Offshore Wind Priority Conflict Topics for Marine Mammals and Birds

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Technology Solutions to Mitigate Use Conflicts: Technology Needs for Scientifically Robust Wildlife Monitoring and Adaptive Management

Task 1.3

Christine Sloan, Project Manager

Prepared by:

Worley Consulting

Houston, TX

Sarah Courbis, PhD
Senior Marine Scientist and Regulatory Specialist

Aude Pacini, PhD
Marine Science/Offshore Energy Specialist

Biodiversity Research Institute (BRI)

Portland, ME

Kate Williams
Director of the Center for Research on Offshore Wind and the Environment

Sarah Dodgin
Ecological Analyst

Edward Jenkins
Avian Biologist

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Acronyms and Abbreviations

BOEM	Bureau of Energy Management
BRI	Biodiversity Research Institute
DOE	Department of Energy
ESA	Endangered Species Act
kWh	kilowatt hours
MBTA	Migratory Bird Treaty Act
MMPA	Marine Mammal Protection Act
m/s	meters per second
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOWRDC	National Offshore Wind Research and Development Consortium
NYSERDA	New York State Energy Research and Development Authority
OSW	Offshore Wind
SEER	U.S. Offshore Wind Synthesis of Environmental Effects Research
USFWS	United States Fish and Wildlife Service

Executive Summary

Extensive effort has been invested in predicting and mitigating the effects of human activities on wildlife, including protected species. In recent years, the expansion and development of the offshore wind (OSW) industry has generated an interest in identifying the risk factors to wildlife associated with the construction, operation, and maintenance of fixed and floating turbines. This memo compiles the most up-to-date information on priority conflicts that are likely to become barriers to OSW progress as environmental compliance issues or stakeholder concerns. This assessment focuses on:

- Identified areas of potential conflict for bird and marine mammal species in the U.S. Pacific, Atlantic, Gulf of Mexico, and Great Lakes regions.
- Species of marine mammals and birds that could be impacted by OSW development, along with the known issues where data gaps exist, proxies are not available, or there is significant uncertainty.
- Providing an overview of potential OSW cumulative effects on marine mammals and birds; and
- Identifying research topics that have been highlighted by experts as priorities for research and monitoring as the industry progresses.

This assessment will inform a broader effort to identify priorities for technological research and development to improve monitoring methodologies for marine mammals and birds at OSW facilities in the U.S.

1 Introduction

1.1 Goal of Review

Data collection and monitoring for offshore wind (OSW) energy development should be question-driven and scientifically robust; otherwise, funding spent on wildlife monitoring may not meaningfully inform future environmental assessments and adaptive management decisions (Wilding et al, 2017). There is currently no comprehensive synthesis of the technologies available to collect statistically robust wildlife data at OSW facilities, inform adaptive management, and reduce precautionary mitigation. Similarly, there is currently no comprehensive evaluation of the capacity of monitoring technologies to be integrated into normal operations and maintenance of windfarms. This project, "Technology Solutions to Mitigate Use Conflicts: Technology Needs for Scientifically Robust Wildlife Monitoring and Adaptive Management," aims to inform technology development relative to the following:

- Achieving statistically robust studies that can inform understanding of the effects of OSW energy development on birds and marine mammals, as well as mitigation and adaptive management of observed effects; and
- Integrating monitoring technologies into OSW operations.

The project incorporates input from a wide range of stakeholders via an expert Project Advisory Board, as well as workshops and individual expert engagement efforts with research scientists, resource managers, turbine engineers, technology developers, and OSW operation and maintenance specialists.

As a first step, this memo provides a comprehensive assessment of marine mammal and bird conflict areas and barriers to industry advancement. This memo highlights the research priorities related to potential conflicts between OSW and these taxa in the U.S. Pacific[1], Atlantic, Gulf of Mexico and Great Lakes relative to environmental compliance and stakeholder concerns. Identified research priorities and data gaps focus on topics judged to be most likely to become barriers to OSW progress.

1.2 Review Process

Existing databases, reports and publications were comprehensively reviewed by subject-matter experts to obtain the most up-to-date information on research priorities and potential conflicts between OSW and

[1] Alaska, Hawaii, and U.S. territories are not included in this scope.

wildlife. While the full list of references used for this assessment is available at the end of this document, the identified priorities were derived mainly from the following documents and databases:

- Workgroup reports from the 2020 State of the Science Workshop on Wildlife and Offshore Wind Energy[2] sponsored by the New York State Research and Development Authority (NYSERDA)
- Environmental Assessments (EA) and Environmental Impact Statements (EIS), Reports and workshops funded by the Bureau of Ocean Energy Management (BOEM)
- Conservation Biology Institute data modeling project in California
- Natural Resources Defense Council (NRDC) Workshop West Coast
- Regional Wildlife Science Collaborative (RWSC) marine mammal Subcommittee
- State of the Science Reports – Pacific Northwest National Lab (PNNL)
- Massachusetts Clean Energy Center (MA CEC)/BOEM/ Centre for Research into Ecological and Environmental Modelling (CREEM) workshop
- Tethys Knowledge Database[3]
- U.S. Offshore Wind Synthesis of Environmental Effects Research (SEER) Workshop Proceedings and Briefs.
- A database of research priorities developed for the NYSERDA-funded regional synthesis workgroup,[4] a Specialist Committee of NYSERDA's Environmental Technical Working Group[5]
- Joint Nature Conservation Committee (JNCC) Offshore Wind Environmental Evidence Register
- Skov et al. 2018 (Offshore Renewables Joint Industry Programme Collision and Avoidance Study)
- Dutch Governmental Offshore Wind Ecological Programme (WOZEP)
- Other recently published reviews, including Cook et al. 2018, Allison et al. 2019 and Van Parijs et al, 2021)

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[2] https://www.nyetwg.com/2020-workgroups

[3] https://tethys.pnnl.gov/

[4] http://www.nyetwg.com/regional-synthesis-workgroup

[5] https://www.nyetwg.com/

For birds, this process focused on the review and synthesis of a database of OSW-wildlife research priorities that were developed by the Biodiversity Research Institute (BRI) for the NYSERDA-funded regional synthesis workgroup,[6] a Specialist Committee of the Environmental Technical Working Group[7]. The database was generated through literature review of the Tethys database and other sources, and (as of April 2022) included over 240 research priorities for birds in relation to OSW development that had been previously identified in the scientific literature, workshop reports, and other documents between the period of 2015 and 2022.

1.3 Potential Stressors Associated with Offshore Wind

The development and operation of offshore wind facilities present a variety of potential stressors, or impact-producing factors, that may affect wildlife. This section summarizes the potential stressors associated with offshore wind development during the pre-construction, construction, and operational phases. Stressors vary somewhat between floating and fixed turbine foundations, and major differences between these two types of developments are noted in the sections below when applicable. Stressors presented during the pre-construction and construction phases are shorter in duration, while post-construction stressors are long-term (Table *1*).

Table 1 Potential Offshore Wind Construction and Post-Construction Stressors and Effects

Pre-Construction and Construction		
Potential Stressors (Short-Term)	**Potential Effects to Marine Mammals**	**Potential Effects to Birds**
Sound (Non-Pile-Driving)	Behavioral disturbance, displacement, injury/mortality	n/a
Pile-Driving Sound	Behavioral disturbance, displacement, injury/mortality, masking effects	Behavioral disturbance, displacement, effects to prey
Increased Vessel Traffic	Behavioral disturbance, displacement, injury/mortality	Behavioral disturbance, displacement
Artificial Light	n/a	Behavioral disturbance, displacement, attraction, injury/mortality
Post-Construction		
Potential Stressors (Long-Term)	**Potential Impacts to marine mammals**	**Potential Impacts to birds**
Sound	Behavioral disturbance, displacement	n/a
Electromagnetic Fields, Vibration, Heat	Behavioral disturbance, displacement/barrier effects	Effects to prey
Long-Term Structures	Attraction (due to lighting, presence of structures, or changes in habitat and	Attraction (due to presence of structures and/or changes in

[6] http://www.nyetwg.com/regional-synthesis-workgroup

[7] https://www.nyetwg.com/

	prey), displacement/barrier effects, injury/mortality, reef effects and other habitat creation/modification/fragmentation	habitat and prey), displacement/barrier effects, injury/mortality, reef effects and other habitat/prey modifications
Increased Helicopter/Vessel Traffic	Behavioral disturbance, displacement, injury/mortality	Behavioral disturbance, displacement
Artificial Light	n/a	Behavioral disturbance, displacement, attraction, injury/mortality

When assessing potential OSW/wildlife conflicts, it is important to differentiate impacts from effects. Hawkins et al. (2020) defined an effect as a ‘change caused by an exposure to an anthropogenic activity that is departing from a prior state, condition, or situation, which is called the ‘baseline’ condition.” Similarly, impact was defined as 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.” Some stressors may affect individual animals, population distributions, or other endpoints without causing an impact to individual fitness that could lead to population-level consequences (see Section 1.4). For clarity’s sake, in this memo the two terms are used according to Hawkins et al.’s definitions, so “effects” are changes of neutral or unknown fitness consequence, while “impacts” are related to potential population-level consequences.

