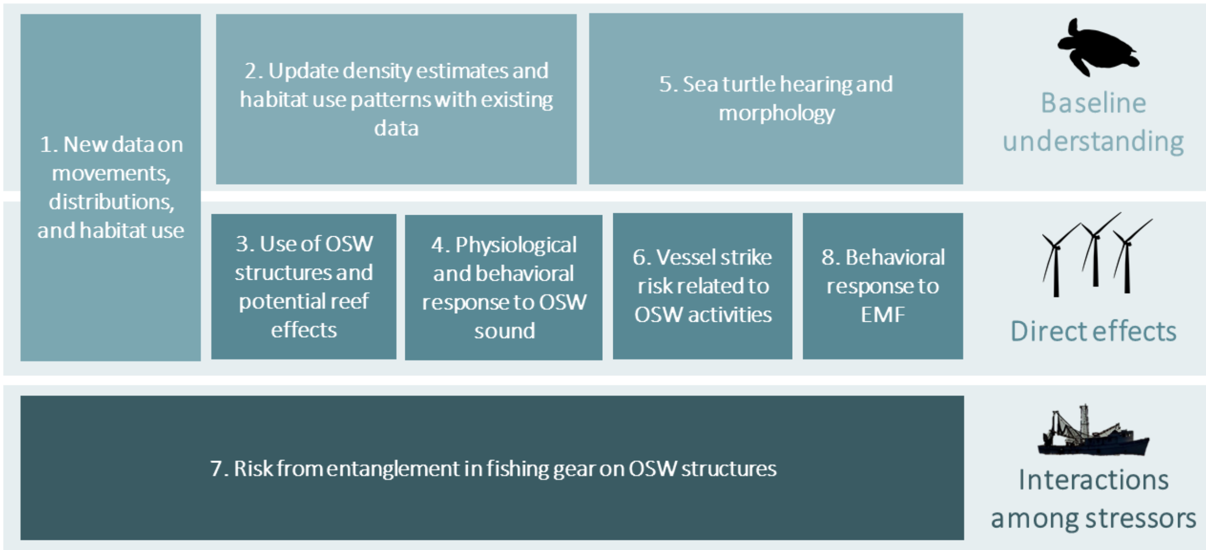


Fig 8. Research priorities to better understand the effects of offshore wind energy development on sea turtles in the eastern U.S. over the next five years. EMF = electromagnetic fields. **Baseline understanding** includes sea turtle distributions, habitat use, and hearing capabilities that can in turn help inform potential effects from OSW development; **Direct effects** include behavioral and physiological responses of individuals or populations to OSW activities; **Interactions among stressors** relate to potential effects from offshore wind energy development interacting with other potential stressors (e.g., fisheries).

- **Topic 8. Examine sea turtle behavioral response to electromagnetic fields (EMF) generated by OSW infrastructure.** Several species of sea turtles are known to be magnetosensitive (Normandeau et al. 2011), and an examination of their behavioral response to EMF from OSW transmission cables would inform our understanding of the potential for effects on navigation, particularly for adults during migration and hatchlings navigating away from nesting beaches at night.

Multiple approaches will be required to address these research needs and understand the cumulative impacts of OSW development on sea turtles. There are substantial spatial and temporal data gaps in our understanding of sea turtle populations and distributions in wind energy areas, as well as our understanding of the potential effects to sea turtles posed by OSW development. Overall, workgroup members prioritized research to fill gaps in baseline data on sea turtle distributions, abundance, habitat use, and movements before stressor-specific investigations of effects to turtles. This included an emphasis on understanding the environmental drivers of sea turtle presence and movements. This prioritization of baseline data is, in part, due to a recognition of the need for sequencing of priorities and the current status of OSW development in the U.S. However, the workgroup felt that a focus is also needed in the immediate term on improving our understanding of the potential effects of OSW on sea turtles as development proceeds. Substantial information is available from research and mitigation efforts relating to the offshore oil and gas industry in the Gulf of Mexico, which may help inform these studies.

5 Conclusions

Plenary sessions and workgroup efforts provided an opportunity for researchers, managers, and other stakeholders from around the world to share and synthesize knowledge on the potential effects, and in turn cumulative impacts to wildlife from OSW development. Throughout this process, it became apparent that, in most cases, there is currently a lack of information necessary to understand cumulative impacts. However, by working to address both shorter- and longer-term research priorities simultaneously and utilizing population modeling and other consequence modeling frameworks to guide research efforts, researchers, resource managers, and funders can ensure that data are collected effectively and efficiently to improve understanding over time. Learning from the experience of European colleagues, advanced planning and careful study design provides an opportunity for the OSW-wildlife community to "cut off the DRIP" (data-rich information-poor; Wilding et al. 2017), ensuring that data collection can meaningfully answer questions and be coordinated across studies to contribute to a broader understanding of cumulative impacts. The need for data collation across studies also highlights the importance of data transparency and sharing to ensure that data are available and accessible for use in cumulative impact assessments (NYSERDA 2021).

Workshop activities provided opportunities for both taxon-specific and cross-cutting discussions across disciplines. While the identification of research priorities happened largely independently within each of the seven State of the Science workgroups, group leaders noted that priorities will need to be considered in an integrated framework across taxa and ecosystem components to: 1) appropriately prioritize future research and monitoring; and 2) identify interconnections between studies and protocols proposed by different groups. Several large-scale research projects that integrate monitoring conducted by developers with targeted new research, and that can sample multiple OSW areas, may be more efficient than small, piecemeal projects.

Understanding cumulative impacts is a complicated and evolving challenge that will require long-term, integrated solutions. However, efforts such as this workshop and related workgroup efforts will contribute to continued improvements in the scientific understanding of cumulative impacts while avoiding or minimizing them as much as possible as the OSW industry develops.

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Appendix A: Workshop Agenda

Session 1: Framework for Understanding Cumulative Impacts from Offshore Wind Moderator: Howard Rosenbaum, Wildlife Conservation Society
Opening Remarks from NYSERDA *Doreen Harris, Acting President and CEO of NYSERDA*
Welcome and Setting the Stage *Greg Lampman, NYSERDA*
Cumulative Anthropogenic Impacts on the World's Oceans *Sara Maxwell, University of Washington*
Framework for Defining the Scope of Cumulative Adverse Effects Assessments for Offshore Wind *Wing Goodale, Biodiversity Research Institute*
An Ecosystem Functioning Approach for Thinking about Cumulative Impacts *Steven Degraer, Royal Belgian Institute of Natural Sciences*
Metapopulation PVA: Developing Methods for Reducing Uncertainty in Impact Assessments *Julie Miller, Marine Scotland Science*
Panel Q&A and Discussion
Session 2: European Efforts to Understand Cumulative Impacts from Offshore Wind Moderator: Sophie Hartfield Lewis, Ørsted
Assessing Cumulative Effects: Challenges Faced by Offshore Wind Developers *Madeline Hodge, Ørsted*
WinMon.BE: The Belgian Countrywide Research Program to Understand Cumulative Impacts of Offshore Wind energy development *Steven Degraer, Royal Belgian Institute of Natural Sciences*
Offshore Wind Farms: Cumulative Impact Assessments in the Netherlands *Astrid Potiek, Bureau Waardenburg*
Developing a Cumulative Effects Framework (CEF) for Key Ecological Receptors in Relation to Offshore Wind in the UK *Kate Searle, UK Centre for Ecology and Hydrology*
Panel Q&A and Discussion

Session 3: Lightning Talks Round 1 Moderator: Matt Robertson, Vineyard Wind
Interactions of Scientific Surveys/Advice on Offshore Wind energy development *Andy Lipsky, NOAA Northeast Fisheries Science Center*
Migratory Paths of Horseshoe Crabs in Peril due to Offshore Energy Development *John Tanacredi, Center for Environmental Research and Coastal Oceans Monitoring*
Pelagic Fish and Zooplankton Abundance and Distribution in the New York Bight *Joseph Warren, Stony Brook University*
Large Bony Fish Information from New York OPA *Jeff Clerc, Normandeau Associates Inc.*
Q&A and Discussion
The BOEM 'RODEO' Program: Lessons Learned from Environmental Monitoring at Multiple U.S. Offshore Wind Farms *Kristen Ampela, HDR, Inc.*
Mapping the Distribution and Habitat Use of Atlantic Cod Spawning Aggregations on Cox's Ledge to Assess Potential Impacts of Offshore Wind energy development *Rebecca Van Hoeck, University of North Carolina at Chapel Hill & Ali Frey, University of Massachusetts Dartmouth School for Marine Science & Tech.*
Multi-scale Relationships Between Marine Predators and the Distribution of Forage Fish *Evan Adams, Biodiversity Research Institute*
Benthic Habitat and Epifaunal Monitoring at the Block Island Wind Farm *Zoe Hutchison, University of Rhode Island*
Q&A and Discussion
Expected Effects of Proposed Large-Scale Offshore Wind Farm Implementation of Common Guillemots (*Uria aalge*) in the Southern North Sea *Verena Peschko, University of Kiel*
Protected Species Observer (PSO) Detections of North Atlantic Right Whales (NARW): Contributing to Science, Conservation, and Management *Craig Reiser, Smultea Sciences*
Age-based Habitat Use of Humpback Whales in the New York Bight and Implications for Vessel Strikes *Julia Stepanuk, Stony Brook University*
Review of Night Vision Technologies for Detecting Cetaceans at Sea *Mari Smultea, Smultea Sciences*
Q&A and Discussion

Session 4: Current Knowledge on Cumulative Impacts I Moderator: Jillian Liner, Audubon New York
The Vineyard Wind SEIS: Assumptions Made in the Cumulative Impact Scenario *Ian Slayton, Bureau of Ocean Energy Management*
Cumulative Impacts of Displacement on Seabirds *Stefan Garthe, Kiel University*
Cumulative Impacts to Birds from Collisions with Offshore Wind Farms *Aonghais Cook, British Trust for Ornithology*
Panel Q&A and Discussion
Session 5: Current Knowledge on Cumulative Impacts II Moderator: Ruth Perry, Shell New Energies
Cumulative Physical Effects of Offshore Wind Energy Development on Oceanographic Processes *Jeff Carpenter, Institute of Coastal Research, Helmholtz-Zentrum Geesthacht*
Cumulative Effects of Offshore Wind on Benthic Habitats *Drew Carey, INSPIRE Environmental*
Cumulative Noise Impacts Upon Fishes (and Turtles) from Offshore Wind Construction and Operation *Arthur Popper, University of Maryland & Anthony Hawkins, Loughine Ltd.*
Designing Studies to Detect the Ecological Impacts of Offshore Wind energy development *Elizabeth Methratta, contractor to NOAA Northeast Fisheries Science Center*
Panel Q&A and Discussion
Session 6: Current Knowledge on Cumulative Impacts III Moderator: Francine Kershaw, Natural Resources Defense Council
Decision Framework to Identify Populations that are Vulnerable to Population-level Effects of Disturbance *Cormac Booth, SMRU Consulting*
Cumulative Noise Impacts to Marine Mammals from Offshore Wind energy development and Operations *Brandon Southall, Southall Environmental Associates Inc. & Howard Rosenbaum, Wildlife Conservation Society*
Vessel Encounter Risk Model Tool *Mary Jo Barkaszi, CSA Ocean Sciences Inc.*
Population Impacts to Bats from Wind Energy Development *Cris Hein, National Renewable Energy Laboratory*
Panel Q&A and Discussion

