Bird Workgroup Report

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

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Disclaimer

Additional Information

This report is one outcome from a broader effort to review the state of knowledge regarding offshore wind energy development's effects on wildlife and identify short-term research priorities to improve our understanding of cumulative biological impacts as the offshore wind industry develops in the eastern United States. This effort, titled *State of the Science Workshop on Wildlife and Offshore Wind Energy 2020: Cumulative Impacts*, included a week of plenary presentation sessions and contributed talks in November 2020, as well as the formation of six other workgroups similar to the bird workgroup that met over the winter of 2020-2021. This report, and those from the six other workgroups, are available on the workshop website at http://www.nyetwg.com/2020-workgroups.

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Contents

Background 4
Introduction 5
Methods 5
Prioritization of research needs 6
Results: Short-term Research Priorities 8
General/preliminary needs 8
Link between distribution and habitat 13
Seabird connectivity 17
Exposure of migratory populations 18
Information for collision risk models 20
Population studies 22
Conclusions 26
Literature Cited 28
Appendix A. Workgroup Collaborators 33
Appendix B. Full List of Research Topics Generated by the Workgroup 35

Background

The 2020 State of the Science Workshop, hosted by the New York State Energy Research and Development Authority (NYSERDA), was held virtually from November 16-20, 2020. This workshop brought together over 430 stakeholders engaged with environmental and wildlife research relevant to offshore wind energy development. The aim of the workshop was to assess the state of the knowledge regarding the potential cumulative impacts of offshore wind development on wildlife populations and ecosystems. **For this effort, cumulative impacts were defined as 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** (see call-out box for definitions of "effects" and "impacts").[1] Attendees included stakeholders from offshore industry, government agencies, non-profit organizations, and academia. More information can be found at http://nyetwg.com/2020-workshop.

Following the plenary sessions in November, workshop attendees formed seven workgroups focusing on benthos, fishes and mobile invertebrates, birds, bats, marine mammals, sea turtles, and environmental change. Under the guidance of lead technical experts, workgroups met virtually in late 2020 and early 2021 to identify scientific research, monitoring, and coordination needs to improve our understanding of cumulative impacts from offshore wind energy development. **The goal for each group was to identify a list of studies that could be implemented in 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.**

The intended audience for this report encompasses a range of stakeholders including researchers, state and federal agencies, offshore wind energy developers, regional science entities, environmental non-governmental organizations, and funding entities who could potentially target these priorities for future funding. The priorities identified below should not be interpreted as research that must occur prior to any development activity; rather, these priorities are intended to further inform environmentally responsible development and minimize cumulative impacts over the long term. Many of these research needs are specifically directed at understanding and measuring effects as the industry progresses.

Defining Impacts vs. Effects (from Hawkins et al. 2020)

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.

Impact: a biologically significant effect that reflects a change whose direction, magnitude and/or duration is sufficient to have consequences for the fitness of individuals or populations.

Workgroup members represented a wide range of perspectives from offshore wind developers, the fishing industry, government agencies, non-profit organizations, and academia, and provided critical input based on their respective specialties. Workgroup meetings included presentations as well as small and large group discussions to identify and prioritize key topics of interest. Workgroup members also provided input on the relative priority of different topics via live polls during meetings and/or online surveys between meetings. All workgroup documents were shared with workgroup members via a document collaboration platform (e.g., Google Drive, Microsoft Teams),

[1] This effort was focused on better understanding effects specifically from offshore wind energy development. This was not intended to imply that offshore wind is causing greater impacts than other stressors. Cumulative impact estimates for offshore wind energy development will be useful in broader cumulative impact frameworks that include impacts from multiple types of anthropogenic activities.

and workgroup members had multiple opportunities over the course of several months to provide written input on earlier drafts of this report. The report indicates a general consensus among workgroup members unless otherwise noted; where there was stated disagreement among workgroup members on a recommendation in this report, this disagreement is noted in the text. Despite the substantial input and influence of workgroup members on the workgroup reports, final report contents were determined by the technical leads, in some cases with support from an additional small subgroup of experts within the group. More information about the workgroups can be found at www.nyetwg.com/workshop-work-groups.

Introduction

A variety of bird species use the Atlantic coast of the U.S. and may have the potential to interact with offshore wind (OSW) energy development in the region. While terrestrial taxa such as shorebirds and passerines may use the offshore environment specifically during migration, some seabirds may use the area throughout their annual cycle, and the potential effects posed to different taxa by OSW development likewise vary. Birds may respond to wind farm infrastructure at a variety of spatial scales from the macro-avoidance of the wind farm as whole to the 'last-second' micro-avoidance of the turbine rotor-swept areas (May 2015, Cook et al. 2018). Of particular concern is the potential for birds to either collide with turbines (Fox et al. 2006, Masden and Cook 2016, Allison et al. 2019) or be displaced by the wind farm as a whole, leading to effective habitat loss (Vanermen et al. 2015a, Dierschke et al. 2016, Mendel et al. 2019). However, changes in habitat and prey resources (Perrow et al. 2011, Slavik et al. 2019) and the potential for birds to be attracted to wind farms (Dierschke et al. 2016) have also been the focus of research. Increasingly, the potential for significant, negative cumulative impacts is being raised as a concern (Busch and Garthe 2018, Brabant et al. 2015) though the potential consequences on U.S. bird populations are largely unknown (Goodale and Milman 2016). Therefore, identifying research needs to inform adaptive management of current and future projects will be important as the OSW industry develops in the eastern U.S. Workgroup members identified a wide range of priorities, including examination of habitat and prey drivers of seabird distributions and behaviors, development of reliable estimates of collision risk, and several strategies for focusing further research (e.g., identifying key taxa of concern, using population modeling frameworks to identify potentially high-impact topics on which to focus further study).

Methods

The bird workgroup leads were Aonghais Cook (Senior Research Ecologist, British Trust for Ornithology) and Jillian Liner (Director of Conservation, Audubon New York), with technical and logistical support from Kate Williams, Edward Jenkins, and Julia Gulka (Biodiversity Research Institute) and others (Cadmus Group). The workgroup consisted of 76 members (Appendix A), who met virtually three times in the winter and spring of 2020-2021 to discuss research priorities to improve our understanding of cumulative impacts to birds from offshore wind development on the east coast of the U.S.

The workgroup went through a multi-step process to identify these research priorities (Figure 1). Following the initial creation of a long list of potential research studies (Appendix B), workgroup leads assessed the sequence in which studies on related topics should be implemented. Group discussions coalesced around 19 topics, which were then prioritized via online survey, with workgroup members indicating which topics they felt to be the most urgent immediate need using a set of pre-defined criteria (see below). When new data collection was required to address a topic, the feasibility, timeframe, and utility of new data collection efforts were described.

In the Results section below, the 19 topics are listed by thematic category, rather than in priority order, as this structure more clearly identifies relationships between research topics. The thematic categories are:

- **General/preliminary needs** to focus and inform implementation of future research studies, including review studies and data compilation efforts to ensure maximization of the utility of existing data and identification of key remaining gaps.
- **Links between distribution, habitat, and resource availability** to identify key prey and habitat resources for focal seabird species, examine how these resources may be affected by offshore wind development, and understand how these drive seabird distributions, movements, and habitat use.
- **Seabird connectivity** to examine how the distribution and habitat use of focal seabird taxa relates to OSW development areas in the winter season, and whether specific subpopulations may be disproportionately exposed to OSW development.
- **Exposure of migratory populations** to understand offshore movements during post-breeding dispersal and migration periods for terns, shorebirds, and landbirds, and the drivers of these offshore migration patterns.
- **Information to inform collision risk models** to estimate potential effects.
- **Population studies** to allow for the eventual examination of potential cumulative population-level impacts to birds from OSW development.
- **Other** including miscellaneous topics that do not fit the above categories.

Prioritization of research needs

Following development of research topics, workgroup members participated in an online survey, whereby they were asked to rank the 19 topics in order from highest to lowest priority. Given the goals of this workgroup, members were asked to consider the following criteria when identifying priorities:

- *Urgency of information need.* Objectives should be prioritized that will most effectively improve our understanding of cumulative impacts and inform decision making.
- *Sequencing of objectives*. If the results of Study #1 are needed to inform the design of Study #2, the former should be designated higher priority in the short term.
- *Ability to inform cumulative impact models.* Will the information from this study improve our ability to model population-level cumulative impacts?
- *Effectiveness at addressing one or more key societal concerns,* as identified through multi-stakeholder engagement processes.

Weighted average ranks were divided into thirds (e.g., top 33rd percentile, middle 33rd percentile, and bottom 33rd percentile) and assigned a prioritization tier of 1-3, with 1 indicating the highest priority. However, respondents indicated that relative rankings should only be interpreted at a gross scale; some of the priority topics could, and likely should, be addressed collectively in a single project, while others could occur concurrently within the next 5 years. For example, several topics were identified as top priority for reasons of sequencing of objectives; however, these preliminary studies will only be necessary in some cases. For example, though development of an exposure/vulnerability risk matrix will help drive the selection of focal species for further study, we are already aware of some species that are going to be priorities for research due either to their conservation status (e.g., Roseate Tern *Sterna dougallii*), or a combination of their expected exposure and vulnerability (e.g., Northern Gannets *Morus bassanus*). Thus, many workgroup members argued against a strict sequencing of priorities in favor of a more nuanced evaluation of priorities relative to 1) their ability to inform potential management outcomes, and 2) achieving a balanced portfolio of short- and long-term studies.

