Technology Gaps for Bird Monitoring in Relation to Offshore Wind Energy Development

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

Task 4.4

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Acronyms and Abbreviations

AI	Artificial intelligence
ADLS	Aircraft detection lighting systems
BRI	Biodiversity Research Institute
GPS	Global positioning system
LiDAR	Light detection and ranging / laser imaging, detection, and ranging
Motus	Motus Wildlife Tracking System
OSW	Offshore wind
R&D	Research and development
RGB	Red-green-blue
SME	Subject-matter expert
UAS	Unoccupied aerial system

Executive Summary

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 OSW turbines. Wildlife monitoring for OSW energy development should be question-driven, scientifically robust, and integrated into OSW development and operation procedures; otherwise, funding spent on wildlife monitoring may not meaningfully inform future environmental assessments and adaptive management decisions. A variety of technologies are available for wildlife monitoring, but there is currently no comprehensive assessment of the capacity of available technologies to collect statistically robust wildlife data at OSW facilities, inform adaptive management, and reduce precautionary mitigation.

As part of an effort to develop targeted recommendations for research and development (R&D) of bird and marine mammal monitoring technologies, subject matter experts (SMEs) were invited to two workshops in the autumn of 2022 to provide input on the technology types, limitations, and possible improvements to technologies that are used or have potential to be used to monitor marine birds in relation to OSW energy development. This report summarizes discussions from these workshops, including:

- The technologies and methods (including sample size and scale considerations) needed to answer priority research questions;
- Factors influencing the level of uncertainty in results produced by these technologies;
- Major bottlenecks and limitations of available methods/technologies that additional R&D could address; and
- Ideas to streamline bottlenecks.

Workshop participants identified a broad range of technologies used to monitor birds and OSW development, as well as the limitations inherent in those technologies. Strategies to address these limitations included investments in further R&D to improve specific technologies. For example, SMEs suggested that R&D for tags and other bird-borne sensors focus on increasing sensor reliability and accuracy, further miniaturization of tags and improved battery life relative to tag size and increasing remote download capabilities. Tag integration was highlighted as a potential solution to some existing technological limitations, for example by improving integration of altimeters or pressure sensors with other tag types to obtain more reliable altitude data. More generally, SMEs noted the potential value of integrating a range of monitoring technologies that provide data of differing types or at complementary scales.

SMEs indicated that engaging with wind energy projects and turbine manufacturers as soon as possible, preferably several years prior to construction, is important to streamline and facilitate the operationalization of turbine- or platform-based monitoring at OSW sites. SMEs also focused on the

importance of standardization and flexibility in platforms and technologies, including designing systems to be able to operate on different countries' electrical systems and a common need for front-end engineering for common scientific research needs on platforms. It was felt that the incorporation into turbine designs of built-in capacity designated for wildlife monitoring systems (including power, internet/data transfer, and physical space) would greatly facilitate the ability of offshore wind developers to meet environmental monitoring requirements, which are typically finalized much later in the development process. It was also suggested that the development of government requirements for data sharing protocols, standards, or platforms could help to drive collaboration and innovation. Ultimately, a combination of focused R&D, cross-sector coordination and streamlining, and acceleration of development and testing timelines were recommended to improve bird monitoring technologies.

1 Introduction

1.1 Objectives

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 and inform adaptive management. Similarly, there is currently no comprehensive evaluation of the capacity of monitoring technologies to be integrated into normal operations and maintenance of wind facilities. 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 informing mitigation and adaptive management of observed effects; and

Integrating monitoring technologies into OSW operations.

The project incorporates input from a wide range of subject matter experts (SMEs) and 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. The geographic focus of this effort includes the U.S. Atlantic, Pacific, Great Lakes, and Gulf of Mexico. However, many of the technology limitations and needs identified during this project are expected to be global in their application.

The first task of this project was to write a memo to compile information on priority conflicts that are likely to become barriers to OSW progress as environmental compliance issues or SME concerns. This assessment was written collaboratively by Advisian, Worley Group and Biodiversity Research Institute (BRI) and focused on:

- Identifying 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.