Session 7: Lightning Talks Round 2 Moderator: Jenny Briot, Avangrid
ICES – International Council on Exploration of the Sea *Andy Lipsky, NOAA Northeast Fisheries Science Center*
A Stakeholder driven Vision: Regional Wildlife Science Entity for Atlantic Offshore Wind *Kate McClellan Press, NYSERDA*
The Responsible Offshore Science Alliance (ROSA): Establishing Regional Research and Monitoring for Offshore Wind and Fisheries *Lyndie Hice-Dunton, Responsible Offshore Science Alliance*
U.S. Offshore Wind Synthesis of Environmental Effects Research *Rebecca Green, National Renewable Energy Laboratory*
Q&A and Discussion
Updating Collision Risk Models to Quantify Cumulative Impacts for Endangered Birds *Christopher Field, University of Rhode Island*
Analysis and Visualization of Marine-life Data in the Context of Offshore Wind Energy Development *Marta Ribera, The Nature Conservancy*
Development of Monitoring Protocols for Automated Radio Telemetry Studies at Offshore Wind Energy Areas *Pam Loring, U.S. Fish & Wildlife Service*
New Technology Reduces the Probability of Vessel Strikes on Whales – In Certain Situations All the Way to Zero *Dave Steckler, Mysticetus*
Ecosystem Dynamics: An Examination of the Relationships Between Environmental Processes, Primary Productivity, and Distribution of Species at Higher Trophic Levels *Frank Thomsen, DHI Group*
Q&A and Discussion
Session 8: Designing Studies to Assess Cumulative Impacts Moderator: Kate Williams, Biodiversity Research Institute
Synthesis of the Science: Interactions Between Offshore Wind energy development and Fisheries *Andrew Lipsky, NOAA Fisheries, Brian Hooker, Bureau of Ocean Energy Management, Annie Hawkins, Responsible Offshore Development Alliance, & Lyndie Hice-Dunton, Responsible Offshore Science Alliance*
Approaches to Understanding Cumulative Effects of Stressors on Marine Mammals *Peter Tyack, University of St. Andrews*
Designing Monitoring to Detect Cumulative Impacts and Address the Confounding Variable of Climate Change *Jon Hare, NOAA Northeast Fisheries Science Center*
Panel Q&A and Discussion
Charge and Process for Working Groups *Kate Williams, Biodiversity Research Institute*
Closing Remarks *Kate McClellan Press, NYSERDA*
Session 9: Informal Breakout Groups

Appendix B. Session 1: Frameworks for Understanding Cumulative Impacts from Offshore Wind

Moderator: Howard Rosenbaum, Wildlife Conservation Society

Opening Remarks from NYSERDA

Doreen Harris, Acting President and CEO of NYSERDA
Welcome to the largest gathering dedicated to understanding the impacts of OSW development on wildlife to date, with the aim of identifying key research needs to be conducted over the next few years. New York is committed to 100% zero-emission electricity by 2040, and an 85% reduction in greenhouse gas emissions by 2050. The goal is for OSW to produce 9,000 megawatts (MW) of energy by 2035, and we currently have three projects in development, Empire Wind at 815 MW, Sunrise Wind at 880 MW, and South Fork wind farm at 130 MW for a total of 1,826 MW. New York is also in the process of evaluating bids from a second offshore wind solicitation, which will account for up to 2,500 MW of additional energy. We have an important responsibility to think creatively and strategically about ways to work together develop OSW in a way that is environmentally responsible and mitigates potential impacts to wildlife.

Welcome and Setting the Stage

Gregory Lampman, NYSERDA
The primary goal of this workshop is to discuss how to understand and avoid cumulative impacts to wildlife by focusing on biological (rather than regulatory) aspects, and specifically on the effects of OSW development (rather than all anthropogenic activities), though they can be difficult to disentangle. It is important to learn from each individual project through an adaptive management approach as more projects come online. New York's renewable energy goal has increased from 2,400 MW by 2030 set in 2018, to 9,000 MW by 2035, and the regional goal across New Jersey, New York, Connecticut, Rhode Island and Massachusetts is now approaching 30 gigawatts.

Multiple entities play a role in the process of developing OSW areas. Firstly, BOEM oversees the identifying and leasing of areas within the OCS and provides oversight for all federal permitting, while private industry designs the project, plans the supply chain, and fulfills federal and state permitting. The state sets the energy goal for the development and supports research and other advancements. Stakeholder engagement is an important part of this process and to support this, New York state instigated four different technical working groups (TWGs) focused on maritime issues, jobs and supply chains, commercial fishing, and the environment (NYSERDA 2018). This workshop was instigated by the E-TWG, which is comprised of OSW developers, non-governmental organizations, and regional state and federal government agencies.

As a non-regulatory entity, NYSERDA has limited control over projects and the permitting process. However, through the procurement process, we require developers to provide environmental and commercial fishing mitigation plans, as well as provide information on how they are considering the carbon footprint of the projects. We have also recently adopted a requirement for developers to provide $10,000 per MW to support regional monitoring of wildlife and commercial fish stocks. These requirements could result in up to $25 million to support regional monitoring from NYSERDA's 2020 solicitation (NYSERDA 2020). Two recently established organizations aiming to advance science to better understand the impacts of OSW energy development are ROSA, which focuses on fisheries (ROSA 2021), and the RWSE, which focuses on the environment (New York Environmental Technical Working Group 2021).

Cumulative Anthropogenic Impacts on the World's Oceans

Sara Maxwell, University of Washington

Cumulative impacts are the sum of all impacts on a species, habitat, or ecosystem. This workshop is focused specifically on the effects of OSW energy development, but from a conservation perspective, it is important to look beyond the impacts of a single human activity and also consider resource competition from fisheries, climate change, shipping and fossil fuel industries, pollution, and other potential stressors. These many impacts can be broken down into individual components using quantitative frameworks. For example, by combining animal tracking (TOPP 2021) and human impact spatial data (Halpern et al. 2009), we located the areas of greatest anthropogenic impact intensity in the California Current. We also need to understand the relative impact of each effect on each species; after a literature review, we reached 192 sensitivity scores across all impacts and species, which, combined with the two spatial datasets, allowed us to use a cumulative utilization and impact algorithm to conclude that cumulative anthropogenic impacts were greater near coastlines due to both concentration of human activities and species presence (Maxwell et al. 2013). However, we cannot decouple the spatial distribution of species and the distribution of impacts. This study had important implications for expanding national marine sanctuaries (NOAA 2015) as it looked at not only where species are found but where the most heavily impacted areas are.

Cumulative impacts may not be additive, and occur across space and time. For example, if a seabird population was reduced decades ago, that impact is still accumulating as they attempt to recover. If a seabird spends time in two distant parts of the ocean, they could experience impacts in both locations, as well as during transit between locations. Quantifying population-level consequences of impacts is also critical, especially those that do not lead to mortality but reduce fitness enough to alter breeding success. Finally, it is important to remember that the ocean system is incredibly dynamic, and we need to consider dynamic management approaches that are more responsive in near-real time to the impacts being faced by animals and ecosystems.

Framework for Defining the Scope of Cumulative Adverse Effects Assessments for Offshore Wind

Wing Goodale, Biodiversity Research Institute

Cumulative impacts are the accumulation of all stressors through space and time. However, adverse cumulative impacts have been historically difficult to define (Norman et al. 2007), as they may be linear, complex, and uncertain (Renn 2008); this also makes it difficult to define a clear scope for studying and assessing them. To have a risk of adverse effects there must be a hazard, vulnerability to that hazard, and exposure to that hazard (Crichton 1999). In this case, the hazard is OSW development, and the effects pathways are both direct and indirect, with indirect effects being a major challenge to understand. Assessing the vulnerability of an organism requires understanding its behavior, physiological constraints, and habitat specialization. Choosing which receptor (e.g., species, group, community) to focus on is also important, as is delineating exposure of that receptor to the hazard by selecting temporal and spatial boundaries. When developing a research agenda, it is vital to be specific with definitions and assumptions and keep a tight scope (recognizing that scopes may vary across species). Both empirical field data and modeling are needed. Overall, it's generally most effective to identify the technological restraints we currently face and focus on smaller, more realistically achievable studies to gradually fill gaps in our understanding, rather than trying to answer too big a question all at once.

An Ecosystem Functioning Approach for Thinking about Cumulative Impacts

Steven Degraer, Royal Belgian Institute of Natural Sciences

The impacts of OSW energy development can be negative, such as the displacement of harbor porpoise (*Phocoena phocoena*) by pile driving (Hammond et al. 2013), but they can also be positive, such as turbines supporting prey for harbor seals (*Phoca vitulina;* Russell et al. 2014). Commercial species such as Atlantic cod (*Gadus morhua*), European lobster (*Homarus gammarus*) and edible crab are attracted to wind farms by prey and shelter (Reubens et al. 2014). Many studies focus on the local scale, such as a single turbine or wind farm, but to understand cumulative effects, it is necessary to consider three wider goals: 1) tackling issues at the appropriate spatial scale, 2) understanding the relevant cause and effect relationships, and 3) spatially contextualizing the locally observed impacts. In the case of European plaice (*Pleuronectes platessa*) for example, we know their population is unevenly distributed throughout the North Sea (Barbut et al. 2020), and that they show increased body condition close to wind farms due to improved foraging opportunities. In an example of spatially contextualizing locally observed impacts, it is estimated that 1.3% of all primary production within Belgian waters is consumed by the fouling organisms growing on existing turbines (Mavraki, Degraer, Vanaverbeke, et al. 2020). After gathering these kinds of information, it becomes possible to promote the beneficial impacts on the ecosystem while working to mitigate the negative effects. Wind energy infrastructure can be designed with benefits to wildlife in mind, an approach that is now mandatory in the Netherlands. In order to better understand cumulative impacts, we must consider the positive effects alongside the negative, expand the scope of research projects beyond the small scale, and consider options for restoration or creation of natural value when planning development.

Metapopulation PVA: Developing Methods for Reducing Uncertainty in Impact Assessments

Julie Miller, Marine Scotland Science

OSW energy development has the potential to affect individual animals, and by extension to affect populations of animals such as seabirds. Population growth is driven by births, deaths, and connectivity via immigration and emigration, as well as additional regulating influences such as density dependence and environmental conditions. However, there are knowledge gaps in seabird population data, especially regarding young and non-breeding birds due to their capacity for long-distance movement, leading to uncertainty in population estimates, and therefore to uncertainty in PVAs. Population assessments typically assume that there is no immigration or emigration and that populations are closed, even though this is unlikely for many species. Thus, we aimed to estimate population connectivity in black-legged kittiwakes (*Rissa tridactyla*) across colonies in Shetland, UK, to help understand the effect that an added impact, such as mortality from collisions with OSW turbines, would have on the metapopulation.