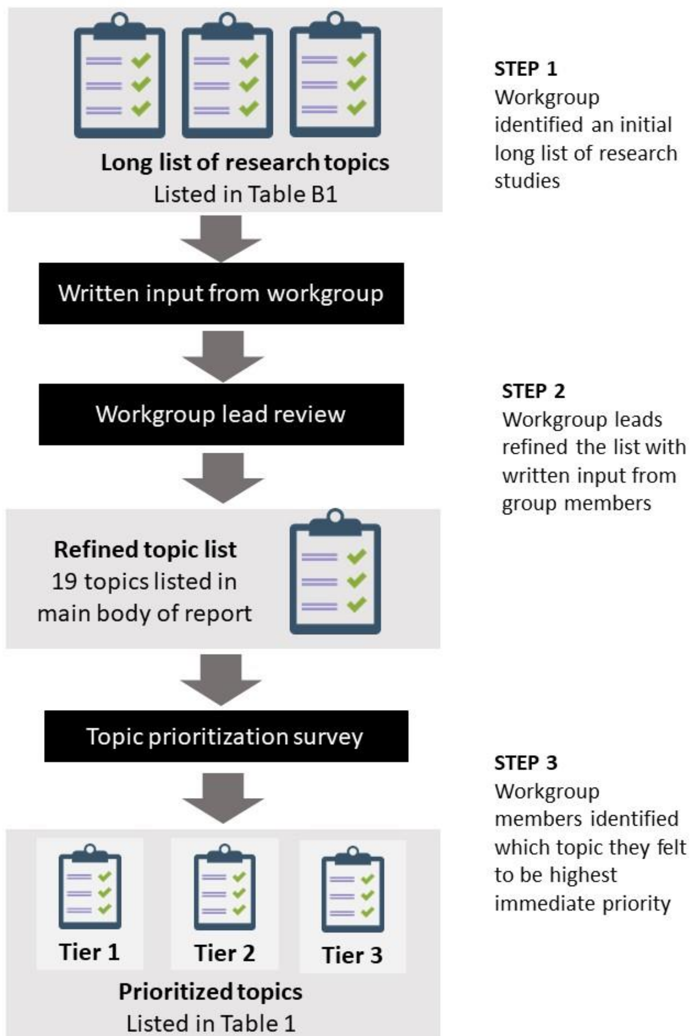

Figure 1. Bird workgroup process for identifying short-term research priorities related to cumulative impacts from offshore wind development. Workgroup members identified an initial long list of research studies at the second meeting in February 2021 and began assigning a priority level to each research topic. Following the meeting, group leads refined this list into 44 discrete topics (Table B1), and with further written input from workgroup members distilled the long list down to a shorter list of 19 priorities. Workgroup members then identified which of the 19 topics they felt to be highest immediate priority via online poll.

Results: Short-term Research Priorities

Using the process described above, group discussions coalesced around 19 priority topics, which are listed by prioritization tier in Table 1. In the text, these topics are ordered by thematic category. Where the workgroup felt there was a clear link between suggested studies, that has been highlighted in the text ("relevant topic" numbers listed below correspond with both priority topics list (Table 1) and the long-list of topics (Table B1). In instances where significant overlap between suggested studies was identified, we have attempted to highlight the overlap and/or how the studies could be extended to cover additional topics. We further felt that these topics lent themselves to a clear sequencing, with initial projects focused on informing research needs and gathering existing data, with a view to understanding the potential exposure of key species to OSW development and highlighting gaps in existing data. Where gaps exist, these may be filled by new data collection (e.g., through additional surveys or tracking studies), and we have attempted to highlight the type of studies for which additional data collection would be most beneficial.

General/preliminary needs

There are several preliminary studies that could be conducted with existing data to focus and inform implementation of future research studies, including determining the extent to which data already exist that could be used to answer questions relating to the exposure and effects of developments.

1. Develop an exposure/vulnerability risk matrix to identify priority species by OSW lease area (Tier 1)

Goal: Quantify exposure and potential vulnerability at proposed development areas to inform siting and risk assessments, identify key gaps in knowledge, and ensure that research studies are focused on species of greatest potential risk.

Taxon: All

Spatiotemporal scale: All regions, year-round

Development phase: All

Methods/Approaches: Similar approach to Bradbury et al. (2014) and/or Certain et al. (2015); i.e., examine bird distribution across all lease areas to assess which species are likely to be most exposed to OSW development at each site (e.g., Goodale et al. 2019) and relate this data to species' expected sensitivity to collision, displacement, and other effects. Examine whether particular species consistently come up in relation to development zones. This analysis would build off of site-specific assessments in the U.S. using similar methods (e.g., in Construction and Operations Plans [COPs] and other documents) but apply a consistent, peer-reviewed process across all OSW lease areas in order to develop a commonly agreed-upon list of priority species by lease area/region. This process should also acknowledge any uncertainty in the assessment of risk, either generally or to specific taxa.

Existing data: The National Oceanic and Atmospheric Administration's National Centers for Coastal Ocean Science (NOAA NCCOS)'s Marine-Life Data Analysis Team (MDAT) models (large update in

Table 1. Prioritization “tiers” for the 19 priority topics identified by the workgroup. Tier 1 topics were identified to be of highest immediate priority (see text for caveats).

Topic	Prioritization Tier	Topic # in Text
Develop an exposure/vulnerability risk matrix	**1**	1
Develop standardized protocols for collecting and storing survey data	**1**	2
Review available tracking data across all taxa of interest	**1**	3
Develop baseline estimates of demographic rates and sensitivity analysis	**1**	4
Assess the role of habitat and/or prey abundance in species distribution and movements	**1**	8
Examine the connection between seabird behavior and collision risk	**1**	13
Improve species-specific seabird flight height information and its relationship to environmental/weather conditions	**1**	14
Review seabird diet information and conduct a gap analysis	**2**	5
Identify the distribution of seabird prey resources (e.g., forage fish, mollusks)	**2**	6
Assess movement and space use of terns during pre-migratory staging and migration	**2**	11
Explore passerine and shorebird use of offshore environment during migration	**2**	12
Develop population models to assess degree of displacement or collision that could affect population viability	**2**	16
Identify potential mitigation strategies, including technical feasibility and cost-benefit analysis	**2**	19
Examine the effects of offshore wind development on important seabird prey species, initially focused on sand lance	**3**	7
Assess non-breeding habitat use of alcids and drivers of interannual variability in habitat use patterns	**3**	9
Examine the degree of Northern Gannet metapopulation connectivity in the non-breeding season	**3**	10
Develop standardized/sustained monitoring of tern colonies population/productivity	**3**	15
Assess attraction of passerines and storm-petrels to lighting	**3**	17
Examine occurrence and distribution of smaller/endangered petrels (e.g., Black-capped petrel, Bermuda petrel)	**3**	18

progress, to be completed in late 2022[2]); regional and state survey datasets (among other data) from the Northwest Atlantic Seabird Catalog; existing vulnerability assessments, such as Willmott et al. (2013); previous spatial modeling exercises to minimize wildlife conflicts (e.g., NYSERDA 2017); existing tracking datasets and other behavioral information to inform vulnerability assessments; conservation status information.

Relevant topics: This topic would assist with prioritizing species for a range of future studies, including **#4**

Expected outcomes: A common understanding of the species most vulnerable to potential OSW effects by lease area, and at greatest risk at a cumulative level.

2. Develop standardized protocols for collecting and storing survey data (Tier 1)

Goal: There is no centralized database or accepted data standards for some data types in relation to OSW monitoring (e.g., some types of tracking data, marine radar, passive acoustics, demographic information). In order to facilitate future analyses and reduce redundancy in data collection efforts, it is important to ensure that there are centralized repositories and standardized data formats for reporting, such that data can be used collectively to quantify displacement or other cumulative impacts as the industry develops, and that data remain accessible and comparable in the longer term.

Taxon: All

Spatiotemporal scale: All regions, year-round

Development phase: All, but with an initial focus on baseline data collection pre-construction.

Methods/Approaches: By standardizing data collection for new studies as they are initiated in the short term, we will increase our chances of having the necessary statistical power to assess effects, including cumulative effects, in the future. For example, quantifying the degree of displacement and attraction to offshore wind facilities was identified as a priority topic (**#24**). However, studies in Europe highlight that achieving the statistical power to quantify these effects is extremely challenging, and we are unlikely to be able to fully quantify cumulative effects of displacement within the timeframe of the current work program (Vanermen et al. 2015b); combining survey data across multiple OSW lease areas may be required in some cases, and would be facilitated by standardized data collection and data transparency. Thus, a series of workshops focused on different data types, including passive acoustic data, radar, visual observations, and others, could help identify common existing approaches, gaps, and recommendations. These recommendations should include a focus on data and metadata standards, transparency, and long-term data accessibility, and should draw from existing protocols from European OSW and other relevant industries/topic areas, as appropriate. Several other ongoing data standardization efforts are noted below.