1.3.1 Pre-Construction Stressors

Pre-construction activities include a variety of surveys, including geophysical and geotechnical surveys, wildlife surveys, wind resource assessments, and other activities to inform the development process. Activities such as installation of temporary buoys to measure wind speeds are not expected to represent substantial stressors to birds or marine mammals (note that projects in the future are expected to continue to use buoys rather than meteorological towers; meteorological towers did represent sound-related and collision-related risks to wildlife, but their use has been supplanted by cheaper and less invasive buoy-based systems). Pre-construction activities also present additional vessel traffic, though generally not to a degree to cause substantial concern regarding wildlife interactions due to the vessels’ relatively smaller sizes and slower speeds compared to commercial shipping. Geophysical and geotechnical surveys can produce underwater sound, depending on the survey type, which may be of concern for marine mammals.

1.3.2 Construction Stressors

The construction phase involves the period of offshore wind development with the installation of wind turbines (base, support structure, and wind turbine generator), cables (offshore export cables and interconnection cables), offshore substations and other interconnection points, and additional supporting activities. Construction stressors include sound (including pile-driving sound, which is mainly associated with fixed-turbine installation), increased vessel traffic and habitat alteration.

1.3.2.1 Sound

Sound can be generated when installing moorings and anchors, dredging, operating vessels, building substations, trenching, drilling, and other activities that could disturb marine species (NYSERDA, 2017; Marine Mammal Organization 2013). Much of the sound produced from construction activities would be localized and temporary but is expected to increase the underwater soundscape levels and potentially overlap with the frequency range of marine mammal hearing and communication.

Pile-driving occurs when installing wind turbine monopiles or jackets. Pile-driving can be used in both floating and fixed-bottom turbine technology installations, though less pile driving (or none in some cases) would be expected to be necessary for installation of moorings. Pile-driving with a hammer produces sound in the substrate and water column that can propagate outward (Popper and Hawkins 2018). Marine birds and pinnipeds can generally avoid underwater sound exposure by hauling out or remaining at the surface. Cetaceans, however, cannot readily escape sound exposure. Pile-driving has been identified as an activity of primary concern, especially for marine mammals, due to the high intensity pulse-like sounds generated during these activities (as opposed to continuous sounds such as shipping; European Commission 2016; Marine Mammal Organization 2013; BOEM Office of Renewable Energy Program 2017). Pile-driving sound may also affect the distribution and movement of some prey species for both seabirds and marine mammals.

1.3.2.2 Increased Vessel Traffic

Vessel traffic can increase during construction as vessels are needed for turbine, cable, and substation installation. Vessels may represent a variety of size classes and move at a range of speeds, depending on their purpose.

1.3.2.3 Artificial Lighting

Artificial lights are used for worker and navigational safety on construction vessels and barges, including flood lights in work areas.

1.3.3 Stressors During OSW Operations

1.3.3.1 Sound

Operating wind turbines produce underwater sound from the rotating blades, the electricity generator, and the gear box, which move downward and transmit into the water column and bottom substrate and from the bottom support structure (Hawkins et al. 2021). Operating wind turbines generate underwater sound at low frequencies (< 1 kHz) that, depending on the area, does not exceed ambient sound levels (Madsen et al. 2006). Sound levels and distance traveled may differ with foundation technology types (Tougaard et al. 2020). Sound associated with vessel traffic will continue to occur post-construction, as maintenance vessels will remain active during the operational phase but at much reduced activity levels as compared to the construction phase.

1.3.3.2 Electromagnetic Fields

Offshore wind-generated electricity is transported from the turbines to shore to connect into the grid through transmission cables. Electricity moving through transmission cables generates electromagnetic fields (EMF) that electro- and magneto-sensitive animals may be able to detect if they are in proximity to the cables. EMF is more likely to be present in the water column in floating wind energy projects because cabling may run through the water column between turbines in some deep water projects (as opposed to being buried).

1.3.3.3 Long-Term Structures and Related Changes in Habitats

Long-term structures can represent a collision hazard for marine birds as well as other avian taxa, such as some songbirds and shorebirds, that migrate over the ocean. Long-term structures in the water can also overlap with or replace important habitat for feeding and migrating marine mammals and marine birds; serve to repel or attract marine mammals and birds via several mechanisms; and change prey abundance or availability in the vicinity of structures. Birds may change their behavior to avoid or approach structures; for marine birds, this may lead to short- or long-term changes in habitat use, including displacement from former foraging or roosting areas as well as (for some species) attraction to perching opportunities on turbine platforms.

New hard substrate in an area with very little hard substrate could provide new habitat for some marine species, potentially changing the structure of local ecosystems (European Commission 2013; Marine Management Organization 2013; Palmquist and Guard 2017) via the formation of artificial reefs (Dauterive 2000; Degraer et al. 2000; van Hal et al. 2017). These changes in biodiversity and abundance of marine organisms may also lead to changes in ecosystem function (Causon and Gill 2018) and attract higher trophic level predators. The presence of turbines may also affect local hydrodynamics, including stratification of the water column, with currently unknown effects on the distributions of important prey taxa (van Berkel et al. 2020, Ocean Protection Council, 2021).

1.3.3.4 Increased Helicopter/Vessel Traffic

Increased helicopter traffic and vessel traffic can occur in support of the operation and maintenance of the offshore wind farm throughout the post-construction phase.

1.3.3.5 Artificial Lighting

Navigational and aircraft safety lighting are operated on turbine platforms and towers, respectively. In the U.S., aircraft safety lighting on the tower and nacelle will generally be blinking red lights, following Federal Aviation Administration guidance for lighting on communications towers and other tall structures, and will generally be required by BOEM to employ some type of Aircraft Detection Lighting System (ADLS), so that lights are only on when aircraft are within radar range.

1.4 Conceptual Framework for Categorizing Research Priorities and Data Gaps

The marine mammal workgroup for the NYSERDA-funded 2020 State of the Science Workshop on Wildlife and Offshore Wind (Southall et al. 2021) recently identified a range of data gaps and research needs to better understand the cumulative effects of offshore wind energy development on marine mammals in the eastern United States. The workgroup recognized four overarching research areas relating to understanding the effects of OSW development on marine mammals, including the following:

- **Occurrence:** information on the distribution, abundance, and habitat use of species, including temporal variability, as well as aspects of behavioral, movement, foraging, and acoustic ecology.
- **Conditions and stimuli:** characteristics of OSW activities that may affect wildlife (also referred to in this memo as “stressors”), including sound and presence of structures, vessel collision risk, turbine collision risk, and changes to habitat and prey distribution.
- **Response:** how animals respond to a stressor, including changes in behavior, physical condition, communication, navigation abilities, movements, and habitat use.
- **Consequence:** the short- and long-term effects of exposures and responses to stressors, including individual effects and how these changes may affect fitness through changes in reproduction, growth or survival, as well as resulting population-level changes to demography. Topics focused on

understanding baseline characteristics of population demographics (e.g., to contextualize changes due to OSW impacts) and integration of results into frameworks and predictive models are also included in this category.

These categories are used to classify key "conflict topics," or questions and research priorities, for both birds and marine mammals in the remainder of this memo. In addition, this memo recognizes a fifth category of research priority focused on methodological development and data availability/standardization.