First, a classic population model for kittiwake was built using productivity and abundance data from 84 kittiwake colonies (JNCC 2021), as well as a matrix of relative site distances. Using abundance and productivity time series data for each colony, a Bayesian hierarchical approach was used to estimate survival and productivity regulation. Then, by adding what is known about connectivity in the species (i.e., recruitment facilitated by breeding performance and distance of natal colony; Boulinier et al. 2008), the model predicted that the probability of an individual transferring between colonies decreases as distance increases. We then took the derived estimates for all the demographic processes and input them into a metapopulation PVA. By altering factors such as connectivity and rate of mortality (e.g., if a stressor such as OSW development increased collision mortality at specific locations), we can estimate metapopulation dynamics over the next 25 years, including metrics such as abundance and population growth rate for individual colonies and for the metapopulation as a whole. Future steps include geographic extension of the model to elsewhere in the UK. Overall, we need to make population modelling for assessment more realistic for the benefit of both conservation and renewable energy development.

Q&A and Panel Discussion

Q: Do you have recommendations for efficient ways to convert findings about cumulative impacts into adaptive management to mitigate adverse impacts, or enhance beneficial impacts?
A: Miller: By using existing knowledge to test scenarios, we can estimate cumulative impacts and then build on that knowledge as more real-world data is made available.

Q: When will the first wind facilities begin construction within US federal waters?
A: McClellan Press: Information on status of projects by state can be found here.

Q: Could commercial fishing fleets help to document offshore migrations of birds and bats?
A: Lampman: Commercial vessels could serve as platforms for documenting wildlife. The challenge would be developing and deploying a systematic approach to capture data and standardize it across vessels.
A: Miller: There are often sensitivities within the fishing fleet regarding the sharing of location data. Another issue is ensuring the consistency of data collected. One method could be to have specific observers or surveyors on vessels, however, the manner in which commercial vessels might move or stop may not be conducive to reliable data collection.

Appendix C. Session 2: European Efforts to Understand Cumulative Impacts from Offshore Wind

Moderator: Sophie Hartfield Lewis, Ørsted

Assessing Cumulative Effects: Challenges Faced by Offshore Wind Developers

Madeline Hodge, Ørsted

Cumulative impact assessments (CIAs) are challenging, with questions regarding the levels of impact that a population can tolerate and whose responsibility it is to determine that threshold. CIAs are led by developers in the UK, which also leads to differing parameters and assessment methodologies, and reduced data transferability between assessments. Illustrative case studies include:

- **The Hornsea One Offshore Wind Farm in the UK.** Part of the CIA involved identifying other developments with which the proposed project may interact to produce cumulative effects, and defining each development's likelihood of interaction with the Hornsea One project. Assessing confidence in the data was key for making a realistic assessment, especially for overlapping projects in very early phases of development. However, as projects are assessed on a case-by-case basis, the result is a 'first past the post' scenario for approvals.
- **The Forth and Tay Wind Farms** are four OSW farms in eastern Scotland that were consented in 2014. Key issues were raised with regard to nearby protected seabird populations. Each of the three developers carried out CIAs using varying methodologies (e.g., using differing reference populations and collision risk models), and submitted them at different times, making a difficult job for regulators. To address the different approaches and allow for a more robust CIA, the regulator worked with nature conservation bodies and developers to revise and update the CIA. Due to the regulatory process in Scotland, the 'first past the post' scenario in the Hornsea One Project example was avoided, but it led to substantial delays to the permitting process.
- **The Netherlands**, where the government carries out the entire permitting process and wind farms are sited only in zones reserved for them. Unlike in the UK, the Dutch approach to assessing cumulative effects (the Framework for the Assessment of Ecological and Cumulative Effects, or KEC) focuses on the ecological impact of all wind farms as a whole and therefore is not project-specific. The KEC is updated periodically with new data, and the government manages strategic monitoring and liaises with stakeholders, making this a powerful tool for assessing cumulative impacts. However, critics might say the KEC is too conservative and limited in scope when compared to a developer-led approach.

Overall, though the permitting regime differs by place, CIA approaches should be consistent, transparent, include best practice guidelines, and be flexible to include new data as they become available. While some level of uncertainty regarding project-level effects may be unavoidable, targeted monitoring to address these uncertainties improves the process.

WinMon.BE: The Belgian Countrywide Research Program to Understand Cumulative Impacts of Offshore Wind energy development

Steven Degraer, Royal Belgian Institute of Natural Sciences

WinMon.BE is the Belgian long-term monitoring program focused on understanding the cumulative effects of OSW development. WinMon.BE started in 2005 and is expected to run at least through 2023. The first zone designated for OSW farms in Belgium was delineated in 2004, and a second zone is expected to launch in 2023. The total capacity of these two zones is >4 GW.

OSW developers contribute to a central WinMon.BE fund managed by the Royal Belgian Institute of Natural Sciences. This central fund is then apportioned to the research organizations that best fit the proposed studies. The benefits of a centrally managed monitoring program of this kind include the avoidance of redundant research and improved flexibility. WinMon.BE also has an open data policy and produces annual reports. Research goals are reached through a collaborative, multi-step approach to address societal concerns regarding wind farms by consulting with fisheries, the public, environmental nongovernmental organizations (eNGOs), and developers. Of the eight windfarms making up the first zone of OSW development in Belgium, three were selected for monitoring based on varying distances from shore. The program focuses on several different aspects of ecosystems, including marine mammals, seabirds, bats, benthos, fouling organisms, and fish. Emphasis is on both the basic monitoring of site-specific ecological impacts of OSW development, as well as trying to understand the cause-and-effect relationships that result in observed impacts at a larger spatial scale. For example, monitoring found that catch per unit effort of Atlantic Cod (*Gadus morhua*) was linked to wind farms locations (Reubens, Braeckman, et al. 2013), and further research involving telemetry and dietary studies found that cod were attracted to the improved foraging opportunities provided by the structures (Reubens, Pasotti, et al. 2013, Mavraki, Degraer, Moens, et al. 2020). Recommendations from the Belgian experience are to focus on a long-term, integrated, and adaptive monitoring approach, and try to understand, not just observe, impacts.

Offshore Wind Farms: Cumulative Impact Assessment in the Netherlands

Astrid Potiek, Bureau Waardenburg

The Dutch Governmental Offshore Wind Ecological Programme (WOZEP; Noordzeeloket 2021) focuses on filling gaps in the CIA of all planned OSW farms in the southern and central North Sea (including non-Dutch projects) until 2030. WOZEP conducts research on birds, bats, and marine mammals using ship-based and aerial surveys, as well as radar and tracking studies (Bureau Waardenburg 2017). Data collected via these various methods are used for CIA of turbine collisions and habitat loss due to OSW development. As an example, collision risk was calculated for multiple bird species in the Southern North Sea (Leopold et al. 2015), with gulls, skuas (jaegers), waterfowl, terns and Curlew (*Numenius arquata*) found to be most sensitive to collisions. Next, Leslie matrix population models were used to project the impact of collision mortalities on various populations, taking demographic, mortality, fecundity, and initial population size data into account (Potiek et al. 2019). As use of offshore areas varies by age for some species (e.g., adult lesser black-backed gulls [*Larus fuscus]* use offshore areas more than non-adults), the age distribution from offshore data were used.

Modelled results of the expected additional mortality of OSW collisions on lesser black-backed gull predict a reduction in population size in the North Sea by 17% after 30 years, contrasted with the slight growth predicted in an unimpacted population. Most species showed predicted population size decreases of 1-5% due to planned wind farms, with Lesser black-backed Gull, Black Tern (*Childonias niger*) and Common Shelduck (*Tadorna tadorna*) impacted the most. These population models will be used in environmental impact assessments. The next step is to decide what level of impact is acceptable.

Developing a Cumulative Effects Framework (CEF) for Key Ecological Receptors in Relation to Offshore Wind in the UK

Kate Searle, UK Centre for Ecology and Hydrology

A CEF has been collaboratively developed for seabirds and marine mammals in relation to OSW in the UK. The process started with stakeholder agreement on key themes, including transparency and reproducibility of methodology, as well as clear presentation of uncertainty. Next, three key stages were identified to assess the impacts of collision and displacement on seabirds, including 1) specifying their baseline spatial distribution, 2) estimating the impacts of wind farms on demographic rates, and 3) conducting a PVA.

Using an ecological framework modeling approach, various datasets including at-sea surveys, colony abundance, prey, and movement data were used to estimate seabird spatial distribution and behavior. From these, the risks of collision and displacement were calculated using collision risk models (Band 2012) and displacement risk models (individual-based models for the breeding season and matrix models for non-breeding seasons), respectively. These risks were then translated into an estimation of overall annual impacts on seabird demographic rates, which, in conjunction with baseline population data, resulted in a PVA. Additional consideration was needed in presenting uncertainty, as quantification varied among the different stages of the CEF.

Other CEF efforts have included a data library of key knowledge such as parameters and data, an integrative R package to link the tools and outputs across multiple wind farms, and a user interface that provides the required audit trail and transparency, all of which are interconnected. In a case study in Scotland, the CEF compared the impacts of two different development scenarios on five seabird species, revealing species-specific differences, with black-legged kittiwakes most impacted. Next steps identified to improve the CEF include additional data collection, inclusion of key ecological processes such as attraction to wind farms and meta-population dynamics, and improved uncertainty quantification. Finally, an agreed-upon system is needed for updating the CEF based on guidance from conservation bodies.

Q&A and Panel Discussion

Q: What is the most prominent cumulative impact from OSW development in Europe?

A: Degraer: The state of knowledge regarding bird displacement and collision effects is quite good, but many other cumulative effects remain unknown. There is a risk of considering impacts that we know more about to be more prominent than those that we know little about.

Q: How have the discussed projects engaged with eNGOs in Europe?

A: Potiek: Through collaboration, we have used survey and tracking data collected by eNGOs.

A: Searle: We did not have much engagement with eNGOs in the UK when OSW farms began to be consented, and that lack of dialogue was challenging and led to some significant delays. However, we have learned how to have a healthy dialogue between policy makers, government developers, eNGOs, and academics, and the current situation is much better. As eNGOs tend to sit on a lot of project steering groups, and the number of those groups has increased, trust has been built among all the stakeholders.
A: Hodge: We (Ørsted) spend a lot of time engaging with eNGOs and in a lot of cases, they can be good partners. For example, we have had partnerships with the Royal Society for the Protection of Birds to carry out tagging work at protected sites.

Q: How has the significance of cumulative impacts been assessed for different species?

A: Potiek: In the Netherlands, we are currently discussing how to define levels of acceptable impact, which will likely depend on the conservation status of the species, especially as many species are already declining. However, a standard continent-wide approach would be ideal.
A: Searle: The UK approach has been to use the same philosophy to underpin how CIAs are carried out for different species by focusing on the mechanisms to which those species are responding. For example, both seabirds and marine mammals are high mobile, long-lived species, and consequently there are similarities in how changes to their demographic rates may play out on the population scale. Overall, finding the commonalities among the ecology of different species allows for a consistent framework for assessing cumulative impacts.

Q: How are displacement effects translated into quantitative changes in survival or reproduction for use in PVAs?