Based on the findings of this memo, priority questions were identified and used to guide the discussion during two workshops with SMEs. These workshops focused on identifying:

- The technologies and methods (including sample size and scale considerations) needed to answer priority research questions;
- Factors influencing the level of uncertainty in results produced by these technologies;
- Major bottlenecks and limitations of available methods/technologies that additional R&D could address; and
- Ideas to streamline bottlenecks.

This report focuses on bird monitoring and the findings from the bird SME workshop. A similar workshop was conducted for marine mammals and findings are reported in a separate document, titled "Technology Gaps for Marine Mammal Monitoring in Relation to Offshore Wind Development". Subsequent project activities will focus on documenting the technical specifications and capabilities of existing monitoring technologies, identifying limitations and opportunities for integrating monitoring technologies into OSW infrastructure and operational procedures, and synthesizing findings into a final project report with targeted recommendations for R&D of bird and marine mammal monitoring technologies. This report summarizes the predominant technologies, uncertainties, bottlenecks, and potential solutions that were identified by bird SMEs as part of the Task #2 workshops.

1.2 Workshop Details

1.2.1 Format

The bird workshops were conducted in two sessions (2.5 hours each) in October and November 2022 using video conferencing and a Mural virtual whiteboard (www.mural.co). The Mural whiteboard remained open for the participants to add comments and suggestions for an additional week following each session. Prior to the workshop, SMEs received 1) a condensed version of the Task #1 priority memo summarizing priority questions on which workshop discussions would focus and 2) a brief summary of workshop objectives and the elicitation process to be used during workshop sessions.

The Mural virtual whiteboard was organized to help facilitate discussion during workshop sessions and to capture participant ideas in a collaborative format. After a brief introduction to the project and Mural platform, attendees were invited to contribute specific technologies and uncertainties around those technologies (in the first meeting), and bottlenecks and potential solutions (in the second meeting) via discussion and comments on the Mural platform.

1.2.2 Participants

In addition to project personnel, a total of 21 SMEs (Table 1) participated in one or both of the bird workshop sessions. SMEs had expertise in a variety of bird taxa and monitoring methods and represented academia, nonprofit organizations, the offshore wind industry, environmental consultants, and government agencies.

Table 1. List of Bird Workshop Participants

Name	**Affiliation**
Josh Adams	U.S. Geological Survey
Mark Collier	Waardenburg Ecology
Aonghais Cook	British Trust for Ornithology
Robert Diehl	U.S. Geological Survey
Zara Dowling	Bird & Bat Subcommittee Coordinator, Regional Wildlife Science Collaborative for Offshore Wind
Shilo Felton	Renewable Energy Wildlife Institute
Julian Fraize	National Offshore Wind Research & Development Consortium
Andrew Gilbert	Biodiversity Research Institute
Jeff Gleason	U.S. Fish and Wildlife Service
Kate Goodenough	University of Oklahoma
Holly Goyert	AECOM
Cris Hein	National Renewable Energy Laboratory
Juliet Lamb	The Nature Conservancy
Pam Loring	U.S. Fish and Wildlife Service
David Mizrahi	New Jersey Audubon
Andie Nicholls	RPS Consulting UK & Ireland
Kim Peters	Orsted
Jennifer Stucker	Western EcoSystems Technology, Inc.
Allyn Sullivan	TotalEnergies Renewables USA
Timothy White	Bureau of Ocean Energy Management
Desray Reeb	Bureau of Ocean Energy Management

1.2.3 Priorities for Bird Monitoring

The memo written to meet the objectives of Task #1 identified the following goals for bird research and monitoring efforts in relation to OSW facilities in the United States, categorized into four main topic areas (after Southall et al. 2021). These topic areas were used to organize workshop discussions during the first session.

1.2.3.1 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 (Rijkswaterstaat 2016; Allison et al. 2019; Cook et al. 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); and
- Understand the drivers of marine bird[1] distributions and offshore migration of non-marine birds (Cook et al. 2021).