2 Birds

2.1 Introduction

Most studies on OSW-related effects to birds, including collision, displacement and behavioral disturbance, and changes to prey distribution, originate from Europe, including Denmark (Larsen & Guillemette 2007), the Netherlands (Piet et al. 2021), the UK (Langston 2013, Thaxter et al. 2015), Germany (Mendel et al. 2019, Peschko et al. 2020), and Belgium (Vanermen et al. 2015). Offshore wind structures are known to affect marine birds (Fox and Petersen 2019) and are known or have the potential to affect other avian taxa that migrate over the ocean, including species of songbirds, shorebirds, wading birds, and raptors (Hüppop et al. 2006; McGrady et al. 2006; Loring et al., 2019). The magnitude of effects and impacts, however, is in some cases still poorly known, and can be highly species-specific; the science required to determine characteristic responses to offshore wind farms at the individual, species, population, and community levels is still ongoing (Vanermen et al. 2015, Peschko et al. 2021). Understanding how birds are affected by offshore wind farms is an important first step for developing strategies and solutions for preventing or mitigating displacement, collisions, or other types of observed effects.

The *Migratory Bird Treaty Act* (MBTA) was established in 1918 to ensure the sustainability of populations of all protected migratory birds in the United States, Mexico, Canada, Japan, and Russia. The MBTA prohibits the take (including killing, capturing, selling, trading, and transport) of more than 1,000 species (USFWS 2022) without prior authorization by the U.S. Fish and Wildlife Service (USFWS). The MBTA gives the USFWS principal responsibility for conserving migratory birds, including threatened and endangered birds, through the Migratory Bird Program. The Program's mission "is to conserve migratory bird populations and their habitats for future generations, through careful monitoring, effective management, and by supporting national and international partnerships that conserve habitat for migratory birds and other wildlife" (Sparling 2014).

The USFWS is also one of the agencies responsible for implementing the U.S. *Endangered Species Act* (ESA). Established in 1973, the ESA prohibits the import, export, or taking of fish, wildlife, and plants that are listed as threatened or endangered species. Ninety-nine bird species are currently listed as endangered or threatened by the U.S. Fish and Wildlife Service (USFWS 2022).

In addition to these two statutes, bald and golden eagles are specially protected under the *Bald and Golden Eagle Protection Act*, which may be applicable if wind turbines are installed in locations where bald and golden eagles occur.

2.2 Bird Receptor groups

2.2.1 Marine Birds

Marine birds, as defined here, are species that use the marine environment at some point in their life cycle (including loons, grebes, sea ducks, phalaropes, and seabirds). Seabirds spend the majority of their time on the ocean, beyond the intertidal or surf zone, and generally feed exclusively in the marine environment. These birds are often long-lived and typically nest on small islands or in other coastal areas. Other marine birds use the oceanic environment during certain seasons or life history stages, such as loons and some ducks that breed on freshwater lakes and ponds and move to marine environments in the nonbreeding season. Marine birds frequently cross maritime limits and boundaries of the United States and other countries to access breeding grounds, wintering grounds, and foraging areas.

2.2.2 Non-Marine Birds

Non-marine birds include any bird that uses offshore airspace, especially during migration, but does not roost or forage in the aquatic marine environment. Non-marine birds are most likely to encounter offshore wind structures during migration, and due to how they use the marine environment, are susceptible to a smaller subset of potential effects than marine birds. Non-marine birds include shorebirds (excluding Phalaropes), passerines (songbirds) and near-passerines, hummingbirds, wading birds, and raptors. (It should be noted that some of these taxa may forage on the wing while migrating offshore but are generally not foraging in the water itself).

2.2.3 ESA-listed Species

There are several ESA-listed birds and candidates for listing that spend part of their life cycle in the U.S. Atlantic, Great Lakes, Gulf of Mexico, and/or the U.S. Pacific and have the potential to be affected by one or more phases of offshore wind development.[8] These include the following:

2.2.3.1 Marine Birds

- **Black-capped Petrels** (*Pterodroma hasitata*) are proposed for listing under the ESA. They nest on Hispaniola and possibly Cuba (January-June), and during breeding season will range long distances to forage in deeper waters (200–2,000 m) in the Atlantic, Gulf of Mexico, and Caribbean (Simons et al. 2013). In the non-breeding season, Black-capped Petrels regularly use the Gulf Stream and shelf

[8] Other ESA-listed species may also have some potential to interact with OSW during migration, but have not been listed here due to a lack of evidence indicating their use of offshore habitats.

edge of the U.S. South Atlantic Bight, commonly as far north as Cape Hatteras and occasionally beyond (Jodice et al. 2015).

- **Roseate Terns** (*Sterna dougallii dougallii*) nest in colonies along the U.S.' northeast Atlantic coast and in Atlantic Canada, and winter in South America. Over 90% of remaining individuals breed at four colonies in Massachusetts and New York. During breeding (April-July), Roseate Terns generally forage in shallow waters (<5 m) and stay within about 10 km of colonies, though they may travel 30–50 km from the colony while provisioning chicks (USFWS 2010, Burger et al. 2011, Loring et al. 2017). Following the breeding season, Roseate Terns move to post-breeding coastal staging areas (July-September) during which foraging activity may occur up to 16 km from the coast (Burger et al. 2011). Roseate Tern migration routes appear to be primarily pelagic, occurring well offshore (Mostello et al. 2014, Nisbet et al. 2014).

- **Short-tailed Albatrosses** (*Phoebastria albatrus*) nest on islands near Japan and forage over a large pelagic range, primarily along the margins of the continental shelf. Juveniles generally use shallower waters than adults (e.g., <200 m water depth) and are more often observed off the west coast of the U.S. Most observations in recent years have been in fall and early winter, with a few records through early spring; however, incidences in the contiguous U.S. are relatively rare, with 38 records of the species off California between 1998 and 2020 (BOEM 2022).

- **Hawaiian Petrels** (*Pterodroma sandwichensis*) breed in Hawaii. Individuals are recorded off the Pacific coast of the continental U.S. in the summer, with most records occurring in July and August (BOEM 2022). This species is typically encountered well offshore in deep water.

- **California Least Terns** (*Sternula antillarum browni*) nest on sandy beaches along the coasts of California and Mexico in April-September. Most foraging occurs in nearby lagoons and estuaries, though individuals may also forage up to 3–5 km from shore (BOEM 2022). There are anecdotal observations of migration activity as much as 32 km offshore of California (BOEM 2022).

- **Marbled Murrelets** (*Brachyramphus marmoratus*) are a small auk that nest and roost in inland forests and spends the remainder of its time in nearshore marine waters. Abundance of Marbled Murrelets at sea is strongly correlated with proximity to contiguous old-growth forest with suitable nesting habitat (BOEM 2022). Most individuals occur within 1.6 km of shore, though small numbers are consistently observed up to 7 km from shore (BOEM 2022), and they may occur farther offshore over the continental shelf during the non-breeding season.

- **Scripps's Murrelets** (*Synthliboramphus scrippsi*) and **Guadalupe Murrelets** (*S. hypoleucus*) were collectively known until recently as Xantus's Murrelet and are now both federally listed. Both species nest on small islands in southern California and Mexico and disperse northwards during the post-breeding period in summer to mid-fall and are likely to be rare visitors to OSW areas during warm-water events such as El Niño years (BOEM 2022).

2.2.3.2 Shorebirds

- **Red Knots** (*Calidris canutus rufa*) nest in the Arctic tundra and winter from the southeastern United States to Argentina. Red Knots migrate in coastal and offshore areas of the U.S. Atlantic coast, congregating in key migratory stopover locations such as Delaware Bay. Recent tracking studies indicate that individuals use a range of coastal and offshore migration pathways (Loring et al. 2018).

- **Piping Plovers** (*Charadrius melodus*) nest on sandy beaches along shorelines of the U.S. Atlantic, Great Lakes, and Great Plains (May-August), and winter along the coasts of the southeastern U.S. and Caribbean. Nonmigratory movements tend to remain close to shore. Formerly thought to closely follow coastlines during migration as well (Burger et al. 2011), recent tracking studies indicate that individuals also use offshore migration pathways to move between coastal areas (Loring et al. 2020).