A: Searle: In the UK there are two common methods for seabirds. The first is to assume a mortality rate of displaced birds (from empirical evidence where available, but most often from expert elicitation as there is very little empirical evidence to inform this estimate), and then to multiply it by the density of birds within an OSW farm footprint, and the proportion of birds that are assumed to be displaced from it. This gives you the number of birds predicted to suffer mortality as a result of the project, which can then be apportioned back to breeding colonies, and combined with data on abundance and age class structure to convert to a change in the survival rate of affected birds by age class. The second method is to use an individual-based model that simulates the behavior of individual birds throughout a season, and their interactions with OSW farms, and again combine that with an estimated mortality rate.

Q: How does the quality of baseline data impact the cumulative impact models? What are the ideal baseline data to start with?

A: Searle: High quality baseline data is hugely important, including data on the spatial habitat use of wildlife. We found that when we ran cumulative assessments using different types of input data for bird habitat use (at-sea surveys versus GPS tracking data) we got very different estimates for the overall population-level impact.

Q: What challenges do you see with wind farms adopting “shut-down on demand”?

A: Potiek: In the North Sea, WOZEP is working on a network of bird and weather radars to automatically shut down wind farms at moments of intense nocturnal migration (Bradarić et al. 2020, Manola et al. 2020).

Q: Can the PVA models also include positive effects, like improved feeding opportunities for some species (e.g., seals) as well as negative effects like displacement and collision?
A: Searle: For seabirds, yes, positive impacts can be included in PVAs the same way as negative impacts.
A: Degraer: It is important to consider the positive effects of OSW development. For example, although species such as seals and eiders may be displaced from the area during construction, once they are used to the change, they may learn that the areas offer improved foraging opportunities which may in turn positively impact the local population.

Appendix D. Session 4: Current Knowledge on Cumulative Impacts I

Moderator: Matt Robertson, Vineyard Wind

The Vineyard Wind SEIS: Assumptions Made in the Cumulative Impact Scenario

Ian Slayton, Bureau of Ocean Energy Management

Assessments of cumulative impacts from OSW energy development must consider the expected amount of future development. Information used to understand the scope of future possible development includes information on the specific project, in this case Vineyard Wind I, as well as other projects in the pipeline that have either submitted or had a Construction and Operations Plan (COP) approved, and those that have secured a commercial lease. In addition, BOEM considers state capacity commitments for available leases within transmission range of the projects; leased areas with no associated project are assumed to be developed to the extent necessary for nearby states to meet their OSW energy commitments.

Key assumptions that were made during development of the Vineyard Wind I Supplemental Environmental Impact Statement (SEIS; BOEM 2020b) include: 1) all announced project schedules and state goals are kept (i.e., most rapid buildout scenario), 2) parameters and associated impacts from the largest turbines commercially available (12 MW) for projects that have not submitted plans detailing turbine size, 3) no limitation in specialized vessel availability to complete the necessary construction of projects on proposed timelines, 4) turbine array layout following a 1x1 nautical mile (nm), 5) use of fixed monopile foundations in all existing lease areas (which are assumed to have greater or similar impacts to jacket and gravity-based foundations (ICF 2020), 6) resolution of challenges regarding all transmission infrastructure (e.g., interconnection points, offshore cabling), and development of unique infrastructure for each project (i.e., no regional transmission systems). As project plans are solidified, the cumulative impact scenario will become more certain, but these assumptions currently serve to explore the potential cumulative effects of the most impactful scenario for wildlife and habitats.

Cumulative Impacts of Displacement on Seabirds

Stefan Garthe, Kiel University

Some seabird species, including loons and gannets, show strong avoidance behavior of wind farm areas (e.g., displacement) while the avoidance response of other species, like sea ducks, are less consistent (Dierschke et al. 2016). In contrast, some species, such as gulls and cormorants are attracted to wind farms. Displacement is generally a response to the turbine structures, with potential stronger effects when turbines are rotating, though may also be a response to increased boat traffic. Data used to study displacement include at-sea surveys and individual GPS tracking.

Studies on the interaction between ship traffic and seabirds have demonstrated that species including scoters and loons are disturbed up to 1.6 km ahead of boats and will fly around for a long period, which can lead to increased energetic costs and effective habitat loss in areas of frequent disturbance (Schwemmer et al. 2011, Fliessbach et al. 2019, Mendel et al. 2019). GPS tracking studies and surveys of seabirds at OSW farms in the North Sea have shown displacement in common murres (*Uria aalge*), northern gannets (*Morus bassanus*), and black-legged kittiwakes (Peschko et al. 2021, Vanermen & Stienen 2019, Peschko, Mendel, et al. 2020, Peschko, Mercker, et al. 2020). While most individual gannets exhibited displacement, a small number were found to primarily utilize the wind farm area. In contrast, a study of lesser black-backed gulls in the UK found a large portion of individuals regularly visiting OSW farms, but avoiding turbines within the wind farm footprints (e.g., exhibiting meso-scale, rather than macro-scale, avoidance; Thaxter et al. 2018). The largest study to date on cumulative displacement effects of OSW farms on seabirds was a study of red-throated loons (*Gavia stellata*) in the southeastern North Sea during spring (pre-migration staging area). The study area included 12 OSW farms (755 turbines, 3.4 GW) using a before-after-control-impact study combining ship-based, visual aerial, and digital aerial surveys. The study found significantly reduced abundance up to 12 km from the wind farms, and additional decline up to ~20 km (Mendel et al. 2019). While we are beginning to understand these larger-scale displacement patterns, which result in habitat restriction and loss, we still lack understanding of how displacement relates to population dynamics. While we are beginning to understand these larger-scale displacement patterns, we still lack understanding of how displacement may affect body condition, survival, or reproduction and thus potentially influence population dynamics (Vanermen & Stienen 2019).

Cumulative Impacts to Birds from Collisions with Offshore Wind Farms

Aonghais Cook, British Trust for Ornithology

The UK has nearly 2000 installed turbines, with a target of installed capacity of 30-40 GW by 2030. As a result of high-profile incidents onshore (Everaert 2009), collision risk is a potential effect of concern for birds in the offshore environment. Collisions are difficult to measure offshore, as we are unable to use approaches such as carcass searches. There are technologies in development to better quantify collision rates offshore, but the current approach relies on pre-construction predictions using collision risk models (CRMs), the most widely used being the Band Model (Band 2012). This model utilizes information about bird size and behavior and turbine operational parameters to predict the probability of collision. The CRM is known to be sensitive to a number of input parameters, and uncertainty in these parameters requires consideration of a reasonable worst-case scenario. This leads to concern that magnification of this uncertainty can lead to unduly precautionary results. In assessments where predicted collisions were simply added across wind farms, this precaution is propagated through assessments and has resulted in quite high cumulative mortality estimates for particular species (Brabant et al. 2015, Busch & Garthe 2018). In order to take a more realistic rather than unduly precautionary approach to collision risk assessment, we need to collect better data, including:

- **Avoidance rates.** CRMs are particularly sensitive to avoidance rates (Cook et al. 2018), which can occur at a variety of spatial scales from macro-scale avoidance of the wind farm itself to last-second micro-avoidance of turbines. Meso- and micro-avoidance, in particular, are difficult to measure. The use of GPS tracking technology is vastly improving our ability to study these behaviors.
- **Behavioral modes.** We can use analytical methods such as hidden Markov models to partition GPS tracks into different types of behavior, such as commuting and foraging, which can have implications for collision risk (Thaxter et al. 2019).

- **Flight speed.** Higher flight speeds result in higher estimates of collision risk. Flight speed can vary both spatially and in relation to wind speed, and accounting for these differences can lead to more accurate assessments of risk.
- **Flight height.** GPS data can significantly improve estimates of flight height and how they may vary over space and time.

In addition to accounting for variation in key model parameters, there is increasing interest in technologies to quantitatively measure collision rates and avoidance behavior rather than relying on models. This can be accomplished through the use of high-resolution tracking data, such as a study of lesser black-backed gulls that demonstrated fine-scale avoidance of rotor-swept areas of turbines (Thaxter et al. 2018). Turbine-mounted technology, such as cameras and radar systems, can also be used to examine micro-scale avoidance behavior and in some cases to detect collisions.

Q&A and Panel Discussion

Q: Given that the U.S. does not yet have large-scale OSW developments, what type of data should be collected now in order to understand cumulative impacts?
A: Cook: In order to understand the population-level effects of displacement and collisions, we require really good baseline demographic data (e.g., survival, productivity, population trends) in order to understand the impacts to these parameters once wind farms are built.
A: Garthe: Baseline surveys are also key to understanding the abundance and distribution of species prior to OSW farms being built.

Q: What are the potential causes of displacement demonstrated in red-throated loons? Does it relate to vessel disturbance, resource changes, or response to the physical structures?
A: Garthe: It is likely a combination of these factors. We see displacement even when there are no vessels, but vessel activity will further affect bird distributions. Likely the vertical structures themselves are most important, and there is even evidence that they avoid wind farms at night as well as during the day. Species that feed on discards may change distributions in response to fishing vessels.
A: Cook: It’s important to note that these effects are species-specific. For example, lesser black-backed gulls do not avoid the wind farms themselves, but do avoid the rotor-swept area of the turbines.

Q: Do you see the same patterns of displacement occur across wind farms as when looking cumulatively? Did you control for changes in overall habitat?
A: Garthe: We included distance to different wind farms in the analysis to control for changes in habitat. We see similar patterns of displacement when examining certain clusters of wind farms as we do with the overall dataset, suggesting similar displacement effects across space.

Q: What are recommended methods for collecting accurate flight height data?
A: Cook: This is a challenging question as there are issues with all methods. Traditionally, data was collected from boat-based surveys, but there are issues with attraction to vessels and other biases. With GPS tracking data, the question becomes how representative the individuals that you are tracking are of the population; you may be restricted temporally and in terms of the

subgroup of the population you have access to. With radar, you don't get species ID. There is ongoing work being done in relation to generating flight height from aerial survey data.

Q: How does distance to shore affect the level of impacts on marine life from OSW development? How does distance to shore for European projects compare to plans for the U.S.?
A: Garthe: Generally, the further offshore you go, the lower the biodiversity and abundance of species, but if you are in an area where a given species occurs, you will likely see the same effects, regardless of distance from shore. In Germany, most OSW farms, and those where the loon studies occurred, were 23 km (12 nm) from the coast.
A: Cook: In the UK, many operational wind farms are within 20-30 km from shore, but future projects are increasingly further offshore, up to 130 km from shore.

Q: Are there any studies that document the population-level impacts of displacement?
A: Garthe: This is the main knowledge gap currently with displacement. Preliminary models estimated ~10% mortality from displaced birds, but there is no quantitative evidence for this number. Population-level impacts are difficult to quantify experimentally. We are currently collecting population size estimates of loons to try to get at this question, but we still require more data. Loons are difficult because their breeding distribution is dispersed across the Arctic and sub-Arctic, making it difficult to estimate the total population size.

Q: With some individual gannets showing affinity to using wind farm areas, do you think this will lead to a larger proportion foraging in the area in the future?
A: Garthe: We assume that those individuals foraging within the wind farm will continue to do so, unless they experience mortality (i.e. collision), but over four years of tagging so far, we do not see an overall change in the proportion of individuals using the wind farms. Potentially younger birds for which the wind farms have always been present may be more habituated to the presence of wind farms than older individuals. There may also be good resources within the wind farms, and lower competition may play a role in this pattern. We don't yet have data to understand whether birds that use the wind farm continue to do so over time.