1.2.3.2 Conditions and Stimuli

This category focuses on the characteristics of OSW 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); and
- 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).

1.2.3.3 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 (Rijkswaterstaat 2016);
- Investigate diurnal and nocturnal collisions and flight behavior (e.g., micro-avoidance) in close proximity to OSW turbines (May et al. 2017; Cook et al. 2021); and

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[1] 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)

- Examine changes in marine bird foraging activity and/or energetics due to OSW development and correlations with changes in prey (NYSERDA 2020; JNCC 2021).

1.2.3.4 Consequences and Long-Term Research Priorities

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

- Assess the fitness and demographic consequences of cumulative collisions/displacement at OSW facilities (Skov et al. 2018; Allison et al. 2019); and
- 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).

2 Uncertainty and Limitations by Data Type

SMEs identified several data needs and bottlenecks that were associated with general types of monitoring data (e.g., distribution and abundance, collisions and flight behavior, environmental drivers, and fitness and demography), as well as with the use of specific technologies (Section 3, below).

2.1 Distribution and Abundance Data

Discussion of the limitations of data used in distribution and abundance modeling primarily focused on issues of scale, temporal variability, and reduction of uncertainty. Obtaining sufficient data to develop high quality models of distribution and abundance often requires accumulating data over long periods of time or multiple seasons (McPherson et al. 2006). Therefore, it can be difficult to capture intra-seasonal or inter-annual temporal variability in distribution, abundance, or behavior (Winship et al. 2018). Additionally, the spatial scale of data collection can greatly influence how it can appropriately be used (McPherson et al. 2006). For example, many models are developed at large spatial scales and are for seasonal time periods, which can be of limited utility for decision-making processes at finer spatial scales (such as micro-siting of turbines) or temporal scales (such as the timing of certain activities to minimize the potential for wildlife interactions). In addition, it is often difficult to incorporate or reduce statistical uncertainty for distribution and abundance data. First, accounting for detection and availability biases can be difficult and can require substantial external data sources. Second, distribution and abundance models are often data hungry, and it can be difficult to model rare species, species distributions in areas where they are uncommon, or species that are distributed in highly non-uniform ways. Lastly, the uncertainty in model estimates may be poorly documented and/or difficult to communicate to end users, and there is little standardization of the requirements to validate distribution models, whether internally or using external datasets.

2.2 Collisions and Flight Behavior

Data on flight behaviors and collisions can be used to assess collision risk and inform potential mitigation measures. Data on actual collisions is scarce and can be challenging to collect, particularly in the marine environment (Skov et al. 2018). Substantial amounts of data are needed to understand the environmental conditions that may influence collision or avoidance. Collision risk models have been developed to help assess risk in the absence of real-world data, but validation of these collision risk models is likewise difficult due to the same lack of data (Madsen and Cook 2016). The rarity of collisions likely means that long-term and large-scale monitoring studies are needed to collect sufficient collision data (Skov et al. 2018). In addition, links between behaviors (e.g., foraging, commuting, different types of flight) and collision risk are largely unknown, which could impact our understanding of collision risk from a behavioral perspective.

The technology to detect collisions is relatively new and is not well established, however; collision monitoring is particularly difficult in poor weather and at night, and for detecting collisions and micro-avoidance in small-bodied species at substantial distances from cameras (Dirksen 2017). Non-camera systems, such as impact detection sensors, exhibit limitations based on sensitivity and signal-to-noise ratios (as the turbine itself also produces vibrations).

2.3 Environmental Drivers

Understanding the environmental conditions that influence bird distributions, abundance, and/or behavior requires the collection of environmental data at a spatial and temporal scale relevant to birds. Specifically for pre- and post-construction data, SMEs highlighted the importance of collecting data on weather and/or sea state, which are often lacking, alongside bird observation data.