- **Western Snowy Plovers** (*Charadrius alexandrinus nivosus*) breed along the Pacific coast from Washington State to Mexico (March-September), nesting on coastal beaches, dunes, and salt pans. The winter range is somewhat broader, possibly extending to Central America, and birds may winter on any beaches with suitable habitat within this range (BOEM 2022).

2.3 Potential Impacts

The potential impacts of wind farms on bird populations can be grouped into three major categories: direct mortality due to collision with turbines/infrastructure; physical habitat modification and resulting changes to prey distribution from turbines and associated structures; and avoidance/attraction responses of birds to turbines, lighting, and vessel activity (Masden et al. 2009, Allison et al. 2019).

2.3.1 Injury/mortality

Avian collisions with terrestrial wind turbines are relatively well-documented (Allison et al. 2019), with estimates of average annual bird fatalities in the continental U.S. ranging from 230,000 to 600,000 birds per year, the majority of which are passerines. Estimating bird mortality at OSW facilities, however, is much more difficult and offshore collision data are limited. Birds may die by hitting stationary OSW turbine towers, stationary or rotating rotor blades, or possibly by being caught and fatally injured in the vortices created by the rotor blades (Fox et al. 2006). Birds are generally thought to collide with moving OSW turbine blades, although collisions with the tower have also been recorded (Perrow 2017). Although exact mortality rate estimates are currently unavailable, European studies so far have concluded that collisions with towers or blades are a rare occurrence (Skov et al. 2018).

In general, mortality risk is thought to increase in individual adult seabirds with the pressure to provision chicks (Perrow 2019). Sex-biased mortality of Common Terns (*Sterna hirundo*) during the egg-laying and incubation periods at a colony in proximity to a coastal wind farm in Belgium is thought to be the result of higher foraging activity of males provisioning mates, thereby increasing their exposure to and risk of injury from the wind turbines (Steinen et al. 2008; Everaert & Stienen 2007). Behavioral changes in Common Terns have been studied in other contexts as well (Henderson et al. 1995); breeding adults were found to fly lower over power lines on outgoing and incoming foraging journeys to provision food for offspring. Once chicks had fledged, however, adults returned to higher flight heights, suggesting that greater risk of collision may occur during the nestling phase, with a return to normal during the courtship, incubation, and fledging phases. Additionally, juveniles were found to be at a greater risk of collision, flying even closer to power lines. This may be because they are not as skilled flyers as their parents or exhibit naivety toward obstructions (Henderson et al. 1995).

A study by Thaxter et al. (2015) found a similar patterns in the behavior of Lesser Black-backed Gulls at colonies near OSW facilities. Adult birds rarely used offshore wind areas during incubation, but there was significantly higher use of these offshore areas in the chick-rearing period, particularly by adult males (and thus higher estimated collision risk for males during this period).

2.3.2 Changes to Prey

The effects of OSW construction on fishes are not well understood but could have implications for marine birds. A suspected example of this occurred at a wind farm in the UK, at which pile-driving occurred at an Atlantic Herring spawning ground during the spawning period (Perrow et al. 2011). For two years following construction, Little Terns (*Sternula albifrons*) at a nearby colony had record levels of egg abandonment, presumed to be due to lack of sufficient local herring prey to support successful reproduction. Similar evidence from other sites is extremely limited, perhaps because only a subset of fishes have the hearing capabilities necessary to be affected by pile-driving sound.

As artificial reefs develop on submerged OSW infrastructure during the operational period, diving sea ducks may be attracted to colonizing blue mussels (*Mytilus edule*) and other bivalves (Perrow 2019). Reefs may also attract fishes and other mid-level predators, which in turn may attract piscivorous marine birds, though it is currently unclear whether such changes can actually increase the carrying capacity for predators within the ecosystem. Likewise, local changes in stratification around wind turbine structures may increase vertical mixing, increase surface-level productivity, and reduce temperature differentials between surface and bottom waters during some seasons, with the potential to affect patterns of prey concentrations (van Berkel et al. 2020); however, the scale and degree to which such changes may affect fish populations remain quite poorly understood.

2.3.3 Displacement and Avoidance

At low levels of disturbance, changes in bird behavior may be correspondingly subtle. Behavior changes within or in close proximity to an offshore windfarm could include increased vigilance, more frequent flushing from the ocean surface, and slight deviations in flight paths. Higher levels of disturbance, however, may lead to avoidance. Disturbance from vessel activity is at its peak during construction activities, when many different types of vessels are present to carry out a variety of construction tasks (Perrow 2019). Once construction is complete, some species may return to the wind farm where they are likely to experience much lower levels of disturbance from regular maintenance vessels.

Marine bird displacement, in which individuals avoid the vicinity of turbines for foraging, roosting, or other activities, can lead to effective habitat loss. The exact mechanism of this response is unclear but is generally thought to be a direct response to the present of the structures themselves, at least in part. Short- or long-term displacement at OSW facilities has been observed in multiple taxa including Red-throated Loons, Black Scoters, Long-tailed Ducks, Northern Gannets, Razorbills, and Common Murres (Fox & Petersen 2019).

Where the flight paths of commuting, foraging, or migrating birds are disrupted by the presence of structures, the resultant displacement is typically termed a barrier effect. In a classic example, Kahlert et al. (2004) and Desholm & Kahlert (2005) demonstrated that Common Eiders significantly increased their flight distance from the Nysted OSW farm in Denmark, modifying their flight direction 1 to 3 km away from the facility and distancing themselves up to 900 meters away from the outermost turbine while flying around it. Such avoidance can also occur in the vertical plane (Plonczkier and Simms 2012).

Barrier effects are not thought to add sufficient additional flight distance to be energetically costly for most migrants, though the degree to which they affect migratory birds depends on variables such as body condition, morphology, energy required for flight, and foraging characteristics (Masden et al. 2010). Repeated avoidance of OSW facilities along a migratory flyway, or repeated encounters with a single facility as a part of daily foraging or commuting flights, may have a higher chance of deleterious effects (Masden et al. 2010).

2.3.4 Attraction to structures

Great Cormorants, European Shags, and several gull species are documented to show strong attraction to offshore wind farms (Vanermen et al. 2015, Dierschke et al. 2016). Wind farm infrastructure is thought to particularly benefit cormorants and shags by providing suitable perches on which to dry their feathers, a requirement that most marine birds do not share.

Migrating passerines are thought to be more vulnerable to collisions at night and in low visibility, especially when turbines are illuminated (Allison et al. 2019). However, as OSW turbines in the U.S. are expected to have ADLS systems in place to minimize the time that lights are activated, and to use blinking red aviation safety lighting, such attraction should be minimized under most conditions. Conversely, there is evidence that some nocturnally active seabirds are repelled by artificial light during the breeding season (e.g., Syposz et al. 2021). Light intensity, duration, and color all influence species responses, as do species, life history stage, weather conditions, and other factors.

2.3.5 Cumulative Impacts

Cumulative impacts are defined as interacting or compounding effects across spatiotemporal scales that result in negative outcomes to a population. There is growing concern in Europe regarding the potential for cumulative negative impacts of displacement for some bird species, especially Red-throated Loons (*Gavia stellata*) and Northern Gannets (*Morus bassanus*; Mendel et al. 2019; Dierschke et al. 2016). Cumulative effects of collision risk to gull species are also a concern in some areas, though notably these concerns are typically based on modeled estimates of collision risk rather than empirical data. The individual fitness consequences of displacement, as well as the potential population-level impacts of both displacement and collisions, remain poorly understood.

2.4 Research Priorities

While much has been learned in Europe regarding OSW effects on birds, a substantial number of remaining data gaps have been identified in the scientific literature and recent research prioritization efforts (Section 1.2). This is perhaps particularly true in the eastern United States, where a range of efforts in recent years have attempted to identify key priorities for future research as the industry progresses in the U.S. Key topics that have been identified across multiple prioritization efforts, and seem relevant to the U.S. context, have been summarized here. Identified research priorities have been grouped into five categories: Occurrence, Conditions and Stimuli, Response, Consequences, and Methodologies (Section 1.4).