Q: What are the next steps to better understand collision risk?
A: Cook: There are ongoing studies that will improve our understanding of collision risk that are using turbine-mounted camera-radar systems to collect more data about how birds are using the wind farm. Next year we will be putting GPS tags on black-legged kittiwakes and simultaneously collecting data from a camera-radar system to improve our understanding of that species.

Q: Where can we find a summary of current knowledge of avoidance behavior by species?
A: Cook: There are multiple resources including Cook et al. 2018, Dierschke et al. 2016, and Vanermen & Stienen 2019 that summarize the current state of knowledge on seabird avoidance.

Q: What is the tradeoff in impacts for seabirds in terms of turbine spacing (further apart vs. closer together)?
A: Garthe: This is challenging, as increased spacing may mean overall a larger wind farm footprint, which could eventually lead to turbines everywhere except ship traffic areas. We need to do additional studies comparing turbine spacing across a region to understand the impact for different species.

A: Cook: There have been some studies in Europe that suggest increased turbine spacing to reduce displacement of birds. This is a potential win-win as increased turbine spacing reduces wake effect and therefore increases energy generation.

Q: For species present in both Europe and the U.S. (e.g. loons, gannets), would we expect to these species to show similar responses to OSW development?
A: Garthe: Given that we have seen a relatively consistent response for these species across studies in Europe, I would expect to see similar responses in the U.S. However, there are species, like gulls, that show different responses across studies. Some species may be easier to predict than others.

Q: Recognizing the European focus on seabirds, are you aware of any research examining potential impacts to nocturnal migrants (e.g., passerines)?
A: Cook: There are studies in Germany looking at attraction of migrant birds to lighting on meteorological masts, assuming that there might be a similar response to turbines.
A: Garthe: We have done some studies looking at shorebirds, with some exhibiting wide migration corridors with potential overlap in vertical space with wind farms. We still lack information to understand whether they exhibit displacement.

Q: Through the Vineyard Wind I cumulative impact assessment, did you identify any environmental information needs/data gaps to better inform those assessments and reduce uncertainty?

A: Slayton: Yes, there are a variety of assumptions in the assessment that will need to be further evaluated. Several projects are in the planning stages to address key information needs. The BOEM Environmental Studies Program’s Studies Development Plan identifies some information needs over the next few years (BOEM 2020a).

Q: Do current studies address potential cumulative effects of multiple pile-driving rigs operating concurrently during the construction of a particular project?
A: Slayton: At this point in time, no construction plan for an OSW project in the U.S. has proposed concurrent pile-driving. All concerns regarding concurrent activity so far are focused on nearby or neighboring projects being built simultaneously.

Q: For BACI studies, do visual aerial surveys remain useful or should we focus on boat-based and digital aerial surveys moving forward in the U.S.?
A: Garthe: Visual aerial surveys fly at low flight altitude and therefore are not possible in wind farm areas post-construction. It is useful to focus on both digital aerial and boat-based surveys before and after establishment of the wind farms.

Q: With high potential for cumulative impacts in seabirds that are already in decline, does Europe prohibit OSW development in important bird areas?
A: Garthe: Unfortunately, there are even wind farms in protected areas, which does not fit with the overall objective of those protected areas. There are enough areas of the ocean that can be developed that these areas should be avoided.

Q: Are there any European bird species not expected to be impacted by OSW that were found to be impacted once projects began operating en masse?

A: Cook: Largely due to where wind farms have been built to date, the species affected have been those we expected. However, with more wind farms planned for the west coast of the UK, there are questions about the potential impacts on species like shearwaters that we don't understand yet.

Q: Are collision risk models used to site new offshore development in Europe or only after an area is already slated for development?
A: Cook: In the UK, these models are used both ways. At an initial strategic level, they are used to identify areas where collision risk may be a significant issue to scope out during the consenting (permitting) process. However, these assessments tend to be based on crude data. Once a site is identified, it then goes through a more rigorous assessment using baseline survey data from that location.

Q: Can you provide more information on how you refined CRMs based on ancillary data from GPS tags?
A: Cook: We developed an approach to model flight height estimates from GPS error where we incorporate data such as the number of satellite fixes in order to get an understanding of the error associated with each measurement (Ross-Smith et al. 2016). We are also looking at technology such as altimeters to measure species flight heights and hope to have more published in this space soon (e.g., Largey et al. 2021).

Q: Have there been studies examining flight trajectories from shore during migration? Might seabirds intersect with OSW farms as they initiate migration?
A: Cook: We recently completed a pilot study on Shelduck looking at this, and we hope to do more tracking next year to collect additional information (Green et al. 2020).

Appendix E. Session 5: Current Knowledge on Cumulative Impacts II

Moderator: Jillian Liner, Audubon New York

Cumulative Physical Effects of Offshore Wind Energy Development on Oceanographic Processes

Jeff Carpenter, Institute of Coastal research, Helmholtz-Zentrum Geesthacht
Coauthors: Larissa Schultze, Lucas Merckelback
There are several ways in which OSW farms could impact the physical structure of the ocean. Oceanic wakes, caused when ocean currents move past the foundation structures and create areas of increased turbulence, can extend ~1km past the structures (Vanhellemont & Ruddick 2014). Shelf seas consist of three primary layers during the summer: the surface mixed layer, a bottom mixed layer, and a thermocline, which separates the lighter water on the surface from the colder, heavier water at the bottom. This density stratification acts as a stable structure that limits vertical transport. As tidal currents move the stratified water column back and forth across turbine foundations, wakes are generated that cause mixing of the water column. The level of turbulence is comparable to and can exceed the natural state in very concentrated areas around the turbine foundations (Carpenter et al. 2016, Schultze et al. 2017).

To understand the degree to which this turbulence can affect shelf sea stratification, we use idealized and theoretical modeling, field observations and measurements at wind farms, and numerical modeling. In a 2016-2017 study conducted at a series of wind farms in the North Sea, we found lower levels of stratification inside than outside of the wind farms (Floeter et al. 2017). We can compare these field studies to idealized models to understand how good our models are at predicting the degree of mixing. We also use simulations to examine the effect of stratification, and from these we see that when water column stratification is stronger to start, there is less mixing from currents flowing past turbine structures (Schultze et al. 2020), as it acts to stabilize the water column and resist mixing, with effects up to 400 m from the structures. The level of stratification and potential wake effects also vary over time, with peak stratification in summer and subsequent mixing during the winter, and with interannual variability in stratification strength (Carpenter et al. 2016). Another factor influencing the level of mixing is the length of time water will spend within the wind farm and the number of structures that it interacts with (Carpenter et al. 2016, Schultze et al. 2020). Ongoing modeling efforts include scaling up these wind-farm level effects to simulate potential regional changes throughout the North Sea. With OSW development built over large scales, we expect to see significant seasonal changes in stratification. In the future, we will build off this work to integrate these physical impacts into the wider picture of what this might mean for primary production, ecosystem structure, and fisheries.

Cumulative Effects of Offshore Wind on Benthic Habitat

Drew Carey, INSPIRE Environmental
Offshore structures introduce new benthic habitat that can have cascading effects on marine ecosystems. Benthic substrates can include sand, gravel, silt, and mud, with some OSW lease areas dominated by hard bottom habitat and others by soft bottom habitat. Potential effects

from OSW energy development include benthic habitat modification, enrichment of benthic-pelagic coupling, connectivity and habitat expansion, and changes in habitat suitability:

- Benthic Habitat Modification – Offshore structures introduce hard substrata to offshore areas, leading to colonization of surfaces. This can lead to changes in surrounding sediments, the flow of energy, and local food webs. Most changes in bottom habitat are due to organic enrichment from the organisms colonizing the structure. They filter plankton and discharge waste directly to the surrounding sea floor, leading to a fining of the sediment, increases in organic content, and introduction of new organisms to this food-rich habitat (Degraer et al*.* 2020).
- Enrichment of benthic-pelagic processes – With the colonization of structures by filter-feeding organisms, there is a net increase in energy flow from pelagic sources to benthos. Demersal species, such as starfish and crabs, move up the structure and finfish that are attracted to the structure move further from the sea floor. The presence of these predators attracts higher trophic level species (e.g., tuna, marine mammals). The majority of the sediments present in these offshore lease areas are coarse and support relatively low densities of benthic infauna. As these sediments get finer and organic materials increase, these habitats will acquire more biomass. This results in a more complex food web of animals that feed directly on bacteria and detritus and scavengers feeding on biological waste. These animals in turn are prey for demersal fish.
- Connectivity – To understand cumulative effects, we must understand interactions between changes at each structure, with other surrounding habitats, and with more distant wind farms. This requires a detailed understanding of the specific habitats in and around each project.
- Habitat suitability – We need to focus on the function of the elements of each habitat, including provision of structure, food resources, refuge, and areas suitable for spawning. This concept of function refers to the transformation of energy through the food web, and how changes to that food web and structure affect the resource value of the habitats in the wider ecosystem. Thus, to understand cumulative effects, we need to understand the scale and functional effects of food web changes.

Cumulative Noise Impacts Upon Fishes (and Turtles) from Offshore Wind Construction and Operation

Arthur N. Popper, University of Maryland and Environmental BioAcoustics LLC, & Anthony Hawkins, Loughine Ltd.

Sound travels much faster in water than air and may travel substantially greater distances. Underwater sound has two elements: sound pressure and particle motion. All fishes can hear and can detect particle motion, and some can detect sound pressure. Hearing capability varies substantially by species, with some species, like dab, that only hear very low frequencies and not well, while others, like cod, hear a wide range of frequencies and hear well. Like humans, fishes can detect sound, determine the direction of a sound source, and discriminate sounds of different animals (predators, prey). We know that turtles can detect sound at frequencies similar to some fishes, but we know little about the mechanisms by which they do so or the potential effects of anthropogenic sound on sea turtles. Most fish species will detect pile-driving and other construction sound at some distance, depending on the sound level. Fish that hear well, like cod and herring, may also detect operational turbine sound.

Along with sound level and distance, exposure time also influences potential effects. The most significant potential effect of sound during construction, if in close proximity to an intense source, is mortality. At greater distances, fish may show physiological responses like stress, temporary hearing loss, masking of biologically important sounds, or behavioral changes, such as leaving feeding sites. Lab studies examining the effects of pile-driving sound exposure showed variability between species and an increased effect as exposure level increased (Halvorsen et al. 2012, Casper et al. 2013). This study also reinforced the idea that fish without swim bladders are not affected by impulsive sound. A study in Ireland found that simulated pile driving sound causes schools of fish to change their behavior, causing changes in shoal density and location, but they returned to normal behavior when the sound terminated (Hawkins 2014). Sound from operational wind farms is lower than construction noise and continuous rather than impulsive, and therefore may only lead to masking or behavioral changes. Some lab evidence suggests exposure to continuous sound can cause potential temporary hearing loss in fishes that hear well, but field studies with actual wind farm sounds are needed to better understand the potential for behavior responses of fishes.