2.4 Fitness and Demography

Fitness and demographic data are used to inform population models and consequence models. SMEs identified the importance of collecting demographic data for immature and juvenile age classes, as well as adults. Additionally, they noted that demographic models are often limited by a lack of understanding of population processes such as density dependence and immigration/emigration, as well as the effects of environmental stochasticity and climate change. These limitations can lead to difficulty when estimating parameter values and identifying trends.

3 Uncertainty and Limitations of Bird Monitoring Technologies and Methods

In addition to the broad data limitations mentioned above, SMEs discussed a wide range of specific monitoring technologies and their associated uncertainties. Technologies and methods were categorized broadly as “monitoring systems” if they measured some biological property of birds, and “monitoring platforms” if they served as hosts for such systems. For example, an OSW turbine could serve as a platform for a thermal camera system used to monitor bird movements. Monitoring systems identified by SMEs included tags and other bird-borne sensors, radar, cameras, physiological sampling, population monitoring technologies and methods, artificial intelligence (AI), observational transect surveys, habitat and prey monitoring technologies and methods, several types of models, passive acoustics, and LiDAR. Each of these monitoring systems are discussed below (listed in no particular order).

3.1 Tags and Other Bird-Borne Sensors

3.1.1 Description

This category includes all transmitters and sensors that are designed to attach to birds. The capacity of these technologies varies but can include the ability to provide data on animal locations, movement speed, and other metrics. Behavioral and physiological data can also be obtained, including flight height, heart rate, and accelerometer data, which can be used to identify behavioral states. Technologies identified by SMEs with utility for offshore monitoring included automated radio telemetry (“Motus”; https://motus.org/), GPS and satellite transmitters, and geolocators, as well as accelerometry tags, time-depth recorders, and heart rate monitors. Networked tagging (in which tags deployed on larger-bodied birds are used to communicate with and download data from smaller transmitters) was also identified as a potential technology.

3.1.2 Uncertainties and Bottlenecks

SMEs identified power limitations, lower limits on tag size, and resolution of location data as major bottlenecks across multiple tag types. Battery life often enforces a tradeoff between high sampling rates and long-term deployments, thus limiting the ability of transmitters to either collect data at a fine enough spatiotemporal resolution to answer questions of interest or to collect data for long durations (Clements et al. 2021). Data may be of insufficient spatial resolution to answer fine-scale ecological questions when tags have low sampling rates or variable duty cycles (Ryan et al. 2004). For example, infrequent sampling rates could impact the ability to obtain positions at the spatial scale of a single turbine or wind facility to understand behaviors and smaller-scale movements. However, if the duration of tag recording is sacrificed for higher sampling rates, data may only be obtained for a portion of an individual’s habitat use. For example, if birds are tagged with short-duration tags at nesting colonies, post-breeding distributions may not be captured in the dataset. These power limitations are partially dictated by the size (e.g., weight) of transmitters. In the U.S., there is a rule of thumb that transmitters or other sensors deployed on birds should cumulatively represent no more than 3% of the individuals' body weight (Bird Banding Laboratory 2018). Given that birds are hollow-boned and thus very light for their size, this bird safety measure drastically limits the types of sensors that can be deployed on small-bodied species. Even for larger-bodied bird species, some GPS and satellite tags cannot be deployed on smaller individuals, which can limit data collection to specific age classes, sexes, or other subsets of the population. As a result, gaps in bird-borne data exist for many species and groups. There is also the potential for bird-borne sensors to affect bird behavior, either due to capture effects or long-term effects of carrying the sensor, which could lead to harm to birds or to biases in resulting data if researchers are not careful.