2.4.1 Occurrence

This category focuses on species distribution, abundance, and habitat use, as well as behavioral and movement ecology, including the following:

- *Assess the distribution, abundance, and habitat use of birds in OSW areas by taxon, season, and development phase* (WOZEP 2016, Allison et al. 2019, Cook et al. 2021). Monitoring should be coordinated at a regional scale (Brodie et al. 2021). This is a priority for all species that utilize OSW areas, including breeding and non-breeding marine birds, as well as migratory shorebirds and songbirds; however, it is of particular significance for species listed under the ESA (see Section 2.2.3) and species that have been shown to be sensitive to human activities and/or avoid OSW areas, such as Red-throated Loons (Heinänen et al. 2020, JNCC 2021), Northern Gannets (Peschko et al. 2021), and Razorbills and other auks (Vanermen et al. 2019, Cook et al. 2021).
- *Understand the drivers of marine bird distributions.* Monitor the baseline abundance, distribution, and availability of the various prey species of marine birds (e.g., forage fish, mollusks) in relation to environmental variables to inform understanding of the drivers of marine bird distribution and abundance (Cook et al. 2021, JNCC 2021). If known, prey for key bird species of interest such as Red-throated Loons and auks can be particularly targeted for study (JNCC 2021).
- *Inform collision risk models by improving knowledge of flight behavior*, including flight height, for species of interest in relation to environmental/weather conditions such as wind speed, wind direction, visibility, and time of day (Cook et al. 2021).
- *Understand factors influencing offshore migration of non-marine birds.* Explore the effects of topography/location, weather, taxon, and other factors on offshore migration activity and flight altitude for facultative and obligate passerine and shorebird migrants (Cook et al. 2021).

2.4.2 Conditions and Stimuli

This category focuses on the characteristics of offshore wind projects and related activities that may affect the taxon of interest, including the following:

- *Measure artificial light at OSW facilities during different development phases and under varying weather conditions* (including light intensity, duration, and extent/directionality)
- *Assess the effects of OSW structures on marine bird prey* (via underwater sound, cable laying, formation of artificial reefs, or other factors) and how long these effects last (May et al. 2017, Allison

et al. 2019). Both fixed-bottom and floating technologies should receive attention as they may affect prey in different ways (State of Maine 2021).

2.4.3 Response

This category focuses on how birds may be influenced or react to exposure to a stressor, including the following:

- *Examine changes in abundance and distributions of birds around OSW facilities* (WOZEP 2016).
  - Examine the degree and scale of attraction of marine birds to OSW facilities for perching and foraging opportunities (Vanermen et al. 2020).
  - Examine the attraction of nocturnally active birds such as songbirds (Rebke et al. 2019) and storm-petrels (Gjerdrum et al. 2021) to OSW artificial lights at night (Cook et al. 2021). Such information should be associated with relevant environmental and weather data such as wind speed and direction, temperature, humidity, and barometric pressure, as well as lighting characteristics (including when they are triggered by ADLS; Cook et al. 2021).
  - Examine the degree, severity, and duration of different species' displacement or macro-avoidance behaviors, as well as meso-avoidance behaviors, around OSW facilities (van Kooten et al. 2018), and whether there are covariates that influence the degree of observed displacement.
  - Assess whether habituation to OSW facilities by marine species occurs over time (Gulka and Williams 2019).
  - Examine habitat-mediated impacts to species of interest during the operational period (Allison et al. 2019).
  - Understand how wind facility characteristics, such as facility size and location and turbine size and spacing, influence attraction and avoidance (JNCC 2021).
- *Investigate diurnal and nocturnal collision rates* of birds with wind turbines in relation to individual characteristics (age, sex), time of day/year, and environmental conditions (JNCC 2021, WOZEP 2016). Include a focus on seabirds as well as non-marine birds.
  - Requires reliable, repeatable, and validated collision detection that includes species identification (and age if detectable), timestamp, and ideally covariate information including where collision occurred (e.g., altitude, part of turbine), local weather data from on-site meteorological station, and turbine and wind farm characteristics (Gulka and Williams 2019).
- *Improve understanding of behaviors such as micro-avoidance* by examining flight behavior in close proximity to wind turbines (Cook et al. 2021, May et al. 2017) for species considered at most risk from collisions, such as Northern Gannets (Lane et al. 2020) and large gulls (Thaxter et al. 2019). This requires reliable detection of abrupt changes of direction, speed and/or height, as micro-

avoidance is considered to be rare, and carefully-designed studies to ensure methods have necessary statistical power (Cook et el. 2018).

  - Additionally, linking flight characteristics of marine species to either commuting or foraging behavior will improve understanding of collision risk.

2.4.4 Consequences and Long-Term Research Priorities

This section focuses on understanding the individual and population-level effects of exposures and responses to OSW stressors, including:

- *Assess the fitness and demographic consequences of cumulative collisions at OSW facilities* (Skov et al. 2018, Allison et al. 2019).
- *Assess the fitness and demographic consequences of cumulative displacement from OSW facilities* (Cook et al. 2021).
  - Develop individual-based models, energy budgets, or other approaches as appropriate to look at displacement-related changes in vital rates (can Kooten et al. 2018, Gulka and Williams 2019, JNCC 2021).
- *Develop accurate demographic data for key species of concern* to quantify the population-level significance of (estimated or actual) effects from OSW development and establish appropriate mitigation targets if necessary (Allison et al. 2019).
  - In the risk assessment context, it will be necessary to develop robust estimates of baseline demographic parameters, develop preliminary population models, and conduct sensitivity analyses and other gap analyses to identify key gaps where additional data are most needed – this process will focus and direct research towards areas of greatest need (Cook et al. 2021).
  - Terns may be one taxon of interest for this process in the U.S. Atlantic (will require comprehensive monitoring at tern colonies along the U.S. Atlantic coast; Cook et al. 2021).
- *Identify whether changes in marine bird foraging activity and/or energetics due to OSW development are observable, and whether they align with changes in prey* (NYSERDA 2020, JNCC 2021).

2.4.5 Methodologies

This category includes research priorities focused on methods, data standardization, and data availability, including the following:

- *Develop better methods to measure avian collision mortality and micro-avoidance* (Gulka and Williams 2019), including identifying mortalities to species and monitoring at night and during periods of poor visibility, periods with traditionally poor data records.

- *Standardize project-specific monitoring data and make it open access* (MASTS 2019, Cook et al. 2021).
- *Empirically validate collision estimates derived from collision risk models* (Skov et al. 2018, NYSERDA 2020, JNCC 2021).
- *Develop smaller, lighter, longer-lasting transmitters for deployment on small-bodied marine and non-marine birds* (JNCC 2021).
- *Explore efficacy of potential mitigation approaches* (JNCC 2021).
- *Promote coordinated research at multiple wind energy facilities to enable statistically robust analysis of effects* (Allison et al. 2019).

3 Marine Mammals

3.1 Introduction

Marine mammals consist of five different mammalian groups: cetaceans (whales, dolphins, porpoises), pinnipeds (seals, sea lions, walruses), sirenians (manatees, dugongs), marine and sea otters, and the polar bear. There are over 50 species of marine mammals present in United States waters on the east and west coasts and Gulf of Mexico.

All marine mammals within US waters are protected by the *Marine Mammal Protection Act* (MMPA) which was established in 1972. This Act was developed to protect marine mammal populations and stocks from diminishing to the point of not being significant functioning elements of the ecosystems in which they live and restore diminished species or stocks. The MMPA prohibits the taking and importation of marine mammals and marine mammal products, where "take" means to harass, feed, hunt, capture, or kill any marine mammal, or to attempt to do so with some exceptions. (CFR, 2000,2003)

The other Act some species of marine mammals fall under is the ESA established in 1973. This Act prohibits the import, export, or taking of fish and wildlife and plants that are listed as threatened or endangered species. This Act also adds and removes species from the list of threatened or endangered species to prepare and implement plans for their recovery. The Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) is implemented through this Act.

Agencies such as USFWS, National Marine Fisheries Service (NMFS), and the Marine Mammal Commission (MMC) are charged with protecting marine mammals. Under the Department of Commerce, through the National Oceanic and Atmospheric Agency (NOAA), NMFS protects whales, dolphins, porpoises, seals, and sea lions. USFWS, under the U.S. Department of the Interior, protects walrus, manatees, sea otters, and polar bears.