Existing data:

- NYSERDA requires OSW developers selling power to New York to make their nonproprietary environmental data publicly available. In support of this requirement, NYSERDA is currently developing a report that assesses publicly available databases for housing different types of wildlife data that OSW developers and their consultants may collect at OSW sites (NYSERDA, in

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[2] BOEM Environmental Studies Program ongoing study http://www.boem.gov/sites/default/files/documents/environment/AT-20-03.pdf

prep), assesses gaps in available databases, and makes general recommendations for data transparency. The report acknowledges that a single centralized database for OSW wildlife data would be ideal, but this would require substantial ongoing investment. As such, the report focused primarily on assessing the existence and capacity of existing databases such as Ocean Biodiversity Information System Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP)[3] and Movebank[4] to meet the state's data transparency goals.

- The Northwest Atlantic Seabird Catalog, with the Bureau of Ocean Energy Management (BOEM)-funded SeaScribe survey app to ensure data are collected in the appropriate format, go a long way towards meeting centralized data storage and data consistency goals for boat and aerial survey data (including digital aerial survey data). Digital aerial survey data also has the advantage from a standardization perspective of being collected by relatively few providers. BOEM is planning a data standardization workshop in summer 2021 to further discuss standardization of digital aerial survey data.
- The Motus Network has standardized formats and a centralized database for automated radio telemetry data. As part of a NYSERDA-funded project[5], the U.S. Fish and Wildlife Service (USFWS) is currently working with Motus and other partners to develop guidance for offshore monitoring using the Motus Wildlife Tracking System, including a dedicated portal for OSW-related data submission on the Motus website.
- A need for methodological and data standardization and transparency was also noted in other State of the Science workgroups, including those focused on the benthos (Degraer et al. 2021), marine mammals (Southall et al. 2021), fishes and mobile invertebrates (Popper et al. 2021), bats (Hein et al. 2021), and environmental stratification (Carpenter et al. 2021).

***Relevant topics:* #24, #32, #34, #18**

Expected outcomes*:* A common resource from which the data necessary to carry out robust cumulative impact assessments can be drawn.

3. Review available tracking data across all taxa of interest (Tier 1)

Goal: Assess existing tracking data across all taxa for the offshore region of interest, and determine possible data compilation and analytical approaches for using these data collectively to inform siting decisions and risk assessments, as well as to identify gaps in data for priority species (as identified in **#1**, above).

Taxon: All

Spatiotemporal scale: All regions, year-round

Development phase: N/A

Methods/Approaches: Desk-based review of available data in databases such as Movebank, Seaturtle.org[6], the Seabird Tracking Database[7], OBIS-SEAMAP, as well as in the published literature. This

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[3] OBIS-SEAMAP https://seamap.env.duke.edu/
[4] Movebank https://www.movebank.org/cms/movebank-main
[5] Using radio telemetry to track animals offshore. http://www.briloon.org/renewable/automatedvhfguidance
[6] Seaturtle.org http://seaturtle.org/
[7] BirdLife International Seabird Tracking Database http://www.seabirdtracking.org/

should consider factors such as the types of tags deployed, ancillary sensors, and the spatial or temporal resolution of the available data (e.g., duty cycles, location accuracy, etc.) in order to consider the potential analytical approaches that could be used in order to 1) derive behavioral information, 2) assess exposure to proposed developments using existing datasets, 3) serve as a baseline for which to compare future tagging data collected post-construction and assess response, and 4) inform other priorities listed below.

Existing data:

- In addition to the databases highlighted above (a more complete list is available in NYSERDA in prep), there is the potential to build off of National Audubon's Migratory Bird Connectivity Project.
- Some data may be published but not available through a public database, so a literature review would be needed. Other data is unpublished and not publicly available, and would require direct communications with project investigators.
- Environment and Climate Change Canada is currently undergoing a comprehensive review of existing seabird tracking data for Canadian waters, which could be relevant to this effort for species tracked into U.S. waters. Sarah Wong and Isabeau Pratte are heading up this effort.
- A similar need was identified by other State of the Science workgroups, such as the group focused on sea turtles (Gitschlag et al. 2021).

Relevant topics: **#14, #13, #28, #29, #31, #35, #36, #11, #38**

Expected outcomes: A shared resource highlighting what tracking data are available for the species most vulnerable to cumulative impacts from offshore wind farms as well as key tracking data gaps.

4. Develop preliminary population models and sensitivity analysis (Tier 1)

Goal: To quantify the population-level consequences of effects from offshore wind farms, more demographic data will likely be needed for many populations. Directing research towards areas of greatest need will involve 1) developing robust estimates of baseline demographic parameters, 2) developing preliminary population models, and 3) conducting sensitivity analyses and other gap analyses to identify key gaps where additional data are most needed.

Taxon: Key species/taxa of interest, as identified based on the Risk Matrix (**#1**)

Spatiotemporal scale: All regions, year-round

Development phase: N/A

Methods/Approaches:

- Based on outputs from Risk Matrix (**#1**, above), identify key species of interest and review available demographic data for these species by region, highlighting where we have robust information and where additional monitoring effort may be required via mark-recapture studies or other approaches. This should include assessment of data from breeding colonies (including consideration of juvenile survival for colonial species, as well as productivity and adult survival estimates), as well as non-colonial breeders and species that do not breed in the U.S.
- Develop preliminary population models and conduct sensitivity analyses to assess the relative importance of various demographic parameters (e.g., how robust do various estimates need to

be to significantly affect model predictions?) and identify where additional resources should be directed towards filling key gaps.

Existing data: A group of researchers and resource managers are working on this topic for Roseate Tern and Common Tern (*Sterna hirundo*) demographic data in the northeastern U.S., though Common Tern assessments have generally focused on productivity and breeding population size rather than survival or recruitment. There are existing metapopulation databases (recording the movements of marked birds among colonies) for Roseate Terns, Arctic Terns (*Hirundo paradisaea*), and Atlantic Puffins (*Fratercula arctica*), but all need to be reevaluated with recent data.

***Relevant topics:* #21, #39, #41, #15, #42, #43**. Results would also feed into Topic **#16** (developing population models to evaluate OSW effectss).

Expected outcomes: A framework with which to assess OSW's cumulative population-level impacts on vulnerable species and identify targeted areas for further research on these species.

Link between distribution and habitat

Workgroup members acknowledged that it may be difficult to tease apart the effects of OSW on seabird habitat and prey populations from effects caused by climate change or other factors. Regardless, workgroup members felt that developing a better understanding of the linkages between seabirds and their habitats and prey would enable more informed siting and risk assessments, and that this improved understanding would also be essential to estimate the effects of OSW development.

There is a clear logical sequence for topics in this section whereby the results from one study can feed into the next. However, workgroup members noted that this strict sequencing may not be necessary in all cases (i.e., we already have information on key prey fish species for some seabirds). Thus, the importance of some of the below topics may vary by taxon of interest, and these priorities may be coupled or addressed in tandem depending on the degree of understanding we already have of the linkages between habitat, prey, and seabird distributions. This reality is reflected in the prioritization of topics by workgroup members; Tier 2 topics (Topics **#5** and **#6**) may be essential groundwork for some species, and would strengthen distribution models for all species of interest, but as we can likely use existing data for some species to make inferences about the role of habitat on distributions, these topics may not be essential prior to addressing Topic **#8**.

5. Review seabird diet information and conduct a gap analysis (Tier 2)

Goal: Review existing information on seabird diet, by species where possible, to identify key prey species and gaps in our knowledge, such that assessments of changes in habitat/prey due to OSW development (and efforts to use prey data as a predictor of seabird distribution/movements) are focused on the right prey taxa.

Taxon: All seabirds

Spatiotemporal scale: All regions, year round

Development phase: N/A

Methods/Approaches: Desk-based review on diet information for all seabirds (breeding and non-breeding seasons), targeted laboratory analysis of existing samples, and gap analysis. There is a need to identify diet information from breeding, wintering, and migratory seasons and to focus specifically on identifying data gaps for recent diet data, as diets may be changing. This review should focus on key species identified via the Risk Matrix (**#1**, above).

Existing data: Most data are from the breeding period, and much of the available diet data is old, though data currently collected at breeding colonies varies by region. There is a need to pull together a combination of datasets, potentially including:

- Diet data and fecal DNA data from colonies (though it should be noted that chick provisioning data may not necessarily inform our understanding of adult diet from the same colonies/time periods). This can provide information on temporal variability in primary prey species, which may also be important.
    - USFWS and the National Audubon Society have a Microsoft Access database for tern provisioning in the Gulf of Maine and are currently working with other colony managers in New England to adopt the same protocol and database structure to allow data collation.
    - NOAA and USFWS have analyzed fecal DNA samples from Great Shearwater (*Ardenna gravis*) from Massachusetts and continue to collect samples.
    - Managers of tern colonies in the Gulf of Maine collect chick diet information annually and are using eDNA to look at adult diet.
- Stable isotope data (especially for non-breeding periods) may help determine what species are feeding farther offshore. Canadian researchers may have stable isotope data from feathers that may inform diet info, especially for non-breeding species in the US.
- Analysis of stomach contents from carcasses, including bycatch carcasses collected through the NOAA fisheries observer program. Tufts University has done some stomach content analyses from carcasses in recent years.
- Analysis of gastric lavage, regurgitate, and fecal samples from birds captured at sea for tracking studies

Relevant topics: this study is a first step before other habitat/prey research topics (**#8, #6**) can be properly addressed. Where data are available, this would also link to the energetic consequences of displacement (**#20, #21, #6, #27, #39, #40**) and, potentially, to population modelling approaches such as individual based models (**#16**).