Tag resolution, which broadly includes accuracy and precision of locational data, temporal resolution, and transmission limitations, was identified as a limitation or bottleneck for all tags and bird-borne sensors. GPS tags have the greatest locational accuracy and precision, but spatial uncertainty in three dimensions (e.g., vertical altitude estimation) was still identified as a limitation for this technology, which can have poor altitude accuracy depending on factors such as the type of tag and frequency of locational fixes (Lato et al. 2022). Satellite tags can be lighter than GPS tags but typically have lower spatial accuracy and very limited ability to estimate three-dimensional locations. Light-level geolocators are smaller than both GPS and satellite tags, but have much larger spatial uncertainty (on the order of several hundred miles, depending on location and time of year) so they are currently best suited for identifying only very large-scale movement patterns such as general migration routes (Halpin et al. 2021). Resolution of geolocator data can be particularly poor near the equator and at the equinox, since location is based on the amount of light detected by the sensor. Light-level geolocator tags are also archival, so animals must be recaptured to download the locational data. Some other small tags with better locational accuracy also exist, but likewise have power limitations that may require data to be logged rather than transmitted remotely, requiring recapture or detection by a local base station. Motus tags, which can also be very lightweight, do not provide spatial locations at all, but rather are detected when a tagged animal comes within range of a receiving tower. In addition to requiring a network of receiving stations, this technology requires additional R&D to determine how to model three-dimensional location estimates based on detection data. Regardless of tag type, the use of these data for specific questions of interest often requires managing tradeoffs between the precision of fixes, number of locations, and tag size.

Pressure sensors can be deployed alongside or can be integrated into GPS transmitters to improve altitude estimation, but require validation with known pressure measurements (Lato et al. 2022). Transmission limitations were identified for tags which require proximity to a tower or detector to obtain data as well as for archival tags which require recapture and manual data download. Examples include Motus tags, where the detectability is affected by flight height, and networked tagging technologies, which are limited by network proximity. Any tag that requires detection by a receiver is limited by the number and density of tracking stations. Archival tags include geolocators, time-depth recorders, pressure sensors, and accelerometers, and their requirement to recapture the bird to retrieve data limits the utility of these technologies. Bias towards birds that can be reliably recaptured limits our data collection outside of the breeding season, and often leads to low sample sizes for hard-to-capture bird species.

Regardless of tag type, SMEs also noted the need for improved waterproofing and ruggedizing of tags being used in marine environments, as well as the need for improved long-term and noninvasive tag attachment methods.

3.2 Radar

3.2.1 Description

This category includes all radar that can be used to track birds including marine radar, NEXRAD weather radar, 3-dimensional radar, and aircraft detection lighting systems (ADLS). Radar can broadly be used to detect bird echoes, but specific radar technologies may also provide data on individual bird trajectories, flight height, direction, speed, and wing beat pattern and frequency (which can help to identify animals to general species group in certain cases). Integrated systems that include radar as well as other technology such as cameras also exist and can help to address some of the limitations inherent to radar-only systems.

3.2.2 Uncertainties and Bottlenecks

The primary bottlenecks identified by SMEs included environmental and detection limitations, limitations based on radar resolution, lack of species identification capabilities, and hosting and storage bottlenecks. Environmental and detection limitations include both external environmental factors such as weather conditions that impact radar performance, as well as intrinsic limitations in the radar scanning area such as blind spots. Sea clutter, waves, and weather limit most radars (Kelly et al. 2009). Radar performance is further limited by detectability: for marine radars, for example, the scanning region is limited in the area directly surrounding the technology, and blind spots and shadows from turbines or other structures can impact detection around structures (Kelly et al. 2009).

No radar system described in the workshop can identify birds to genus/species level; this is perhaps the greatest single limitation to this monitoring approach. Radar resolution was also identified as a major bottleneck for obtaining accurate bird detections. Successful target detection is a limitation for both marine and NEXRAD radars, and detection of bird targets using ADLS is still largely hypothetical. Target detection is also size-limited, where smaller targets could be clouded by insect echoes, and systems such as ADLS that rely on detections to initiate monitoring may not be triggered for small targets. Complications with detection include limitations when bird orientation varies relative to radar position, the ability to distinguish individual birds within flocks, identification for small-bodied individuals, and possible influence of masking or clouding by insects. Lastly, while altitude estimates from some radars are reliable (e.g., marine radars), others exhibit large uncertainty, and the detection range and shape of detected area of some radar systems can bias flight height and bird flux estimates.