Sound exposure criteria were developed in 2014 for pile-driving and wind farm operational sound based on current scientific knowledge (Popper et al. 2014), and little has been published since to improve these criteria. These criteria are only for sound pressure, not particle motion. As OSW development continues to progress, we should consider the potential effects of sound exposure, not just hearing capabilities – e.g., if an animal can hear a sound but there is no discernible effect, then it is not necessary to regulate or mitigate that sound (Popper et al. 2020). Major knowledge gaps include 1) hearing sensitivity to sound levels from OSW sources, 2) behavioral effects in the field, 3) effects and exposure criteria for particle motion and substrate vibration, not just sound pressure, 4) understanding variability in potential effects across species, and 5) hearing in sea turtles and invertebrates.

Designing Studies to Detect the Ecological Impacts of Offshore Wind energy development

Elizabeth Methratta, IBSS Corp. contractor to NOAA Northeast Fisheries Science Center

OSW development can interact with marine ecosystems in diverse ways, and potential impacts are co-occurring with other processes such as climate change and commercial and recreational fishing (Reubens, Braeckman, et al. 2013, Boon et al. 2019). For marine fish and shellfish, knowledge gaps include the effects of OSW development on pelagic and highly migratory species, how production at turbines contributes to regional productivity, and how local changes in prey fields affect local and regional food web dynamics. In order to detect and understand the mechanistic basis of ecological effects, rigorous sampling designs are needed (Dannheim et al. 2020, Peterson et al. 2001). Design and analysis are just two steps in a much broader framework needed to advance our monitoring approaches at OSW farms.

The most common design used to study ecological impacts at OSW farms is the BACI design, which considers an impact stratum and a control stratum (Green 1979, Stewart-Oaten et al.

1986, Underwood 1991, Underwood 1992, Underwood 1993, Underwood 1994). The control should be physically and biologically similar to the impact area, and sites are randomly sampled within both areas before and after construction. There are limitations to this study design, however, with no clear consensus on how to resolve these challenges (Underwood 1991, Underwood 1992, Underwood 1993, Underwood 1994, Stewart-Oaten et al. 1986). BACI designs assume that: 1) suitable controls can be found, though it is difficult to find representative controls in a dynamic system and there are often unexplained changes over time, 2) the area within the wind farm is homogeneous, though we know that effect size attenuates with distance from turbine (Bergström et al. 2014, Methratta & Dardick 2019) and that wind energy areas are not physically homogeneous (Guida et al. 2017), and 3) the spatial scale of the effect is known, though we often lack a mechanistic understanding of individual stressors, and these stressors operate over different spatial and temporal scales. The second and third assumptions can be at least partially addressed via the use of stratified sampling designs and inclusion of the nearest neighbor distance to a turbine as a covariate in analyses (Methratta 2020).

An alternative study design is the BAG design, which measures the response variables and potential covariates along a distance gradient before and after the impact. This design examines how the distance versus dependent variable relationship changes over time, allowing for the distance gradient to help explain variability in the response variable, and does not have the same assumptions as the BACI design. Previous studies have demonstrated that the BAG design often has greater statistical power (Ellis & Schneider 1997) and demonstrate the potential benefits of this study design (for examples see Brandt et al. 2011, Rothermel et al. 2020). The method for a particular study should be based on the type of relationship (e.g., linear, nonlinear) we might expect, the hypothesis being tested, and existing knowledge of the species or effect being studied. Other critical design considerations include sample site determination, power analysis to ensure effective statistical power to answer the question, random versus fixed sampling sites, and scaling potential effects from the turbine scale to that of wind farms or regional and ecosystem-level effects.

Q&A and Panel Discussion

Q: Ocean stratification was much higher before the OSW farm was built than afterwards – are there confounding factors that could help explain this reduced stratification?
A: Carpenter: The reason is that this particular measurement was taken at a different time of year, in this case summer, whereas the other observations were during spring. We would generally expect stratification to be stronger in summer than spring.

Q: Have you examined the effect of foundation size on wake?
A: Carpenter: In our simulations, we did not adjust the size of the turbine structure, but I would expect the length of the wake to change with this parameter.

Q: Does the gradual increase in biofouling on turbine structures have a measurable effect on turbulence?
A: Carpenter: We do not currently have an answer for this. From a strictly engineering perspective, if you increase the "roughness" of a structure, you would expect more turbulence, so biofouling could likely have an effect. This would be difficult to measure *in situ* in close

enough proximity to the turbine structures, so we would likely need to rely on simulations to examine this.

Q: Has there been any research of wake impacts on primary productivity?
A: Carpenter: This is a topic of current research, so hopefully we will have an answer soon.

Q: In the U.S. Mid-Atlantic region, we have a seasonal cold pool. Based on your observations, could OSW development disrupt the formation of this cold pool?
A: Carpenter: This sounds similar to the German Bight in the North Sea. The impacts on stratification (i.e., the cold pool) depend on a number of factors, including foundation type, water depth, strength of tides, size of residual currents, and other factors. We are working on parameterizing models for this, and from what we know, it is likely important.

Q: How does sub-surface mixing affect dynamic surface features like temperature fronts?
A: Carpenter: In the North Sea, the fronts are tidal mixing fronts and come from increased turbulence with shallower water depths. If you increase the strength of the turbulence, you could expect a change in the position of the front.

Q: Are there any studies that have quantified the net effect of increased mixing due to turbine foundation wakes and the potential reduction in wind mixing due to lower wind energy in the wake above the sea surface?
A: Carpenter: I am not aware of any work combining these two aspects. There is much work on wind wake but not on the coupled system.

Q: Are there opportunities to use the turbine structures as platforms for turbidity sensors to contribute to our understanding of dynamics inside of the wind farm?
A: Carpenter: This is not something we have done in our studies, as there may be challenges associated with cables and other components, but this may be a possibility.

Q: Would you expect changes in sediment distribution inside and outside of the wind farm as a result of changes in stratification?
A: Carpenter: We would expect the region affected by mixing to extend beyond the wind farm footprint. As far as I know, there is little knowledge on the mechanics of this process, but from observation, stratification wakes are localized while sediment wakes can be observed over much larger scales.

Q: Are there any studies showing that oceanographic mixing contributes to increased foraging habitat and attraction of marine birds or other predators (independent of artificial reef effects)?
A: Carpenter: Not that I am aware of in relation to birds. During one of our larger studies (Floeter et al. 2017), we examined stratification while other co-authors looked at the effects on plankton and larvae in the water column, with mixed results on the influence of the OSW farm.

Q: Is there existing information on benthos changes at cable locations?
A: Carey: Cable installation creates a physical disturbance of the substratum; studies have found the recovery of the benthos after installation to generally be rapid (3-9 months). Studies in Belgium and Germany have not seen long-term effects of cables. Studies at the Block Island Wind Farm also recorded rapid recovery.

Q: Has any applied monitoring of benthos shown behavioral responses, for example in relation to noise or cable EMF?
A: Carey: There are studies that have looked at EMF on specific species, but we don't know about potential population- or community-level effects. This type of study could utilize a BAG design in which you could examine potential effects at different distances from a source. Other existing studies have focused on growth and change on the turbine itself, showing decapods, crabs, lobsters, and demersal fish moving up the structure, which in turn can change the dynamics of a community.

Q: Are there existing studies for the U.S. east coast modeling food webs in the OSW context as there are in Europe?
A: Carey: The only existing study on the U.S. east coast is the Realtime Opportunity for Development Environmental Observations (RODEO) project funded by BOEM at the Block Island Wind Farm (HDR 2020). That study did not directly measure food web processes but did measure biomass of functional groups, which may be useful in food web modeling. Detailed studies are challenging, but if done in a non-site-specific way, can inform larger models.

Q: Why is there so little data on potential sound effects on fishes and sea turtles? Are there any large studies currently underway to address this data gap in the next 1-2 years?
A: Popper: There are not any large ongoing studies in the U.S. There may be some ongoing in Europe, but these studies are very expensive and difficult to design, and require extensive data collection.

Q: Acknowledging there is very little information in the literature on particle motion in substrates during pile driving, at what depth would you recommend for sensors on future monitoring projects?
A: Popper: Amaral et al. (2020) provides a good example of study design. You cannot look just at a single depth, but need to look throughout the water column, as signals will differ between the water surface and the bottom.

Q: What effect do the specific types of scour protection materials have on the benthic community? Are there materials that would increase habitat value without reducing scour protection efficiency?
A: Carey: Scour protection layers are generally small boulders, which increase the complexity of the habitat and introduce additional hard bottom substrata. There are several European efforts to develop and test 'engineering with nature' approaches to utilize forms of concrete that do not introduce contaminants and can be formed into shapes that provide additional refugia for decapods and demersal fish. They require testing for both scour protection properties and habitat value. We also need to consider that scour protection is designed to be removed after the project is complete, so if you create a habitat, the consequence of removing it also needs to be considered.

Q: Were laboratory studies of noise impacts to fish conducted on juvenile life stages, and how might potential effects differ between juveniles and adults?

A: Popper: We primarily used relatively young animals due to size constraints of our specialized tank. One study has indicated that effects slightly decrease in larger individuals of one species (Casper et al. 2013), but more information is needed.

Q: Can you provide further detail on the behavioral response of sturgeon to noise and whether there is risk of mortality, injury, or behavior change given this response?
A: Popper: Animals were observed with telemetry that had limited range from receiver locations, which limits our ability to examine this. However, we suspect that fish moved away from pile-driving sound and would therefore not be subject to the maximum signal for very long.

Q: Is there much known about ambient and episodic sound levels from anthropogenic sources in the Massachusetts/Rhode Island wind energy area?
A: Popper: There is some existing information about ambient sound in the area. See Amaral et al. (2020) and articles in Acoustics Today (Amaral 2020).

Q: How do changes in the benthic community affect finfish?
A: Methratta: The most consistent effect observed with finfish has been a greater abundance of fish associated with areas very close to the foundations, though the mechanisms driving these changes are yet to be resolved. We still know much less about large pelagic and highly migratory fish species and how they associate or interact with wind farms.