Expected outcomes: A clear understanding of seabird diet and the potential consequences of key prey species becoming unavailable as a consequence of offshore wind farm development (e.g., either through direct OSW effects on prey, or via effective habitat loss for seabird predators via displacement).

6. Identify the distribution of seabird prey resources (e.g., forage fish, mollusks) (Tier 2)

Goal: Identify baseline distributions of prey resources to inform our understanding of drivers of seabird distributions and movements.

Taxon: Seabird prey (e.g., forage fish, mollusks)

Spatiotemporal scale: All regions

Development phase: N/A

Methods/Approaches:

- Desk-based analysis combined with targeted field studies for prey fishes (e.g., targeted to the depths, size classes, etc. needed to examine seabird prey).
- Continuation of existing efforts to develop forage fish models and examine links to seabird distributions and movements (e.g., the Biodiversity Research Institute [BRI] Ecosystem Dynamics project[8]).
- Suggested key fish species to study include sand lance (*Ammodytes spp.)*, Atlantic menhaden (*Brevoortia tyrannus*), Atlantic herring (*Clupea harengus*), silver hake (*Merluccius bilinearis*), and capelin (*Mallotus villosus*), though we may need to know more about some seabirds' diet before trying to assess their prey distributions (**#5**).

Existing data:

- Linkage with the aforementioned BRI Ecosystem Dynamics project.
- NOAA trawl data, Northeast Area Monitoring and Assessment Program (NEAMAP)[9] state trawl datasets, essential fish habitat data, and zooplankton data, among other datasets (BRI has compiled a list of datasets for the ongoing Ecosystem Dynamics project that may be useful to reference here).
- Liz Craig and USFWS are working with the University of New Hampshire researchers to examine tern GPS data, environmental variables, and forage fish distribution.
- The UK has used seabed habitat mapping to identify suitable habitat for sand lance as a method of estimating prey distribution.
- Land-based diet studies such as provisioning studies provide data on temporal variability in prey species.
- The State of the Science workgroup focused on benthos identified research needs related to understanding species and habitat distributions, and in particular indicated a need to examine habitat and species distributions in space and time (Degraer et al. 2021). Thus, there is likely overlap in the species of interest for these two workgroup priorities.

Relevant topics: Depending on the degree of existing knowledge, this priority could follow on diet assessment (**#5**) and occur before assessment of the role that habitat and/or prey abundance play in species distribution and movements (**#8**, below) and, potentially, inform population modelling approaches such as individual based models (**#16**). For some species where we know what habitats or forage fish are important (e.g., sand lance), this study could be coupled with **#5** and/or **#8** rather than occurring sequentially.

Expected outcomes: Understanding the potential for seabirds to lose access to key prey resources as a consequence of the cumulative impact of displacement from offshore wind farms.

7. Examine the effects of offshore wind development on important seabird prey species, with an initial focus on sand lance (Tier 3)

Goal: Examine the effects of OSW construction and operations on important prey species for key seabird taxa, beginning with sand lance

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[8] BRI Ecosystem Dynamics project http://www.briloon.org/quantitativelab/marinepredatorprey
[9] NEAMAP http://www.neamap.net/

Taxon: Seabirds (forage fish)

Spatiotemporal scale: All regions

Development phase: Construction, operations

Methods/Approaches: Examine the effects of OSW construction (e.g., sedimentation, including along cable routes, and substrate vibration) and operation (e.g., electromagnetic fields, habitat loss/gain) on key prey species for seabirds of interest identified in the Risk Matrix (**#1**). In some cases, key prey species may need to be identified through further research (e.g., **#5**); however, the importance of sand lance as a prey resource for multiple predators is already established (Staudinger et al. 2020), and thus should be an initial focus. Methods should build off of existing studies of the effects of offshore wind energy development on sand lance in the North Sea (i.e., Leonhard et al. 2011, van Deurs et al. 2012, Stenberg et al. 2015, Degraer et al. 2016) and examine cable routes as well as areas around turbine foundations to assess potential effects to sand lance from wind farm construction and operations.

Existing data: Sand lance are an important prey for at least eleven seabird species of conservation need, including Roseate Terns, Arctic Terns, Atlantic Puffins, Razorbills (*Alca torda*), Common Murres (*Uria aalge*), Great Cormorants (*Phalacrocorax carbo*), Great Shearwaters, Cory's Shearwaters (*Calonectris diomedea borealis*), Sooty Shearwaters (*Ardenna grisea*), Northern Gannets, and Red-throated Loons (*Gavia stellata*; Staudinger et al. 2020). They are the primary prey species for tern species in some regions, including Common, Arctic, and Roseate Terns. While several effects to sand lance from offshore wind energy development have been hypothesized, including loss of sandy shoal habitat and increased predation pressure, studies in the North Sea have found no change or locally increased densities in sand lance at OSW areas (as reviewed in Staudinger et al. 2020). Several other State of the Science workgroups identified similar or closely related research needs for other taxa, including marine mammals (Southall et al. 2021), fishes and aquatic invertebrates (Popper et al. 2021), and the benthos (Degraer et al. 2021).

Relevant topics: This topic could build off of the prey distribution review (**#6**). For prey other than sand lance, this topic could also integrate information from multiple other priorities in this document, including the Risk Matrix (**#1**) and diet review (**#5**).

Expected outcomes: An improved understanding of how OSW farms may indirectly affect seabird species at a cumulative scale through negative effects on key forage species.

8. Assess the role of habitat and/or prey abundance in species distribution and movements (Tier 1)

Goal: Identify prey and habitat drivers (e.g., bathymetry, oceanographic features) of seabird distributions and movements to help understand potential consequences of displacement/habitat loss or change.

Taxon: Seabirds

Spatiotemporal scale: All regions, all seasons

Development phase: N/A

Methods/Approaches: Modeling exercise that builds off of diet review (**#5**), assessment of prey distributions (**#6**), the review of available tracking data (**#3**), and existing survey data. It will also be important to access existing benthic habitat and metocean data to help understand key habitats for species of interest.

Existing data: Existing survey data from the Northwest Atlantic Seabird Catalog, tracking data from a variety of sources, and prey data from trawls and other sources (see **#5** and **#6**, above). A variety of studies have previously explored these links between habitat drivers and seabird distributions and should also be reviewed (e.g., Goyert et al. 2016, 2018). NOAA, BRI, and others are also currently working to address some of these questions (Friedland et al. 2021; ongoing BRI Ecosystem Dynamics project). Similar data gaps have recently been identified for other taxa in relation to OSW development (e.g., Southall et al. 2021).

Relevance topics: Builds off of diet review (**#5**), assessment of prey distributions (**#6**), and the review of available tracking data (above). Also links to research needs focused around occurrence and exposure (e.g., seabird distributions and habitat use), including topics **#9, #34,** and **#18**.

Expected outcomes: An improved understanding of the potential loss of core seabird foraging habitat as a consequence of the cumulative effect of displacement by offshore wind farms.

Seabird connectivity

9. Assess non-breeding habitat use of alcids and drivers of interannual variability in habitat use patterns (Tier 3)

Goal: Assess habitat use of non-breeding alcids among years to 1) examine links between species distribution and habitat/prey abundance over winter and better understand potential displacement from OSW areas, and 2) link non-breeding populations using OSW areas back to their breeding colonies to help understand potential population-level effects of displacement.

Taxon: Alcids (e.g., Atlantic puffin, Common Murre, Razorbill)

Spatiotemporal scale: All regions, non-breeding period

Development phase: All

Methods/Approaches: Surveys and geolocator (GLS) tagging. Whilst GPS would be preferable, at present, devices are too large for long-term deployment on alcids. Survey data can be used to give a better understanding of species distributions in relation to habitat and prey distributions. The GLS data can then be used to link birds present in an area back to their breeding colonies (e.g., Harris et al 2010, 2015), better establishing connectivity between OSW development areas and breeding populations.

Existing data: Aerial and boat-based survey data from the mid-Atlantic. There are also some existing tracking data for several species from the University of New Brunswick (geolocator data for Atlantic Puffins and Razorbills, National Audubon Society (geolocator data for Atlantic Puffins), Memorial University of Newfoundland (geolocator data for Common Murres), University of Manitoba (geolocator data for Atlantic Puffins and Razorbills) and Maine Coastal Islands National Wildlife Refuge (geolocator data for Razorbills).