Radar implementation is limited by installation and platform requirements, and storage, including data downloading and processing. Installation can be difficult to execute, particularly for systems that are proprietary designs. Radar weight/size and the requirement for a stable platform also limits the types of structures suitable to host radar systems. In the marine environment, there are limited stable structures on which to install radars, and the environment is harsh for technology. Therefore, any lack of ruggedness or waterproofing limits the feasibility of radar installation in the marine environment. SMEs also identified the difficulty and importance of calibrating between radar systems when multiple systems are installed. Lastly, the amount of data produced by radar units requires substantial effort to download, host, analyze, and maintain in offsite storage, and there are no current industry standards for storage and data review.

3.3 Physiological Sampling

3.3.1 Description

This category includes the sampling and monitoring techniques used to obtain data on bird physiology, including stress, diet, temperature, sex, and body condition. Techniques and technologies identified by SMEs included environmental DNA, diet analyses, stable isotope analyses, deployment of internal sensors, and physiological metrics including cortisol, the heterophil-to-lymphocyte ratio, and body condition indices (the latter three collectively hereafter referred to as stress metrics).

3.3.2 Uncertainties and Bottlenecks

The ability to obtain, store, and process physiological samples was identified as a bottleneck to successful physiological data collection. The time and effort investment to obtain sufficient sample sizes for analysis for many of these techniques is substantial. Obtaining data can be difficult, particularly for techniques that require technology deployment, such as internal sensors, or techniques that are time-sensitive, such as obtaining physiological stress samples soon after capture (so as not to influence stress metrics). Data are often collected in rugged environments, so sensitive sample storage and transport requirements, for example inappropriate temperatures, could limit successful data collection. The training and permitting requirements to conduct data collection that requires animal handling can also be extensive and could influence the ability to collect these data in multiple regions and on a range of taxa. Additionally, methods such as environmental DNA, stable isotope analysis, and stress metrics all require validation or calibration with external datasets, which can include further laboratory studies and calibration, baseline data collection, and reference library availability.

SMEs also identified multiple biological limitations relating to data collected for physiological sampling. The ability to detect drivers of responses was highlighted as a difficulty generally for physiological sampling. There are complex individual responses to environmental conditions, particularly for stress metrics. In addition, isolating changes being driven by OSW energy development from those driven by background variability will be difficult for physiological data.

3.4 Cameras

3.4.1 Description

Camera technologies include visual or thermal detection systems for birds that are mounted on structures or platforms and can either record continuously or be triggered by bird detections or other signals (cameras placed on aircraft for observational surveys and on birds themselves are addressed in Sections 3.6 and 4.5 of this report, respectively). Camera technologies can provide data for micro-avoidance and collision detection, species identification, and group size. Cameras can be remotely controlled and can operate year-round with relative ease. Camera technologies identified by SMEs include standard red-green-blue (RGB) systems, thermal systems, and dual RGB-thermal systems.

3.4.2 Uncertainties and Bottlenecks

SMEs primarily identified broad limitations that apply to all camera systems, indicating that many camera technologies are limited by similar factors. Detecting (and identifying) birds in camera footage requires a combination of resolution and range. Camera resolution is a trade-off between image resolution and field of view, so higher resolution imagery tends to cover a very narrow slice of airspace, and concerns arise regarding the ability to obtain adequate sample sizes (as well as double-counting individuals that fly in and out of the field of view). In addition, many cameras have limited detection ranges, which can vary based on weather conditions such as fog and rain. Sea spray and other environmental conditions may also physically impair a camera's range or resolution, which limits detectability. For example, variation in ambient temperature affects image quality, and all systems other than thermal cameras are unable to operate successfully at night. Thus, bird detection at longer distances, for smaller-bodied individuals, and in poor weather conditions can be challenging or impossible, and identification to species level for detected individuals can be even more difficult than detection itself. Validating the detection capabilities of camera systems is important, but this can require large amounts of data under varying weather conditions, and as noted above, sample size can be a challenge with these systems. In addition, the camera systems developed for deployment on turbines require careful coordination with turbine owners and platform operators.