Appendix F. Session 6: Current Knowledge on Cumulative Impacts III

Moderator: Ruth Perry, Shell New Energies

Decision Framework to Identify Populations that are Vulnerable to Population-level Effects of Disturbance

Cormac Booth, SMRU Consulting

The primary impact of OSW farm construction on marine mammals is noise, whether from vessels, geo-physical surveys, or most importantly, from pile-driving. Concerns for marine mammals include auditory injury and disturbance (e.g., increased energy expenditure, or reduced energy intake), and a modeling approach may be used to estimate the impact of noise on a population. A PCoD model uses data on the exposure of an animal to a stressor such as noise, and the potential for physiological or behavioral change due to that exposure, and then estimates the consequent cascading effects on the health and vital rates (e.g., survival, fecundity, growth) of the animal or population. However, for most populations of marine mammals we lack data to build full PCoD models. Therefore, two decision frameworks have been developed with the aim of identifying when PCoD models are most useful (Wilson et al. 2020), and which to use in a specific situation (Pirotta et al. 2018). The first framework includes a decision tree with three main components: 1) estimating the spatiotemporal overlap between species and activities being assessed, 2) estimating the risk of multiple exposures, and 3) assessing which PCoD model to apply for high priority populations. The decision tree addresses when the animals are present, whether the animals are of high risk of extinction, whether the proportion of the population impacted surpasses an agreed upon threshold, how long they are exposed for, and whether individuals in sensitive life stages are likely to experience disturbance for ≥ 2 days. To address these, it is important to understand home ranges and whether individuals are resident or nomadic, with resident individuals potentially exposed to higher levels of disturbance. Similarly, knowledge of the lifecycle of the species of interest (e.g., when the majority of animals are pregnant or lactating) will also be important. This approach provides a time-efficient, cost-effective, and reproducible workflow for conducting impact assessments, allowing the prioritization of species with highest conservation needs. To decide which PCoD model is suitable given data availability, the two frameworks (Wilson et al. 2020, Pirotta et al. 2018) can be combined, resulting in a complete and continuous decision tree. These tools are largely qualitative and should complement other semi-quantitative and quantitative tools such as PCoMS models. Key sensitivities of PCoD models are population sizes and impact thresholds, the extent and duration of disturbance, and the transfer functions from disturbance to vital rates, which can be tackled through expert elicitation or dynamic energy budget models. A good understanding of the prey environment is also critical (Hin et al. 2019, Pirotta et al. 2021). Lastly, monitoring for early warning signs, such as assessing the proportion of juveniles in a population, may allow detection of demographic change earlier (Holmes & York 2003).

Cumulative Noise Impacts to Marine Mammals from Offshore Wind energy development and Operations

Brandon Southall, Southall Environmental Associates Inc., and Howard Rosenbaum, Wildlife Conservation Society

The Atlantic coast of the U.S. supports concentrations of many cetacean species including the North Atlantic right whale, humpback whale, and fin whale, which occur in the area for extended periods of time, including for some critical life history stages. There are also large concentrations of small, acoustically sensitive species such as beaked whales, dolphins and harbor porpoise. Human impacts on individuals and habitat are already severe, with 50% of necropsied humpback whales showing evidence of human interaction, and there is an ongoing unusual mortality event involving several species. Combining whale sighting data with anthropogenic activity data allows estimation of whale encounter rates, and Cumulative Utilization and Impact (CUI) Analysis can assess cumulative impacts by modelling habitat use from survey data and defining anthropogenic impact (Rosenbaum et al. 2014, Chou et al. 2020, Maxwell et al. 2013). However, understanding the cumulative impacts of noise on marine mammals is very challenging, and there are multiple complimentary approaches with different levels of complexity including the qualitative PCoD-based approach (see Booth's presentation), a semi-qualitative risk assessment method (this presentation), and the quantitative PCoM-based approach (see Tyack's presentation). The risk assessment method for evaluating acute and aggregate noise exposure uses a matrix to suggest a relative level of risk based on two factors: 1) the magnitude of exposure of a species to noise using an index (or proxy for all noise impacts), and 2) the vulnerability of the species, considering factors such as population and other environmental risks (e.g., oil spills, vessel strikes). The risk assessment method can be used for different temporal and spatial scales and is currently being adapted for use in some wind farm scenarios of the U.S. east coast, where there is already an elevated level of anthropogenic noise in the soundscape (Rice et al. 2014). A current effort to synthesize currently available acoustic and nonacoustic data, including the near-real time acoustic buoys in the New York Bight, will support a regional-scale approach to address cumulative impact and risk assessment to marine mammals.

Vessel Encounter Risk Model Tool

Mary Jo Barkaszi, CSA Ocean Sciences Inc.

Vessel encounters are a threat to marine mammals and sea turtles, but risk can be difficult to assess due to reporting challenges. The objective of the vessel encounter risk tool developed for BOEM is to characterize vessel strike risk while accounting for spatial, temporal, and species-specific parameters for wind energy areas on the Atlantic OCS. Firstly, the user creates a scenario by selecting species, month, vessel type and speed, track line, number of trips, and any aversion factors. Then, the tool points the model to the correct matrix for both animal species characteristics data (e.g., density, size, swim speed, dive profile; Roberts et al. 2016) and vessel characteristics data (e.g., size, speed, draft, tonnage). For all large whales, the percentage of time that the animal occurs at a certain depth is estimated using a matrix of activity (e.g., foraging, transiting), month, and region, using behavioral data from literature and expert elicitation. Sea turtles have a similar, but less complex matrix. Next, the model calculates an encounter rate for each 1 km^2 block of vessel transit, which is then aggregated along the route. The tool allows an analytical encounter model to be built, with results aligning with those from other studies (Martin et al. 2016, Conn & Silber 2013, Redfern et al. 2013). The model interface is an ArcMap add-in using Python and ArcGIS architecture, allowing the user to create many scenarios within a project. The tool also allows comparisons among multiple scenarios, such as wind farms, routes, months, years, or other user-defined variables. Modeled encounter rates are output in text, tabular, and graphic format, the latter in the form of a heatmap. The tool provides solid assessment and is an important first step in standardizing vessel strike risk for marine mammals and sea turtles. It is expected to be modified as new analyses and data are published.

Population Impacts to Bats from Wind Energy Development

Cris Hein, National Renewable Energy Laboratory

Many species of bats worldwide are experiencing declines and range contraction, due both to natural and human-induced stressors. Migratory tree-roosting bats are more likely impacted by wind energy development than cave-hibernating species, however their population sizes are difficult to determine due to small roosts and dispersal across the landscape. The best current estimates from genetic analysis suggest the effective population size (size of the ideal population that would experience the same amount of genetic drift as the observed population) of the Eastern red bat is 100,000s-1,000,000s, the silver-haired bat is 100,000s, and the hoary bat is 1,000s-100,000s (Korstian et al. 2015, Vonhof & Russell 2015, Pylant et al. 2016, Sovic et al. 2016, Ammerman et al. 2019). Bat mortality data from wind energy development comes from land-based wind, however, as bats are also active offshore, inference from onshore can be applied to offshore. Hundreds of thousands of bats are estimated to be killed by land-based wind each year in the U.S. and Canada, with 78% being migratory tree-roosting species, 38% of which are hoary bats (Arnett & Baerwald 2013). Hoary bats are of special concern due to their high mortality rate and low effective population size, with models suggesting a 90% population decline by 2050 (Frick et al. 2017), and a 88% reduction in mortality required to manage extinction risk if the total population is <1,000,000 (EPRI 2020). Therefore, accurate bat population data are critical, and in lieu of any single easy method to assess them, a combination of study types is the most effective approach. Two effective methods are 1) standardized acoustic monitoring across the U.S through the North American Bat Monitoring Program (NABat; USGS 2021), a spatially-balanced sampling design that uses presence data and allows inference to un-surveyed areas, and 2) expanding further on estimating effective population sizes through genetics by collecting more spatially- and temporally-distinct data, allowing better estimates of mutation rates and therefore, greater precision. Overall, the impacts on bat populations from wind energy are high and we may need to respond in the near term. The key next steps are to invest in collecting multiple types of data now to build a weight of evidence-based approach to better understand population status and trends moving forward.

Q&A and Panel Discussion

Q: Is there a way of disentangling the multiple stressors on animals and assign effects to specific sources?

A: Booth: It is very challenging to disentangle multiple stressors. The best approach is to continue investing in a coordinated, comprehensive, and continuous monitoring strategy with clear objectives that involves the engagement of different stakeholders. For example, population and animal health surveys, studies of prey dynamics and energetics, and understanding stress and behavioral responses are critical.

Q: How are detected negative effects on animals resolved after recognition?

A: Booth: Offshore renewable developments in the UK employ adaptive management strategies which are developed in advance of construction/installation/operation. When monitoring indicates a threshold has been reached, mitigation is utilized. An example of such adaptive approach language is from the Strangford Lough tidal turbine (Keenan et al. 2011).

Q: Are they any examples of a PCoD model informing decision making?
A: Booth: PCoD models have been used to guide the sustainable growth of Dutch OSW (Heinis et al. 2015), and we are currently using a harbor porpoise energetic model to trial different piling schedules.

Q: Is there concern that it may take too long to demonstrate negative population-level effects and implement beneficial management?
A: Booth: Time is of the essence in the U.S., but PCoD models exist for multiple species and continue to be improved, acting as tools to help identify potential issues or explore different scenarios. Scientists, industry and regulators are interfacing effectively, which is key.
A: Rosenbaum: Dynamically adjusting activities is difficult from the point of view of developers, especially in the case of pile driving, but understanding the potential issues and having a plan in place is important. There is continued room for discussion, and we hope to tackle this as part of NYSERDA's E-TWG moving forward.

Q: How much is known about the use of offshore regions by bats?
A: Hein: Our knowledge is limited, but we know that bats use the nearshore area and areas around islands, with an increase in activity in fall during migration. We do not, however, have a good sense of an activity gradient moving offshore. This is important information as some bat species are attracted to turbines (onshore) and may make multiple passes within the rotor-swept area, leading to high exposure levels. Attraction may vary by species, but we think turbines may be perceived as a resource for roosting or foraging.

Q: Can you expand upon the role of animal- and agent-based models to assess populations?
A: Southall: The more real data that can be included in models (e.g., swimming speed, dive depth, behavioral state), and the more realistic and complex the environmental data (e.g., prey availability), the stronger and more realistic models will be.
A: Barkaszi: We also need data on other impact-producing factors, such as noise and vessels from other industries. The more real data we can input into these models, the stronger the outcome.

Q: Can noise from pile driving be safe for marine mammals, and what levels are considered safe?
A: Southall: There is reason for concern about the potential acute and chronic impact of noise on marine mammals. However, from what we know about hearing, most concerns regard disturbance as opposed to direct damage (Southall et al. 2019). We need to combine the tools we have with reasonable conservatism in decision-making where we have uncertainty, and use those tools adaptively for targeted monitoring goals. A "safe" level of noise depends on your definition, but aiming for a level with low risk of impact to vital rates may be a good standard.

Q: Are there any studies on negative impacts to marine life from low frequency noise and vibrations from multiple wind turbines in operation?
A: Booth: A few studies from Europe found that sounds from operational wind farms were barely

audible to most species, and if that they were, were highly unlikely to disturb the species. Most of the sound is drowned out by ambient sounds (e.g., wind, shipping noise, biological sounds).

Q: What is the state of knowledge on baleen whale hearing and any efforts to model/understand hearing capability?
A: Southall: We lack direct hearing measurements in any baleen whale. However, models suggest they have good low frequency hearing and a broad range up into the tens of kilohertz (Southall et al. 2019).

Q: Can you tell us more about technologies being developed to detect collisions by birds and bats?
A: Hein: Numerous technologies are currently being tested onshore, but they are still in various early stages of development. The U.S. Department of Energy funded a webinar that discusses several current studies.