Relevant topics: By linking birds back to their breeding colonies, we may get a clearer understanding of population-level consequences of displacement (**#6, #39**) and the link between species distribution and habitat/prey abundance over winter (**#8**, above). This topic overlaps with that focused on assessing connectivity between non-breeding populations and breeding colonies (**#36**) as both require tagging at colonies.

Expected outcomes: Identification of the seabird breeding populations most likely to be vulnerable to the cumulative displacement of birds from offshore wind farms outside the breeding season.

10. Examine degree of Northern Gannet metapopulation connectivity in the non-breeding season (Tier 3)

Goal: Assess the distribution of Northern Gannets during the winter in order to determine the extent of population segregation outside the breeding season and understand how effects over winter may link back to breeding populations.

Taxon: Northern Gannets

Spatiotmporal scale: All regions, non-breeding period

Development phase: All

Methods/Approaches: Surveys and telemetry studies, ideally GPS. Deployment at breeding colonies is easier and cheaper than catching birds on the water in the non-breeding season, and would help minimize potential bias associated with non-breeding capture location; however, improved methodologies may be required for long-term attachment options with tags that can provide data of sufficient spatiotemporal resolution.

Existing data: Aerial and boat-based survey data from the mid-Atlantic. Tracking data from the Mid-Atlantic Diving Bird Study (Spiegel et al. 2017) indicated some potential meta-population patterns, but more data are needed.

Relevant topics: By linking birds back to their breeding colonies we may get a clearer understanding of population-level consequences of displacement (**#6, #39**) and of the link between species distribution and habitat/prey abundance over winter (**#8**, above). The resulting data could also be used to address space use during the non-breeding season (**#31**) and, sex and age-related differences in movement and connectivity over winter (**#29**).

Expected outcomes: Identification of the Northern Gannet breeding populations most likely to be vulnerable to the cumulative displacement of birds from offshore wind farms outside the breeding season.

Exposure of migratory populations

11. Assess movement and space use of terns during post -breeding staging and migration (Tier 2)

Goal: Assess post-breeding dispersal and movements of terns, as well as offshore movements during spring and fall migration, and potential for interactions with OSW farms during these periods.

Taxon: Terns

Spatiotemporal scale: Post-breeding period extending into migration period, over multiple years. Focus on regions with highest potential interactions with tern species of interest.

Development phase: All

Methods/Approaches: Tracking occurring across multiple colonies and years. Focus on regions with highest potential interactions with tern species of interest (especially Roseate Terns, but also species identified in **#1**). Examine environmental covariates of offshore movements and habitat use.

- A combination of newer/lighter satellite tags and Motus tags may be a good approach, however tag effects are a concern for some species (e.g., satellite tags and Roseate Terns). A combination of glue and sutures, rather than harnesses, has worked well for 1-3-month deployments.
- For Motus tracking, we need more offshore receiving stations to understand offshore movements and potential for interactions with OSW.
- Depending on the tag, attachment design, and OSW development stage (e.g., if Motus receiving stations have been deployed offshore), the focal time period of study could also extend to migration. If birds are captured at colonies, we may also be able to obtain data on summer movement and space use.
- Ideally should target birds for capture at both breeding and staging areas. Successful breeders may move differently in the post-breeding period than nonbreeders or unsuccessful breeders. We are particularly lacking data on non-breeding individuals.

Existing data:

- Year-round Arctic tern migration data (GLS), and some existing Common Tern and Roseate Tern GPS and Motus data, mostly from the summer/fall periods.
- Data from a long-term land-based mark-recapture study of Roseate Terns in Massachusetts during the post-breeding period requires compilation.
- The National Audubon Society (Maine) and Shoals Marine Lab (New Hampshire) will be tagging Common Terns with GPS loggers in 2021. Base stations established on Cape Cod should provide detailed foraging data during the post-breeding season.

Relevant topics: Depending on approaches used, this could potentially also address movement and space use during the summer (**#38**). Also linked to **#28.**

Expected outcomes: Assessment of the potential for tern populations to be negatively affected by the cumulative impacts of collision and macro-scale avoidance behavior associated with offshore wind farms during non-breeding periods.

12. Explore passerine and shorebird use of offshore environment during migration (Tier 2)

Goal: Explore environmental conditions leading to high levels of offshore migration activity for facultative and obligate passerine and shorebird migrants, including location/topography, altitude, and timing of offshore migration, and the effect of weather patterns and topography on flight height.

Taxon: Passerines and shorebirds

Spatiotemporal scale: Migration periods, multiple years, all regions

Development phase: Any, although use of OSW infrastructure as platforms for deploying equipment may particularly facilitate studies during construction and operational periods

Methods/Approaches: Combine data from a range of sources, including tracking (mostly Motus; GLS; GPS where possible), marine radar, Next Generation Weather Radar (NEXRAD) radar, acoustic monitoring, possibly band recoveries, and weather data. Look for spatial patterns to inform future development locations (e.g., flight paths, "jumping off points" for offshore migration) and temporal patterns of possible interactions.

- All methods have limitations for answering questions of interest, so the most effective approach will be to combine and integrate different types of data collection where possible (for example, can we design a transmitter that "lights up" on marine radar, so that we can get some information on species composition of animals being detected via radar?). May require extensive technology development though. In meantime, there is a need to develop analytical approaches for combining data types to integrate and use data collectively.

Existing data: eBird[10], Motus database (though limited for offshore data at the moment), coastal NEXRAD radars and existing assessments of offshore movements using those data (e.g., Adams et al. 2015), radar data from Monhegan Island, Maine and Block Island, Rhode Island.

The State of the Science workgroup focused on bats developed similar questions related to bat use of the offshore environment and the weather conditions influencing these patterns (Hein et al. 2021).

Relevant topics: By looking at timing of movements, this links to **#33 and #12.**

Expected outcomes: An improved understanding of the factors that are likely to drive migrant exposure and potential effects from OSW development, and the potential consequences of this at a cumulative level.

Information for collision risk models

13. Examine the connection between seabird behavior and collision risk (Tier 1)

Goal: Understand characteristics of seabird movement such as flight height and speed under different conditions (e.g., time of day, commuting vs. foraging behavior, weather), and relate this to our understanding of collision risk. Ideally, examining flight behavior specifically around OSW turbines can aid in our understanding of how these characteristics vary in proximity to turbines and attraction/micro-avoidance behavior.

Taxon: Seabirds, focusing on key taxa identified in Risk Matrix (**#1**)

Spatiotemporal scale: Potentially all regions, year round

Development phase: N/A

Methods/Approaches:

- GPS tracking to gain more detailed flight behavior data than currently available for many species. Collecting auxiliary data such as dive data would support identification of behavioral states.
- Behavioral modelling (e.g., Hidden Markov Models, Expectation-Maximization Binary Clustering models) of new/existing GPS tracking data to understand characteristics of flights in different

[10] eBird https://ebird.org/home

behavioral states (e.g., foraging vs commuting flights) and relate this to our understanding of potential collision risk.

- Collect data via visual observations around turbines, collision detection systems with cameras, or bird-mounted cameras (e.g., Rutz and Troscianko 2012, Votier et al. 2013).
- Examine flight heights and behaviors in different settings, lighting conditions, and weather conditions, if possible (for example, flight behaviors in the Gulf of Maine with its many islands may be quite different than in the mid-Atlantic U.S.).
- The State of the Science workgroup focused on bats also identified a need to improve understanding of collision risk, with potential overlap in data collection techniques between birds and bats, including visual observations and collision detection systems (Hein et al. 2021).

Existing data: Some existing GPS tracking data for some species building on **#3**, above.

Relevant topics: Links back to **#3**, above. Data would also feed into **#14** and **#8** and could be used to inform **#16.**

Expected outcomes: A better understanding of how different conditions influence seabird collision risk which will, ultimately, lead to a more realistic assessment of impacts at a cumulative scale.

14. Improve species-specific seabird flight height information and its relationship to environmental/weather conditions (Tier 1)

Goal: Improve information on flight height patterns for seabird species of interest in relation to environmental conditions such as wind speed and visibility.

Taxon: Seabirds, focusing on key taxa identified in Risk Matrix (**#1**)

Spatiotemporal scale: All regions, multiple years

Development phase: Any; some methods may be limited to the post-construction period

Methods/Approaches: Collate existing tracking data (**#3**). For new data collection, ideally use a multisensor approach to better understand potential biases associated with different platforms and how representative any individual method might be (Largey et al. 2021). For example, combine GPS tracking for key species (gulls, gannets) with some combination of radar, digital aerial surveys, LiDAR, and visual observers with rangefinders. Each approach is slightly different in terms of spatiotemporal scope, cost, pros/cons and biases, so it would be beneficial to use multiple approaches and understand error/uncertainty associated with different measures. Regardless of exact methods used, there should be robust calibration and method to monitor system operations.

Existing data: Some existing GPS tracking data for some species building on **#3**, above. However, accurate altitude information can be difficult to obtain from many types of tags. There are also flight height estimates available from observational surveys, though there can be substantial biases associated with these estimates (Largey et al. 2021).