3.2 Marine Mammal Receptor Groups

There are multiple approaches to identify receptor groups within the marine mammals. The following highlights some of the more common groups identified in the literature focusing on impacts from offshore wind stressors on marine mammals.

3.2.1 Taxonomic Groups

Marine Mammals are divided taxonomically into three orders: Cetacea, Sirenia, and Carnivora. The Order Cetacea is divided into two suborders, Mysticeti and Odontoceti. Odontoceti or odontocetes are toothed whales which are comprised of a diverse group of porpoises, dolphins, and whales. Mysticeti or mysticetes are filter-feeding baleen whales that tend to be larger than odontocetes. The Order Carnivora contains the Suborder Pinnipedia as well as the Mustelidae and Ursidae. Within the Suborder Pinnipedia or pinnipeds are the seals, sea lions, and walruses (walruses are not discussed further in this report). The Mustelidae Family contains sea and marine otters, and the Ursidae Family contains polar bears (polar bears are also not covered further in this report). The last order of marine mammals is Sirenia which contains manatees (and dugongs which are not found in US waters).

Odontocetes have a single blowhole and are typically small to medium in size, with the exception of the sperm whale. Odontocetes are known to use echolocation to navigate, forage, and avoid predators by producing short sounds and using the echoes to process information about their environment.

Mysticetes are baleen whales; instead of teeth they have baleen on the upper jaw made of keratin. These animals are large in size and have a double blowhole. These species take large gulps of water and use their baleen to filter out their food. Their social structure of baleen whales is simpler than odontocetes and these species tend to occur in smaller groups. Many of the species within this suborder are known for their long seasonal migrations from low latitude, warm water breeding grounds to high productivity and colder waters found in higher latitudes. Mysticetes produce a variety of low frequency sounds, which tend to be associated with mating or feeding behaviors.

Pinnipeds are divided into three families: Otariidae (sea lions), Phocidae (seals), and Odobenidae (walruses). Phocids or true seals, are the largest family of pinnipeds and can be identified by their lack of ear flaps, known as pinna, and their inability to rotate their hind limbs underneath their body. This causes them to have a wormlike appearance while on land. They are a more aquatic family spending less time on land than otariids. Otariids, which are the eared seals and sea lions, are identified by the presence of pinnae and the ability to rotate their hind limbs under their body to enable them to use all four limbs on land. While pinnipeds are aquatic carnivores, they all must return to some form of substrate (ice or land) to bear their pups. Seal species can be found in US waters on the east and west coasts, the Hawaiian Islands, and in the Gulf of Mexico, while sea lions are found on the west coast (including Alaska).

Only one species from the Order of Sirenia is found in US waters, the West Indian Manatee (*Trichechus manatus*). They can be identified by their flat, rounded tail and robust body. They are typically found in either coastal waters or fresh or brackish waters in warm latitudes depending on the season as they are sensitive to cold.

Only two species of otters are considered marine and of these, two subspecies of Sea Otters, the Southern Sea Otter (*Enhydra lutris nereis*) and the Northern Sea Otter (*Enhydra lutris kenyoni*) are found in US waters along the US west coast. These animals are typically found in shallow, nearshore waters. Sea otters were extirpated from Oregon and Washington but have been successfully reintroduced to Washington waters.

3.2.2 Hearing Groups

Marine mammals can generally be grouped in hearing groups to assess their relative sensitivity to underwater sound. In particular, Southall et al (2019) identified five different hearing groups. It is assumed that the intensity, duration, and frequency characteristics of a sound will help predict which hearing group will be most likely to be impacted by an acoustic stressor. Table 2 provides the hearing frequency range for marine mammals and various hearing receptor groups.

Table 2 Hearing Ranges of Hearing Group Marine Mammals

Hearing Group	**Generalized Hearing range***
Low-frequency cetaceans (baleen whales; sirenians also included in this audiogram)	7 Hz to 35 kHz
Mid-frequency cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz
High-frequency cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchids, *Lagenorhynchus cruciger* & *L. australis*)	275 Hz to 160 kHz
Phocid pinnipeds (underwater) (true seals)	50 Hz to 86 kHz
Otariid pinnipeds (underwater; sea lions and fur seals; otters also included in this audiogram)	60 Hz to 39 kHz

Note: * Represents the generalized hearing range for the entire group as a composite (i.e., all species within the group), where individual species' hearing ranges are typically not as broad. Generalized hearing range chosen based on ~65 dB threshold from normalized composite audiogram, with the exception for lower limits for low-frequency cetaceans (Southall et al. 2019) and phocid pinnipeds (approximation). An audiogram from a walrus and a sea otter were included in the phocid pinniped and otariid pinniped composite audiograms. Sirenian data were included in the low-frequency cetacean composite audiogram.

Source: U.S. Department of Commerce 2018

3.2.3 ESA Listed Species

Several marine mammal species within the United States fall under the ESA and will require special consideration because of additional levels of protection. Protection can include area closures, critical habitat designations, as well as species-specific mitigation measures. Within these species are a few highly sensitive species within each region which will be a priority because of declining or otherwise particularly vulnerable populations. There are several ESA-listed marine mammal species and candidates for listing that spend part of their life cycle in the U.S. Atlantic, Gulf of Mexico, and/or the U.S. Pacific and have the potential to be affected by one or more phases of offshore wind development[10]These include the following:

- **North Atlantic Right Whale** (*Eubalaena glacialis*) is considered as one of the most endangered species in the world with about 350 individuals left. This species is found off New England on its foraging ground and migrates to the southeast United States coast from North Carolina to Florida to breed and calve.
- **Blue Whale** (*Balaenoptera musculus*) is the largest animal on earth and is considered endangered throughout its range which includes the Atlantic Ocean, Pacific Ocean and Gulf of Mexico. This migratory species tends to feed near the poles and migrate in the winter towards the tropics to breed and calve.
- **Fin Whale** (*Balaenoptera physalus*) is the second largest animal on earth. This species is also considered endangered throughout its range which includes all the regions of interest covered in this memo. This species is usually found in deep, offshore waters. Some individuals migrate to the poles to feed during the summer and breed and calve in tropical regions in the winter. Some individuals are also observed to remain year around in certain locations.
- **Sei Whale** (*Balaenoptera borealis*) is commonly observed in temperature waters and is observed in the Gulf of Maine, Georges Bank and Stellwagen Bank in the Atlantic Ocean. This species is listed as endangered throughout its range and can be observed in all ocean basins. Unlike other mysticetes, the movement patterns of this species are primarily unknown.
- **Sperm Whale** (*Physester macrocephalus*) is the largest toothed whale species and is currently listed as endangered throughout its range (which includes the Atlantic ocean, Pacific ocean and Gulf of Mexico). Their distribution usually follows food availability and breeding opportunities but vary with the age and sex of the animals.
- **Rice's Whale** (*Balaenoptera ricei*) This species is considered to be one of the most endangered species in the world with less than 100 individuals remaining. This species is observed in the northeastern Gulf of Mexico in depths ranging from 100 to 400 meters. This species was

considered as part of the Bryde's whale species until 2021 where it was determined this resident population was actually a unique species.

- **Killer Whale** (*Orcinus orca*) While this species is observed in all the regions covered in this memo, the Southern Resident Distinct Population Segment (DPS) in the eastern North Pacific with about 72 individuals (2020 estimates) is currently listed as endangered.
- **Humpback whale** (*Megaptera novaeangliae*) Humpback whale stocks were divided in 2016 into different DPSs to reflect some of the recovery of certain populations worldwide. This migratory species currently has one DPS listed as endangered that would overlap with the regions of interest. The Central America DPS migrates between Alaska feeding grounds to their breeding grounds in Central America.

3.2.4 Additional Receptor Groups

When receptor groups are defined relative to potential stressors, there are additional receptor groups beyond hearing groups to consider.

- *Coastal/Pelagic Distribution*: Marine mammals may be affected differently depending on whether they are coastal or pelagic in their distribution, as there are different activities associated with wind farms closer to shore (e.g., cable installation and maintenance) and farther from shore (e.g., turbine installation and presence in the water column).