Appendix G. Session 8: Designing Studies to Assess Cumulative Impacts

Moderator: Francine Kershaw, Natural Resources Defense Council

Synthesis of the Science: Interactions Between Offshore Wind energy development and Fisheries

Andrew Lipsky, NOAA Fisheries, Brian Hooker, Bureau of Ocean Energy Management, Annie Hawkins, Responsible Offshore Development Alliance & Lyndie Hice-Dunton, Responsible Offshore Science Alliance

The National Marine Fisheries Service, BOEM, and the Responsible Offshore Development Alliance have been working to engage the fishing industry interests in OSW development processes and have recently started a 'Synthesis of the Science' effort. This effort aims to advance the science and governance necessary to improve understanding of interactions between OSW and fisheries in a way that integrates the expertise of the fishing industry. This includes reducing potential conflicts between fisheries and OSW development and identifying opportunities for collaboration. The goal is to build a collaborative process involving fishers, wind developers, state and academic partners, and federal agencies to advance ROSA's goals of regional science. The first aspect of this effort was a workshop, held in October 2020, which will be followed by a report developed in early 2021. The topical focus of the workshop and report includes: 1) ecosystem effects including benthic and physical habitat modification and oceanographic process change, 2) fisheries socio-economics, including navigation, safety, impacts to coastal communities, gear loss, and port infrastructure, 3) fisheries management, including impacts on data collection and management, and 4) methods and approaches for research, including cumulative impacts, ecosystem assessments, and regional science planning. There is overlap between this and the State of the Science effort and communication and coordination between groups is ongoing, particularly in efforts to identify priority research and translate those priorities into funding efforts to fill gaps and needs. Workshop participants interested in these efforts should visit the ROSA website (ROSA 2021) for opportunities including attending public advisory council meetings as well as serving as research advisors.

Approaches to Understanding Cumulative Effects of Stressors on Marine Mammals

Peter Tyack, University of St. Andrews

One of the first challenges when studying cumulative effects, whether from OSW or other stressors, is differences in term definitions. Cumulative effects are defined by regulators as the incremental impact of a proposed action when added to other past, present, and reasonably foreseeable actions (U.S. Council on Environmental Quality 40 CRF §§ 1508.7). In contrast, biologists may focus on individual animals or populations repeatedly exposed to stressors. As humans expanded and industrialized across the globe, marine ecosystems have faced many stressors, including pollution, habitat destruction, invasive species, and climate change. Stressors may be additive, whereby the impact of stressor A and stressor B combined is no larger or smaller than the sum of the two stressors separately. Stressors can also be synergistic, whereby the cumulative impact of the two stressors combined is greater than the sum, or antagonistic whereby the cumulative impact is smaller than the sum. It can be difficult to predict which of these will occur, as not only are there multiple stressors acting populations, but the environment of populations changes over space and time and they are embedded within complex ecological systems. It is therefore important to examine indirect impacts on animals, such as prey impacts.

Examining the potential cumulative impacts of OSW development emphasizes the importance of looking at specific geographic effects for these indirect effects. Given the longevity of OSW developments, it is important to consider how impacts may change over time, particularly in the face of climate change. When examining cumulative effects of one or more stressors, we need to consider how smaller impacts accumulate over time, either from aggregate exposure or cumulative risk.

A framework was developed by the National Academies Committee to examine the PCoMS, using intermediate health parameters to integrate the effects of short-term responses to different stressors and link these to long-term changes in survival and reproduction of individuals (National Academies of Science Engineering and Medicine 2017), which in turn can affect population dynamics. Understanding the effects of stressors on individual health is key for this process, for marine mammals measuring individual health might include body condition, organ status, immune status, and stress. However, these may be difficult to collect on wildlife. While experiments are the most scientifically-rigorous approaches to testing for influences of potential stressors, these approaches are often not possible for marine mammals. Inference, therefore, must be based on quasi-experiments, which are subject to confounding, but inference is possible for time series analyses and weight of evidence approaches. An example of this type of approach is examining stress levels in North Atlantic right whales prior to and after September 11, 2001 when vessel traffic dropped significantly. Findings suggest that chronic noise exposure from vessels elevate stress hormones.

There may be a role for adaptive management in identifying which combinations of stressors pose risk to marine mammal populations. In this approach one could develop hypotheses to guide management actions and collect data to assess the strength of impact of individual stressors and cumulative effects using a quasi-experimental approach, applying different management actions to different sites to help evaluate effectiveness and cost benefit of the actions. An ecosystem-based approach may be more practical to examine cumulative effects risk of adverse impacts and to identify practical solutions to reduce risk.

Designing Monitoring to Detect Cumulative Impacts and Address the Confounding Variable of Climate Change

Jon Hare, NOAA Northeast Fisheries Science Center

The National Oceanic and Atmospheric Administration (NOAA) Fisheries has a mission to support productive and sustainable fisheries, safe sources of seafood, and the recovery and conservation of protected resources and healthy ecosystems. This mission is supported by law mandating efforts including Magnuson-Stevens Fisheries Management and Conservation Act, National Aquaculture Act, Marine Mammal Protection Act, and the Endangered Species Act. The Northeast Fisheries Science Center conducts surveys, collects data, conducts assessments, provides status and trends of managed populations and ecosystem components, and conducts research to understand the drivers of the status and trends of these managed populations and ecosystem components. Plans for largescale OSW energy development along the Northeast coast of the U.S. will interact with much of NOAA Fisheries work, including fisheries, wildlife, habitat, ecosystem processes, offshore aquaculture, coastal communities, and the ability to continue carrying out long-term research activities. Historically, NOAA Fisheries has worked at the single-species level, but have recently moved towards ecosystem approaches to fisheries management, to measure cumulative impacts on population and species. When we look at the cumulative impact of wind energy development on marine ecosystems, we think about the consequences of fishing, of climate, and of wind energy developments on managed species, populations, and processes. To examine the impacts of fishing, we use data from many sources through a transparent stock assessment process. Combining the effects of fishing and climate change, NOAA is conducting long-term monitoring, which provides an opportunity to document changing patterns of fish and marine mammals in relation to temperature trends using process-level understanding, survey and observational data, and modeling. Taking the next step to thinking about cumulative impacts, particularly from OSW development, the components needed include observational surveys, process studies (e.g., lab and field experiments), retrospective analysis, technological innovation, and modeling (Fogarty & Powell 2002). In our region, extensive baseline information can aid our conceptual understanding of cumulative impacts to fisheries, wildlife, ecosystems, and habitats. As we continue to conduct research, even small-scale, we need to keep the larger regional ecosystem-scale in mind and move towards large-scale models to examine cumulative impacts.

Q&A and Panel Discussion

Q: How much active participation has there been from the fishing community in the OSW development process and how does this vary by state?

A: Hawkins: There has been a lot of emphasis on involving fishermen in OSW planning. There is more and more participation requested from fishermen all the time, and some fishermen are very active. However, the level of engagement depends on the geography and the fishery. The focus has shifted from participation to ensuring input is actively used in planning processes. We have learned that the model of co-management and involving fishing industry knowledge is critical to improved outcomes.

Q: How are concerns expressed by the fisheries community and environmental advocates similar or different?

A: Hawkins: There are areas of overlap, though also some divergence, with groups examining fish ecology or physical oceanography without considering how harvesting activities influence the ecosystem. This can lead to different priorities from the two groups. The relationships between these groups are still being built. It is important to have a collective effort to ensure collaboration and all questions get answered.

A: Hooker: Everyone has an interest in protected species, not just from a conservation perspective, but also given potential effects on operations.

A: Hice-Dunton: There is an overall concern about the unknown, and emphasis on doing good science to ensure we're answering questions about potential impacts to ecosystems and species. One of the reasons for the deliberate separation between ROSA and the RWSE is the socioeconomic component to fisheries, and concerns relating to gear access, access to fishing grounds, and vessel safety, which aren't necessarily considerations for wildlife conservation.

Q: Are there examples of quasi-experiments that could or should be conducted in relation to OSW development activities?
A: Tyack: One example would be identifying sites that are ecologically similar, one where wind energy development is going to occur and the other where it is not. You could set up a long-term observation process to monitor the sites before construction and then throughout the lifetime of the development to examine long-term changes in exposure to stressors and the response of critical parts of the ecosystem.

Q: How do we ensure that small-scale monitoring at the project level is coordinated for consistent data collection that can be combined to examine larger or regional-scale impacts?
A: Hare: ROSA and the RWSE become the places where we work together to combine data across scales and make sure we're working on high priority topics.
A: Hice-Dunton: We continue to think about ways integrate site-specific data regionally and at the ecosystem scale. From the fisheries perspective, we have been working with the National Marine Fisheries Service to improve monitoring guidance. Part of this guidance is how to collect data in ways that are standardized, which is easier to say than to do. Another important aspect is accessibility of data; there are some existing databases and portals but not at the level and scale needed.

Q: What existing regional efforts are focused on oceanographic and ecosystem changes and how is that going to be integrated with the regional entities (ROSA, RWSE)?
A: Hare: This is a gap. We do have the Integrated Ocean Observing Systems as a possibility, but we need to further consider the data needed to understand ocean ecosystems. Along with focusing on fisheries and wildlife, we need to form an ocean ecosystem collaboration.
A: Hooker: As the OSW industry develops, there will be more structures in the water which may provide additional opportunities for data collection on abiotic oceanographic processes.

Q: What types of studies on marine mammals give us the most bang for the buck to progress cumulative impact assessments, particularly for North Atlantic right whales?
A: Tyack: The unique thing about North Atlantic right whales is that each individual in the population has been tracked extensively, leading to fantastic population data. We have good data to model impacts of an individual stressor like entanglement in fishing gear on the right whale population. The key going forward is to improve our estimates of health and better understand how different stressors impact the health of individuals and interact to impact the population. Energetics is a place where we can integrate impacts from different stressors. Once we understand the mechanisms, we can use predictive models to begin to understand cumulative impacts.

Q: Given that studies will be performed by various groups, is there a framework for researchers to discuss and agree upon key monitoring questions to maximize the utility of data collection?
A: Hice-Dunton: This is central to what ROSA is aiming to do. We started with developing interim monitoring guidance, recognizing that these will need to be built out further. In the structure of ROSA, we are inclusive of federal and state agencies, fishermen, developers, and research scientists, and are beginning to discuss data collection and reporting standards to ensure better

integration.
A: Hare: We have a lot of research priorities from fisheries management councils, protected species, endangered species recovery plans, and marine mammal stock assessments, to name some examples. The limitation will be resources, so we need to prioritize the most urgent topics and those best addressed collectively.
A: Lipsky: There are good examples that we can draw from to ensure we are asking the right questions. Steven Degraer and Lisa Methratta both discussed some of these. We want to catalog research priorities and put them through a framework to help us prioritize the most impactful questions that need to be answered.

Q: How do we reconcile the scientific timelines required for understanding cumulative impacts from OSW with the need to drastically reduce reliance on fossil fuels to reduce climate impacts?
A: Tyack: The regulatory definition of cumulative impacts emphasizes the negative impact of the proposed activities, but the activities might have knock-on positive effects. It is important to take a broad view of all the stressors and reduce the ones we can most effectively reduce. To focus on OSW without the broader perspective of the drivers of climate change would be a policy failure.
A: Lipsky: We already have robust frameworks in place to measure change across the ecosystem. It will take dedicated effort and resources to track changes between receptors and stressors. We are beginning to establish the type of scientific governance structures (ROSA, RWSE) to accomplish this.
A: Hare: This illuminates the idea of trade-offs, which are critical to consider, and occur at different scales. For every activity there are pros and cons. Integrated ecosystem assessments represent a framework to evaluate tradeoffs to inform decisions, and represent one approach to begin thinking about OSW development in the context of climate change.