Relevance topics: Links back to **#3**, above. Data would also feed into **#13** and **#8** and could be used to inform **#16.** Depending on approaches used, **c**ould potentially also inform **#12, #35** and **#37.**

Expected outcomes: Better quantification of patterns in seabird flight height and exposure to collision risk which will, ultimately, lead to a more realistic assessment of impacts at a cumulative scale.

Population studies

15. Develop standardized, sustained monitoring of tern colonies for population/productivity (Tier 3)

Goal: Ensure methodologies used to collect data at tern colonies are standardized to allow comparison, and collect the right data to inform population models[11].

Taxon: Terns

Spatiotemporal scale: All regions, breeding season

Development phase: All

Methods/Approaches: Develop standardized protocols for mark-recapture and productivity studies such that they can best inform estimates of demographic parameters in population models.

- Depending on the degree of effect, a well-designed mark-recapture study put in place far enough in advance of developments may be able to detect effects on survival pre- and post-construction. Expected collision mortality for species of interest in eastern U.S. is low enough that we would be unlikely to have the power to detect OSW effects, but if this goal is built into standardized monitoring (e.g., following recommendations in Horswill et al. 2018 and others), we could assess our power to detect change (e.g., what scale of effect we could detect) and whether effects are below or above that magnitude.
- Productivity data may be useful for detecting OSW-related effects, particularly sublethal effects. Reproductive parameters are likely to be more sensitive to stressors than are overall population size or population growth rate. However, productivity is highly variable already, so our power to detect change related to OSW may likewise be fairly low.

Existing data: Data collection methodologies vary by project. We generally know how many birds are nesting each year (for Common and Roseate Terns), but otherwise, there is a great deal of variation in terms of what data are collected and where. Colonies managed by USFWS and National Audubon Society (Project Puffin) in Maine (Arctic, Common, Roseate and Least Terns), Machias Seal Island (New Brunswick, Canada) and the Isle of Shoals (New Hampshire) use the same methods. Monitoring efforts for Roseate Tern colonies in Massachusetts vary. Productivity is not monitored for Common Terns at a large colony on Great Gull Island, New York.

Relevant topics: Builds on data collected as part of **#4** and feeds into **#16.**

Expected Outcomes: Improve the availability of data to quantify OSW's cumulative impacts on tern populations, and potentially reduce the level of precaution needed in assessments.

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[11] At least one workgroup member disagreed with the inclusion of tern monitoring as a priority for OSW-related research; they acknowledged that while tern colony data will be needed to interpret OSW effects, they felt that such data should be collected and funded via other sources.

16. Develop population models to assess degree of displacement or collision that could affect population viability (Tier 2)

Goal: Assess the degree to which displacement or collision may affect population viability and use sensitivity analysis in order to highlight key areas of uncertainty that need to be addressed when quantifying population-level effects.

Taxon: Depending on approach adopted, either a broad range of species, or one or two key species for which suitable data are available.

Spatiotemporal scale: All regions, year round

Development phase: N/A

Methods/Approaches: Conduct a feasibility study to determine what approaches might be suitable for different species and populations. Options include:

- A relatively simple approach, such as Population Viability Analysis (PVA) to cover a broad range of species with limited data
- A more complex approach, such as an individual based model, for a smaller suite of species where we have more existing data. Such models are more data hungry and require a wider range of parameters (e.g., foraging distribution, energetic content of prey) but allow for investigation of the effects of collision and displacement in more detail.

A useful approach is to start with a species with a lot of data, and explore different modeling approaches at different levels of complexity to determine which approaches strike the best balance of feasibility and informativeness.

Existing data:

- Currently existing survey, tracking, diet, and demographic data from other priority topics.
- A PVA was developed for Roseate Terns in relation to the Cape Wind project, and could potentially be updated with new methods and data.
- A mark-recapture and metapopulation analysis is in progress for Arctic Terns in the Gulf of Maine; a similar analysis was completed for Atlantic Puffins and could be updated with recent data.
- A variety of modeling frameworks have been developed for examining offshore wind's effects on seabirds in Europe (e.g., SNCB 2017, Searle et al. 2018). The UK is now also looking at using simulation methods from multiple runs of intensive agent-based models to develop quick methods for estimating displacement consequences in areas with poor data availability (Searle et al. 2018). This approach allows you to apply what you have learned in high data situations to predict effects in poor data areas.
- The State of the Science marine mammal workgroup recently identified a similar need for further development of models to assess the potential for population consequences of OSW development on marine mammals (Southall et al. 2021).

Relevant topics: This topic integrates information from multiple other priorities in this document, including the Risk Matrix (**#1**), collation of tracking data (**#3**), preliminary population modeling and sensitivity analysis (**#4**), diet review (**#5**), and prey distribution review (**#6**).

Expected outcomes: To build on the preliminary population modelling and sensitivity analysis (**#4**) to enable a more robust assessment of the population-level consequences of OSW development on select species.

Other topics

17. Assess attraction of passerines and storm-petrels to lighting (Tier 3)

Goal: Understand the conditions that could attract birds (particularly passerines and storm-petrels) to artificial lighting associated with OSW farms, including aspects such as lighting color, flashing of lights, the amount of time lights are on (e.g., once they are triggered by Aircraft Detection Lighting Systems [ADLS]), and weather conditions.

Taxon: Passerines, storm-petrels

Spatiotemporal scale: All regions, breeding and migratory periods

Development phase: Construction, operation

Methods/Approaches: Use multiple methods, such as radar, video, and carcass searches on offshore infrastructure to assess how bird attraction to lights vary by flash interval rate, intensity, and other factors. There is existing knowledge on this topic, though results are somewhat equivocal regarding color - so studies should be focused specifically on conditions likely to be present at OSW farms in the U.S. For example, if most OSW farms are using ADLS, examine how long blinking red lights on turbines (with the interval rate, intensity, etc. defined by the FAA) need to be on before they start generating attraction from passing migrants. In relation to collision and stranding concerns, attraction to lighting used during construction, as well as lighting on vessels and substations during the operational period, may be a bigger issue than lighting on turbines themselves, so these situations should be explored.

Existing data:

- Existing data from offshore structures (e.g., Hüppop et al. 2016 and others).
- A variety of studies on light characteristics in relation to attraction of nocturnal migrants (see lighting-related studies listed in the Mitigation and Monitoring Practices (MMP) Tool[12].
- Use of satellite-based methods for monitoring lighting (e.g., Canadian Wildlife Service conducting research on Leach's Storm-petrels (*Oceanodroma leucorhoa*); the Jodice lab at Clemson Univserity has a database of lighting on oil platforms across the Gulf of Mexico).

Relevance topics: Relates to **#12**, above

Expected Outcomes: An improved understanding of the potential for significant, negative effects at a population level due to the cumulative risk of collision by nocturnally-active birds attracted to turbines by lighting.

[12] MMP Tool http://www.nyftwg.com/mmp-tool/

18. Examine occurrence and distribution of smaller/endangered petrels (e.g., Black-capped and Bermuda Petrel) (Tier 3)

Goal: Assess the occurrence and distribution of Black-capped Petrel (*Pterodroma hasitata,* proposed as threatened under the Endangered Species Act) and Bermuda Petrel (*Pterodroma cahow,* listed as endangered under the Endangered Species Act).

Taxon: Black-capped and Bermuda Petrels

Spatiotemporal scale: All regions, year round

Development phase: All

Methods/Approaches: Focus on tracking, not surveys (though surveys can pick up these species and provide supplementary information on their distributions). There is a very limited sample of tracking information for these species currently, so more tracking data is needed from breeding colonies. It may be benficial to start with GLS transmitters to get a broad idea of potential for interactions with OSW development first, before utilizing heavier tags that can provide more detailed information (e.g., satellite, GPS tags). However, developing a better understanding of these species' flight behavior under different weather conditions (which would likely require the latter types of tag) would also be useful for assessing potential interactions with OSW development.

Existing data: Tracking data from colonies in the Dominican Republic (Black-capped Petrel) and Bermuda (Bermuda Petrel), as well as tracking data from Black-capped Petrels captured at sea in North Carolina.

Relevant topics: Tracking data review (**#3**)

Expected outcomes: Improved understanding of the cumulative risk posed by offshore wind farms to rare species which are not well covered by existing survey methodologies.

19. Identify potential mitigation strategies, including technical feasibility and cost-benefit analysis (Tier 2)

Goal: Identify a suite of options that could plausibly reduce the effects of offshore wind farms through mitigation[13].

Taxon: Seabirds/migrating birds

Spatiotemporal scale: All regions

Development phase: Construction, operations

Methods/Approaches: Review options that could be applied to OSW farms during either the construction or operation phase in order to reduce negative effects through mitigation. This may include options such as painting turbine blades (May et al. 2020), raising turbine hub height (Johnston et al. 2014; Cleasby et al. 2015), curtailment (Hayes et al. 2019) and changes to turbine micro-siting. Such a review must include consideration of the technical feasibility and cost of the different options. Ideally, it

[13] This topic was developed with a specific focus on the earlier parts of the mitigation hierarchy (e.g., avoidance, minimization, and restoration; Bennun et al. 2021). However, after prioritization efforts were conducted several workgroup members indicated that compensatory or offset mitigation should also be included in such a review.

would also include modelling of the potential for each identified option to reduce effects, enabling a cost-benefit analysis to be undertaken. The review should focus on options that can be applied within an OSW farm in order to mitigate impacts as opposed to options that may be applied elsewhere in order to compensate for impacts on the population(s) concerned.