- *Migratory/Resident*: The potential for displacement from migratory routes or year-round exposure of residents to operation and maintenance of wind farms may result in different effects for migratory and resident marine mammals.

- *Shallow Diving/Deep Diving*: Dive depths and time spent at the surface may affect the likelihood of vessel collision or secondary entanglement risks for floating wind moorings and mid-water cables.

- *Use of Habitat*: Some areas are important feeding or breeding grounds for marine mammals, and these uses may vary seasonally. The season and use for a marine mammal species in the area where a wind farm will be built may be used to assess the potential for wind farm stressors to affect important life history functions that could have population level impacts.

3.3 Potential Impacts

The potential impacts of wind farms on marine mammal populations can be grouped into three major categories: behavioral disturbance from sound and human activities (which includes displacement, attraction, and avoidance); injury or mortality due to collision with vessels or entanglement (floating wind) or injury associated with hearing damage; and effects of physical habitat modification and resulting changes to prey distribution.

3.3.1 Behavioral Disturbance

Behavioral disturbances of marine mammals can occur due to underwater construction sound, short-term and long-term structures, and increased vessel traffic. Potential results from behavioral disturbances can be acoustic masking, avoidance, Lombard response (increasing of call volume, pitch, etc. to be heard over ambient sound), attraction, and diving behavior. Marine mammals use sound both actively and passively for migration, mating, communication, feeding, and resting, as discussed in Section 3.2.2. Underwater sound during construction can mask sounds used by marine mammals, cause them to avoid areas, dive deeper, and in certain cases increase their vocalization rates, volumes, etc. to combat the increased sound in the area (Parks et al. 2010). Behavioral responses to underwater sound can range from ‘no response’ to mild aversion to panic (Southall et al. 2007). Behavioral responses will generally depend on the species, an animal’s current behavioral state or other contextual factors (Ellison et al. 2012), and the area where the stressor is located. Habitat displacement is another type of behavioral response, and it can occur with species that use the area as a migration route, mating area, feeding area, and/or as a movement corridor to feeding or mating areas. Conversely, habitat changes could negatively impact a species’ overall fitness if the wind farm installation results in increased migration routes, which could ultimately reduce energy reserves (Pirotta et al, 2018, European Commission 2016).

3.3.2 Changes to Prey

Similar to bird species, the impact of OSW on prey distribution (fish and invertebrates) is still poorly understood but could have an impact on marine mammals, Offshore wind turbines could attract marine species causing a ‘reef-effect’ (Section 1.3.3.3). The increase in local biodiversity/density of fish or other food resources could serve as an attractant to other marine species (Dierschke et al. 2016) thus altering feeding ranges of specific species. Complementary trophic web modelling was conducted for a windfarm project in France, and results indicated that apex predators such as marine mammals would likely respond positively to the increase in biomass generated by the presence of the turbines (Raoux et al, 2017). As noted in Section 2.3 for birds, it is also currently unclear whether such changes can actually increase the carrying capacity for marine mammals within the ecosystem. Likewise, local changes in stratification around wind turbine structures may increase vertical mixing, increase surface-level productivity, and reduce temperature differentials between surface and bottom waters during certain seasons, with the potential to affect patterns of prey concentrations (van Berkel et al. 2020); however, the scale and degree to which such changes may affect fish populations remain quite poorly understood and their impact on marine mammals is currently unknown.

3.3.3 Injury/Mortality

Habitat fragmentation can happen at the construction and post-construction phase of a wind farm and occurs when a species' habitat overlaps a wind farm and structures and/or activities cause the species to abandon the area. This can result in temporary and/or long-term habitat loss if offshore wind structures and activities forming a barrier, displacing species that use the area that are now being avoided (Fox et al. 2006). In order to estimate the potential species level impacts of habitat fragmentation or loss it is important to consider a variety of species' characteristics, including sensitivity to human disturbances, adult survival, movement characteristics (depth), population exposure to the wind farm area, population size, and breeding status. Offshore wind turbines could also attract marine species causing a 'reef-effect' (Section 1.3.3.3). The increase in local biodiversity/density of fish or other food resources could serve as an attractant to other marine species (Dierschke et al. 2016) thus altering feeding ranges of specific species. Increased food supply could even lead to increased fitness for some species. Conversely, habitat changes could negatively impact a species' overall fitness if the wind farm installation results in longer migration routes, which could ultimately reduce energy reserves (Pirotta et al, 2018, European Commission 2016).

Construction and post-construction stressors can result in impacts to species that cause injury, and there is at least a minor risk of mortality associated with vessel collision or, for floating wind, secondary or tertiary entanglement (i.e., entanglement in marine debris snagged on cables or moorings or debris already being dragged by whales ensnaring on cables or moorings). Construction and post-construction activities can increase vessels in an area, will create new underwater structures, and increase underwater sound. This section discusses the potential for injury/mortality impacts to marine mammals.

3.3.3.1 Hearing Impacts

Underwater sound resulting from surveys and construction activities is generated during offshore wind development and is most significant when pile-driving is required. Both fixed turbine and floating offshore wind can use pile-driving as discussed in Section 1.3.2.2. Underwater sound can potentially physically injure marine mammals (Jepson et al. 2003; Cox et al. 2006). Sound created from pile-driving, for instance, could overlap with the hearing ranges of marine mammals, potentially resulting in behavioral and physical impacts, stress, and ear injuries (BOEM Office of Renewable Energy Program 2017). Above a certain intensity, sound levels can cause Temporary Threshold Shift (TTS), a recoverable and transient reduction in hearing sensitivity, and/or Permanent Threshold Shift (PTS), a non-recoverable reduction in hearing sensitivity (Finneran 2016). A common injury from sound is TTS and PTS and is referred to as sound-induced hearing loss. Depth, substrate, and topography factor into the distance pile-driving sound propagates in the marine environment. Soft starts, bubble curtains, and other sound reducing mitigations can be implemented to reduce construction sound impacts on marine mammals (Dähne et al, 2017; NOAA 2008).

3.3.3.2 Vessel Collision

The probability of vessel collision of marine mammals increases with increasing time spent near the surface (i.e., shallow diving cetaceans), in areas of high concentration of vessels (e.g., shipping lanes), and vessel use in areas heavily used by marine mammals (e.g., biologically important areas [BIAs]; Douglas et al. 2008; Berman-Kowaleski et al. 2010). Additionally, speed is a factor in the potential for mortality resulting from vessel collision. Collisions with vessels travelling ≥14 knots are more likely to result in mortality (Laist et al. 2001; Jensen and Silber 2004). Conn and Silber (2013) found that mortality from vessel collision was reduced by 80-90% in regulated North Atlantic right whale Seasonal Management Areas with speed restrictions based on modeling of data for pre- and post-speed restriction periods.

3.3.3.3 Entanglement

Entanglement can occur primarily in floating offshore wind mid-water cables and moorings as secondary and tertiary entanglement. Secondary entanglement occurs when a marine organism is entangled in derelict fishing gear or marine debris that is accumulated on a structure; tertiary entanglement occurs when an organism is already entangled in derelict fishing gear or marine debris and the gear then becomes entangled on structures. Marine mammals are more likely to experience secondary entanglement rather than tertiary entanglement (Farr et al. 2021). Benjamins et al. (2014) found that baleen whales had the highest risk of entanglement in mooring among cetaceans, while toothed whales had the least risk. The risk of entanglement was considered modest in comparison to fishing gear.

3.3.4 Cumulative Impacts

Several studies have focused on the cumulative impact of OSW development particularly as more projects developed within a region. Similar to birds, a lot of effort has been invested in Europe to quantify the range of cumulative impact OSW projects could have on marine mammal species (Damian and Merk, 2014, Wright and Kyhn, 2015, Platteeuw et al, 2017, Brignon et al, 2022). Tools such as Population Consequences of Disturbance models and investigating a range of stressors within species-specific life history have been recommended as valuable tools to assess the cumulative impacts of offshore wind marine mammals (Booth et al, 2020).