Existing data: While potential mitigation options from the offshore environment have previously been reviewed (Cook et al. 2011, Harwood and Perrow 2019, Bennun et al. 2021), data to support these approaches are limited. A database of mitigation approaches that have been suggested or implemented, for OSW and related industries, is available in the MMP Tool[14]. This searchable database also includes a summary of the available evidence for efficacy for different mitigation measures.

Relevant topics: This review will build off the Risk Matrix (**#1**) based on the key species and effects identified in that work. It is also of relevance to priorities **#22** and **#25,** which will consider the likely distribution of seabirds and migrating birds in the offshore environment, and **#5**, which will consider how behavior is likely to relate to collision risk. Considering how migrants and storm-petrels may respond to light (#**17**) may also be relevant.

Expected outcomes: An understanding of the potential mitigation measures that could realistically be applied at OSW facilities to reduce potential cumulative impacts to vulnerable species.

Conclusions

Workgroup members identified a wide range of information needs and priorities for research. This included some preliminary desktop studies (e.g., review studies and data compilation efforts) to focus and inform implementation of future research studies. However, workgroup members also emphasized that a mix of short-term and long-term research and monitoring efforts should be initiated in the next five years, and that rather than waiting until all desktop studies have been completed, these efforts should be developed and implemented in coordination with desktop analyses to maximize resources and efficiency.

In workgroup discussions and poll responses, workgroup members called out five general areas as needed focus areas of research:

- **Establish core 'taxa of concern' at locations that are likely to be developed** (based on habitat use patterns by life history stage, as well as expected vulnerability). Workgroup members recognized the need to “triage” research needs and focus funding and research towards species of highest concern. Focusing on species with high predicted exposure and vulnerability will also be important for designing effective studies to detect effects.
- **Focus on habitat and prey drivers of seabird distributions and behaviors**. It was recognized that habitat use and foraging patterns are dynamic and may shift over time, particularly in relation to climate change. However, improving our understanding of key seabird prey and other environmental drivers influencing seabird distributions (e.g., bathymetry, benthic habitats, ocean currents) is fundamental to inform strategic siting of future projects and understand the potential for OSW interactions given the “shifting baseline” posed by climate change.

[14] Mitigation and Monitoring Practices (MMP) Tool, https://www.nyftwg.com/mmp-tool/

- **Understand how existing distributions and migratory movements are likely to change in response to displacement from, and barrier effects associated with, offshore wind farms**. Whilst it was recognized that data are available from Europe with which to predict likely changes in distribution and movement, we still lack the data to make robust predictions about these at a population level. Over the longer term, it will be important to collect data reflecting the energetic costs associated with these changes, and the resulting effects on demographic rates. Establishing baseline values and monitoring programs for key species will be an important aspect of this process.
- **Develop reliable estimates of collision risk.** Collisions, due to their clear effect on individual fitness, are a substantial concern for some workgroup members. This led to the prioritization of several research needs focused on informing collision risk models. However, several workgroup members also expressed concern about over-reliance on collision risk modeling, advocating instead for direct measurements of collisions to assess the degree of impact and determine the need for more widespread collision monitoring and/or mitigation strategies.
- **Begin to assess the potential for population-level effects to key taxa of concern via population modeling**. This is clearly a longer-term goal, but workgroup members agreed that population models and sensitivity analyses should provide a framework for guiding the focus of new research.

Finally, the effect of climate change on the distribution of seabirds and prey was highlighted as a high priority in discussions. The effect of climate change on distributions was similarly highlighted in other State of the Science workgroups (Degraer et al. 2021, Carpenter et al. 2021, Gitschlag et al. 2021). This is an interesting and useful question to consider, particularly given the role of offshore wind development in mitigating the effects of climate change. However, at present, there is uncertainty surrounding the current distribution of seabirds and their prey, as well as how the spatiotemporal relationships between seabirds and their prey vary over space and time and may change in response to changing oceanographic and environmental conditions. BOEM is currently funding NOAA NCCOS to develop forecasts of projected shifts in marine bird distributions to inform planning, leasing, and assessment of OSW on the Atlantic Outer Continental Shelf[15], based on hindcast relationships between oceanographic, environmental, and seabird survey data. Similar efforts are in progress for fishes. However, these models will be regional in scale, and thus may be more useful for siting future OSW development than predicting shifts in distributions at the scale of individual OSW projects. Depending on the degree of uncertainty in model outcomes for this study, it may or may not be feasible within the next five years to incorporate future projections of seabird distributions in response to climate change into models of OSW effects. Regardless, it should certainly be considered a longer-term priority.

[15] BOEM Environmental Studies Program ongoing study http://www.boem.gov/sites/default/files/documents/environment/AT-20-03.pdf

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Appendix A. Workgroup Collaborators

Table B1. Collaborators who attended meetings and/or provided feedback on this report (in alphabetical order by last name).

Name	**Affiliation**
Evan Adams	Biodiversity Research Institute
Taber Allison	American Wind Wildlife Institute
Emily Argo	U.S. Fish & Wildlife Service
Susan Bates	The Nature Conservancy
Alicia Berlin	U.S. Geological Survey
David Bigger	Bureau of Ocean Energy Management
Matt Boa	APEM Ltd
Aaron Boone	Environmental Solutions and Innovations
Stefan Bräger	BioConsult SH
Todd Callaghan	Massachusetts Office of Coastal Zone Management
Mark Collier	Bureau Waardenburg
Aonghais Cook	British Trust for Ornithology
Elizabeth Craig	University of New Hampshire
Robb Diehl	U.S. Geological Survey
Eliza Donoghue	Maine Audubon
Maureen Dunn	Seatuck
Michael Evans	Ørsted
Tom Evans	Marine Science Scotland
Luke Fara	U.S. Geological Survey
Shilo Felton	National Audubon Society
Corrie Folsom-O'Keefe	Audubon Connecticut
Garry George	National Audubon Society
Andrew Gilbert	Biodiversity Research Institute
Wing Goodale	Biodiversity Research Institute
Holly Goyert	CSS Inc. on contract to NOAA
Julia Gulka	Biodiversity Research Institute
Sarah Haggerty	Maine Audubon
Tracy Hart	Maine Audubon
Jeff Herter	New York Department of State
Amy Hoenig	Massachusetts Department of Fish & Wildlife
Cheryl Horton	U.S. Geological Survey
Ed Jenkins	Biodiversity Research Institute
Wendy Jensen	Environmental Solutions and Innovations
Laura Jervis	APEM Ltd
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Kyle Landolt	U.S. Geological Survey
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Pam Loring	U.S. Fish & Wildlife Service

Name	Affiliation
Donald Lyons	National Audubon Society
Kathy Matthews	U.S. Fish and Wildlife Service
Sara Maxwell	University of Washington
Joel Merriman	American Bird Conservancy
Dusty Miller	Black & Veatch
Julie Miller	Marine Sciences Scotland
David Mizrahi	New Jersey Audubon
Verena Peschko	University of Kiel
Paul Phifer	Atlantic Shore Offshore Wind
Dave Philips	Equinor
Astrid Potiek	Bureau Waardenburg
Kate McClellan Press	New York Energy Research and Development Authority
Michael Przybycin	B-finder
Ian Reach	MarineSpace Ltd
Craig Reiser	Smultea Sciences
Heidi Ricci	Massachusetts Audubon
Matt Robertson	Vineyard Wind
Emily Rochon	Vineyard Wind
Martin Scott	HiDef Aerial Surveying
Kate Searle	UK Centre for Ecology and Hydrology
Caleb Spiegel	U.S. Fish & Wildlife Service
Dave Steckler	Mysticetus
Michel Stelter	BioConsult SH
Iain Stenhouse	Biodiversity Research Institute
Jennifer Stucker	Western EcoSystems Technology, Inc.
Gillian Sutherland	APEM
Lesley Thorne	Stony Brook University
Damire Ariel Rojas Tito	Uppsala University
Susi von Oettingen	U.S. Fish & Wildlife Service
Joan Walsh	Massachusetts Audubon
Linda Welch	U.S. Fish & Wildlife Service
Alex Wilke	The Nature Conservancy
Kate Williams	Biodiversity Research Institute
Taffy Williams	NY4Whales
Julia Robinson Willmott	Normandeau
David Wilson	The Biodiversity Consultancy
Brita Woeck	Ørsted

Appendix B. Full List of Research Topics Generated by the Workgroup

Table B1. Possible priority topics for research suggested by the workgroup. Topic #s are referenced in text. Topics in italics are further explored in text.

#	Category	Taxon	Topic	Goal	Tier
1	*General*	*All species*	*Develop an exposure/vulnerability risk matrix*	*Quantify exposure and potential vulnerability at proposed development areas and ensure that research studies are focused on species of greatest potential risk.*	*1*
2	*General*	*All species*	*Develop standardized protocols for collecting and storing survey data*	*Ensure that there is a single repository and standardized data formats for reporting approaches, such that data can be used collectively to quantify displacement or other cumulative effects as the industry develops.*	*1*
3	*General*	*All species*	*Review available tracking data across all taxa of interest*	*Assess existing tracking data across all taxa for the offshore region of interest, and determine possible data compilation and analytical approaches for using these data collectively to inform decision making.*	*1*
4	*General*	*Key species/taxa of interest, as identified based on the risk matrix*	*Develop baseline estimates of demographic rates and sensitivity analysis*	*Develop baseline estimates of demographic rates to inform models of population consequences, and identify key gaps where additional data are needed*	*1*
5	*Habitat and Distribution*	*All seabirds*	*Review seabird diet information and conduct a gap analysis*	*Review existing information on seabird diet, by species where possible, to identify key prey species and gaps in our knowledge, such that assessments of changes in habitat/prey due to OSW development (and efforts to use prey data as a predictor of seabird distribution/movements) are focused on the right prey taxa.*	*2*
6	*Habitat and Distribution*	*Seabird prey*	*Identify distribution of seabird prey resources (e.g., forage fish, mollusks)*	*Identify baseline distributions of prey resources to inform our understanding of drivers of seabird distributions and movements.*	*2*
7	*Habitat/Prey effects*	*Seabirds*	*Examine effects of offshore wind development on important seabird prey species, with an initial focus on sand lance*	*Examine the effects of OSW construction (e.g., sedimentation, including along cable routes, and substrate vibration) and operation (e.g., EMF, habitat loss/gain) on key prey species for seabirds of interest*	*3*
8	*Habitat and Distribution*	*All seabirds*	*Assess the role of habitat and/or prey abundance in species distribution and movements*	*Identify prey and habitat drivers of seabird distributions and movements to help understand potential consequences of displacement/habitat loss or change*	*1*
9	*Seabird Connectivity*	*Auks*	*Assess non-breeding habitat use of alcids and drivers of interannual variability in habitat use patterns*	*Assess habitat use of non-breeding alcids among years to inform decision making*	*3*
10	*Population Consequences*	*Gannets*	*Examine degree of gannet metapopulation connectivity in the non-breeding season*	*Understand the degree of gannet metapopulation connectivity in the non-breeding season*	*3*
11	*Exposure of Migratory Populations*	*Terns*	*Assess movement and space use of terns during pre-migratory staging and migration*	*Assess post-breeding dispersal and movements of terns, as well as offshore movements during migration, and potential for interactions with OSW farms during these periods*	*2*

#	Category	Taxon	Topic	Goal	Tier
12	*Occurrence/ Exposure*	*Passerines and Shorebirds*	*Explore passerine and shorebird use of offshore environment during migration*	*Explore environmental conditions leading to offshore migration for shorebird and passerine migrants, including location, altitude, and timing of offshore migration, and the effect of weather patterns on flight height*	*2*
13	*Collisions*	*All seabirds*	*Examine connection between seabird behavior) and collision risk*	*Understand characteristics of commuting/foraging flights in terms of flight height & speed, and relate this to our understanding of potential collision risk*	*1*
14	*Collisions*	*All seabirds*	*Improve species-specific seabird flight height information and its relationship to environmental/weather conditions*	*Improve information on flight height patterns for seabird species of interest, in relation to environmental conditions such as wind speed*	*1*
15	*Population Consequences*	*Terns*	*Develop standardized/sustained monitoring of tern colonies for consistent comparison of population/productivity.*	*Ensure methodologies used to collect data at tern colonies are standardized to allow comparison, and collect the right data to inform population models*	*3*
16	*Population Consequences*	*1-2 key examples such as Northern Gannet (see relevance to other priorities)*	*Develop population model to assess degree of displacement or collision that could affect population viability*	*For one or two key species, assess the degree to which displacement or collision may affect population viability.*	*2*
17	*Other*	*Passerines, storm-petrels*	*Assess attraction of passerines and storm-petrels to lighting*	*Understand the conditions that attract passerines and storm-petrels to artificial lighting, including aspects such as lighting color, whether or not they blink, weather conditions, etc.*	*3*
18	*Occurrence/ Exposure*	*Pterodroma petrels*	*Examine occurrence and distribution of smaller/endangered petrels*	*Assess the occurrence and distribution of Black-capped Petrel (proposed as threatened under the ESA) and Bermuda Petrel (endangered under the ESA)*	*3*
19	*Collisions*	*All species*	*Identify potential mitigation strategies, including technical feasibility and cost-benefit analysis*	*Review options that could be applied to wind farms during either the construction or operation phase in order to reduce effects through mitigation, including technical feasibility and cost-benefit analysis.*	*2*
20	Displacement/ Attraction	All seabirds	Review habitat requirements of seabirds	Assess habitat requirements (e.g., preferred habitat, environmental parameters, prey) for species identified as of greatest potential risk (through the risk matrix exercise) to inform OSW siting and assess possible effects from existing OSW areas.	NA
21	Displacement/ Attraction and Population Consequences	One or two key examples based on other information (see relevance to other priorities)	Understand the effects of attraction/displacement on energetics	Investigate the effects of displacement and/or attraction of OSW on vital/energetic rates	NA
22	Displacement/ Attraction	All species	Space use and behavior at OSW facilities	Understand spatial patterns in space use and behavior at OSW facilities	NA
23	Displacement/ Attraction	All species	Assessing how to distinguish between habitat loss effects from displacement versus barrier effects from displacement	Assess how to distinguish between habitat loss effects from displacement versus barrier effects from displacement	NA
24	Displacement/ Attraction	Gannets, loons and sea ducks, terns, gulls, shearwaters/auks	Quantifying displacement and attraction at OSW facilities	Understand the degree of displacement and/or attraction observed at OSW facilities	NA

#	Category	Taxon	Topic	Goal	Tier
25	Displacement/ Attraction	Seaducks	Effects of the soundscape on seaduck foraging	Understand the effect of OSW-related sound on the foraging ability of seaducks	NA
26	Displacement/ Attraction	Gannets, loons and sea ducks, terns, gulls	Attraction and collision risk	Assess whether attraction increases collision risk	NA
27	Habitat/Prey effects	Terns	Roseate tern provisioning data collection methods	Develop and implement standardized methodologies for diet studies of provisioning roseate terns	NA
28	Occurrence/ Exposure	All species	Migration movement and space use	Investigate movement and space use during migration (i.e., location, altitude, timing)	NA
29	Occurrence/ Exposure	Gannets	Age and sex influences on gannet space use in the non-breeding season	Assess how gannet age and sex relate to migratory movements, connectivity and habitat use during the non-breeding season	NA
30	Occurrence/ Exposure	Gannets	Climate change and non-breeding gannets	Assess how climate change may influence space- and habitat-use in non-breeding gannets	NA
31	Occurrence/ Exposure	Gannets, loons, seaducks, auks	Non-breeding movement and space use	Study seabird, seaduck and loon movement and space use (including annual and seasonal variation) during the winter season in the Northwest Atlantic	NA
32	Occurrence/ Exposure	loons/sea ducks	Non-breeding duck and loon occurrence and distribution	Understand the occurrence and distribution of seaducks and loons in the non-breeding period	NA
33	Occurrence/ Exposure	Passerines	Passerine migratory flight behavior	Migratory flight behavior of passerines throughout the daily cycle and potential variability in risk	NA
34	Occurrence/ Exposure	Shearwaters	Great shearwater distribution	Assess great shearwater distribution in the southern part of the region	NA
35	Occurrence/ Exposure	Shearwaters	Shearwater flight behavior in high winds	Understand flight height and movement patterns of shearwaters in high wind/wave conditions	NA
36	Occurrence/ Exposure	shearwaters/auks	Seasonal connectivity of shearwaters and auks	Investigate connectivity between non-breeding populations and breeding colonies	NA
37	Occurrence/ Exposure	Shorebirds	Shorebird migratory biology	Better understand the migration biology of smaller shorebird species	NA
38	Occurrence/ Exposure	Terns, gulls, shearwaters	Seabird spatial use in summer	Explore seabird movement and space use during the summer season (i.e., location, altitude, timing, etc.)	NA
39	Population Consequences	All species	Improving population forecasts	Identify the key drivers of species distributions and demographic rates that should be included in population forecasts	NA
40	Population Consequences	Shorebirds/passerines	Energetic costs of barrier effects	Investigate the energetic costs to shorebirds and passerines from barrier effects	NA
41	Population Consequences	Shorebirds/passerines	Population consequences from collision	Assess possible population consequences from collision	NA
42	Population Consequences	Terns	Tern juvenile survival	Improve information on juvenile survival and recruitment data gaps for Arctic, Common and Roseate terns.	NA
43	Population Consequences	Terns	Tern metapopulation dynamics	Improve understanding of metapopulations dynamics for Arctic, Common and Roseate terns.	NA
44	Population Consequences	Terns	Sea level rise and tern colonies	Understand what the consequences of climate change may be tern colonies	NA