3.4 Research Priorities

Research needs and priorities associated with marine mammals have been the subject of several workshops and publications (Bailey et al, 2014, Kraus et al 2019, Gulka and Williams 2019; NYSERDA 2021, NRDC, 2022). While it is generally assumed that regional priorities might vary with topography, OSW technology and species risk (Southall et al 2021, NRDC 2022), general trends and broad research needs have emerged. The research priorities identified below generally follow the priorities highlighted in BOEM (2017). This document also identified some of the “lessons learned” in international offshore wind developments (Verfuss et al 2016). In particular, the characterization of habitats and acoustic parameters associated with pile driving (source level parameters and propagation) were highlighted as important research needs.

The Regional Wildlife Science Collaborative (RWSC, 2022) Marine Mammal Science Plan has outlined research priorities specific to the U.S. Atlantic region, but these priorities can also be generalized to other regions. This plan suggests that research efforts should focus on:

- Defining existing conditions and recent trends (species, prey, seasonality, and climate drivers)
- Identifying changes in distribution
- Describing changes in abundance
- Characterizing changes in behavior

These categories were reformulated in Southall et al (2021a) under four major themes: Occurrence, Conditions and Stimuli, Response, And Consequences. While the first three categories highlight acute, individual-based events and phenomena, the last priority encompasses long-term, large-scale, and population-level priorities. In categorizing and prioritizing the research needs, three tiers were identified in Southall et al (2021a). Tier 1 corresponds to the polled responses from experts who identified the top three cross-taxon priorities, while Tier 2 corresponds to the next four priorities (across species) that ranked the highest. In considering priorities, experts were asked to particularly focus on the “urgency of the information need… the sequencing of objectives and the ability to inform Consequence models such as PCoD models” (Southall et al 2021a).

The following section summarizes the identified short-term, Tier 1 and 2 priorities from Southall et al (2021a) while integrating findings from additional sources (Bailey et al 2014, Kraus et al 2019, Southall et al 2021b, NRDC 2022). For each research priority, receptor groups were highlighted for the geographic areas of interest defined in Section 3.2. As noted earlier, Southall et al (2021a) focused on research priorities in the Atlantic basin so below, additional priorities related to other regions and technologies were incorporated (NRDC, 2022).

Some research questions were identified by experts (Southall et al 2021a, Kraus et al 2019) as third-tier priorities. While they could potentially be relevant globally, they may only become priorities in specific regions or habitats or be species- or technology-specific and are not discussed further in this section.

3.4.1 Occurrence

The priority for research associated with understanding marine mammal occurrence encompasses the basic information on species' distribution, abundance, and temporal habitat use. This includes seasonal and interannual variability, as well as elements of behavioral, movement, and acoustic ecology.

- *Estimate habitat use, distribution, and abundance in OSW development areas by season, and identify dynamic environmental variables driving these patterns.* Marine Mammal abundance and density are evaluated by NMFS for many US stocks, and assessments are readily available. For rare and cryptic species, current methodologies might provide limited information on the abundance of these species or their seasonality, and studies might lack the power needed to inform understanding of population health and dynamics.

- *Establish individual baseline movements and behavioral patterns (foraging, diving, reproduction) specific to OSW development areas.* Understanding of marine mammal behavioral and baseline movement has improved in recent years with the use of archival and satellite tagging. While some species have been extensively studied (e.g., beaked whales in the context of behavioral response studies, Southall et al. 2008), there is still limited information about the major life history parameters of many species (e.g., feeding behavior, migration energetic costs; Jeanniard-du-Dot et al 2017)

- *Determine spatially and temporally explicit species presence in OSW development areas.* Aerial surveys in the Mid-Atlantic have provided strong information about the presence and seasonality of protected species (Robinson Willmott et al 2021). Passive acoustic monitoring via fixed moorings, gliders, and other technologies can also provide information about spatial and temporal presence of species of interest with the development of analytical tools. Van Parijs et al (2021) identified some of the technologies, needs, challenges and requirements associated with these methodologies.

3.4.2 Response

This category encompasses how animals may react to an external stressor on various time scales. The actual responses can include measurable changes in behavior, communication range, abilities to navigate/migrate and/or the animal's physical condition. For these variables to be robustly measured, it is important to first obtain baseline information on the animal's behavior.

- *Identify acoustic exposure and contextual conditions associated with potential acute response to OSW stressors to support development and refinement of risk and consequence assessment*. Archival and satellite tagging methods have provided tools to measure sound exposure at the animal while recording the animal's behavior using triaxial accelerometer data (Cade et al 2021). These promising technologies are still limited by sampling rate and depth restrictions.
- *Evaluate relative threat of mortality/injury from vessel collision and entanglement (floating wind) associated with OSW and non-OSW activities.* Vessel collisions are particularly a concern for large whales, and detection tools are being developed and tested to minimize these interactions (Schoeman et al 2020).

3.4.3 Conditions/Stimuli

This category includes information on OSW activities and their characteristics that may affect marine mammals. These include sound, vessel collision, electromagnetic fields, modifications of the environmental conditions, as well as changes in the food web structure.

- *Evaluate ambient sound levels in OSW development areas prior to development activities as well as during development phases.* Van Parijs et al (2021) identified some of the research needs and limitations associated with passive acoustic monitoring methods and the need to standardize methodologies for comparisons across sites.
- *Evaluate changes in ecosystem and prey conditions in OSW development areas from the pre-construction to operational periods.* This is particularly important when considering the potential reef effects OSW structures could have on the ecosystem with a potential increase in biodiversity.

3.4.4 Consequences and Long-term Research Priorities

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" (Southall et al 2021a).

This priority considers the short- and long-term individual or population-level effects of multiple types of exposures and responses. The understanding and proper mitigation of population-level cumulative consequences requires an understanding of demographic effects of individual responses along with a strong knowledge of behavior and ecology. Consequences may include the long-term effects of modifications to distribution, behavior, social groupings, or/and foraging success. While it might not be feasible to measure how these changes empirically affect individual's fitness through changes in reproduction, growth, or survival, modeling can help inform adaptive management (Booth et al 2020).

This last priority is particularly important for species already identified as vulnerable. These include North Atlantic Right Whales in the Atlantic Ocean, Southern Resident Killer Whales in the Pacific Northwest, Rice's whales in the Gulf of Mexico, and Blue and Fin whales on the West coast.

3.4.5 Data Standardization

Generally, the continuous effort to better inform the research priorities related to OSW has highlighted the need to have datasets that can be easily integrated in larger research enterprise, framework, and modelling efforts (Kraus et al, 2019, NYSERDA, 2021). The emphasis on cohesive, transparent, and collaborative research efforts to better inform management and industry was also highlighted by BOEM (2018). Data standardization and transparency are thus considered a research priority in this document to ensure that there is longitudinal data availability for a regions and robust methodologies and frameworks to implement. The aggregation and standardization of data will ensure that the incorporation of the various datasets into population modeling frameworks can occur (Kraus et al 2019, Booth et al 2020). The standardization of methodology and data availability were identified as essential for future cumulative modeling efforts and opportunities to compare geographical locations and OSW technologies (Lindeboom et al 2015, Van Parijs et al 2021, Wall et al 2021).

4 Next Steps

This memo provides a summary of major questions about OSW effects to marine mammals and birds that may represent barriers to OSW industry advancement. These research priorities will be used by a group of expert stakeholders at upcoming workshops in 2022 that will focus on identification of study design factors and technology parameters needed to achieve robust statistical outcomes in effects research and monitoring at OSW facilities (for example, temporal/geographic scope of study, types/amounts of data needed, and necessary effect sizes and power to detect effects).

Following this effort, the project team will assess the capabilities and limitations of available technologies for monitoring marine mammals and birds during OSW operations, including the ability of existing technologies to address the above study design factors as well as to be reasonably integrated into OSW equipment and operations. The final project report will provide a clear framework to direct further technology development and collaboration, and will provide benefits to multiple end users, including developers, regulators, and other stakeholders. This study for birds and marine mammals will develop a framework to expand to other taxa and will provide outcomes that can be applied to a structured decision framework to focus funding and efforts in technology development. End products will also be of immediate utility to proponents who are currently developing post-construction monitoring plans and must assess the capabilities and limitations of existing technologies.

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