Imagery can be either continuously recorded (to minimize missed detections) or through triggered detections (which reduces data storage requirements but poses the risk of missing detections). Local data storage can be a challenge, and there is often limited capability to access data remotely (given the large size of files for most visual data). Once data are acquired from the system, the manual processing time is often substantial and there are currently no industry standards for image review.

3.5 Population Monitoring Technologies and Methods

3.5.1 Description

Population monitoring technologies broadly encompass any methods or technology used to assess habitat, population size and demographics, or large-scale species distributions over time. Technologies or methods identified by SMEs include colony-based monitoring, doubly-labeled water, mark-resight methods, remote imaging of colonies, and color banding for survival estimation, among other methods. Population monitoring for marine birds often occurs at breeding colonies; obtaining reliable information on population trends and demography can be quite difficult even at breeding colonies, and these challenges are often magnified for species that nest individually.

3.5.2 Uncertainties and Bottlenecks

Temporal changes in population size or demographics may be due to environmental or climate change drivers, interannual variability, sampling bias, or other factors (Reif 2013), and SMEs stated that determining the drivers of population variability or trends was difficult to achieve and is therefore a bottleneck. In addition, SMEs stated that accessibility to research sites for population monitoring (including breeding colonies as well as remote nesting sites) was also a limitation. Conducting colony counts and other monitoring at nest sites is also difficult for logistical reasons, and SMEs indicated difficulties with access to remote imaging data for colonies to conduct remote counts.

Successful monitoring relies on birds being available to be counted, which is difficult for rare species with low detectability, specifically for mark-resight procedures, and for techniques such as colony monitoring and doubly-labeled water which rely on seasonal presence of breeding adults at colonies. In addition, some methods such as doubly-labeled water require recapture of the animals, which can be quite challenging in general and can be particularly limiting for rare species. Lack of data on population dynamics such as density dependence and immigration/emigration is also a key gap that hinders effective population modeling and analysis.

3.6 Observational Transect Surveys at Sea

3.6.1 Description

Observational survey methods identified by SMEs in relation to OSW included both boat-based surveys and digital aerial surveys. These approaches are generally focused on identifying the distribution and abundance of bird species or communities. Survey data can inform general habitat use and distribution or can be integrated into more complicated statistical models to estimate density and abundance.

3.6.2 Uncertainties and Bottlenecks

The primary bottlenecks identified for surveys were generally related to weather conditions and planning and coordination. Conducting surveys in adverse conditions is difficult and can be a human safety hazard. However, data from poor weather periods is necessary to understand bird behavior and potential risk under those conditions. For OSW energy areas specifically, there may also be restrictions on vessel or plane operations in areas with turbines.

For boat-based surveys specifically, SME feedback focused on variability in observer quality. Observers undergo varying levels of training and operate at different skill levels. This can lead to varied estimates for field measurements, particularly for metrics that are difficult to measure by eye, such as flight height (Largey et al. 2021). Digital aerial surveys are a relatively less biased way of obtaining bird flight height data, and observer biases in detection and identification can be quantified by conducting blind re-reviews of imagery. The cost of digital aerial surveying and post-processing is high, but digital aerial surveys become more cost-effective relative to vessel-based surveys for larger survey areas located farther offshore. There is also a tradeoff in the design of digital aerial surveys between ground sampling distance (the number of image pixels representing a given spatial area on the ground or at sea, which affects species identification rates) and the amount of area that can be covered by the camera’s field of view (thus determining the sample size of observations). In addition to reducing the field of view, higher ground spatial resolution typically involves lowering the altitude of plane operations, which can impact human safety and ability to operate near wind turbines.

3.7 Artificial Intelligence

3.7.1 Description

AI, in the context of workshop discussions, includes a variety of methods in varying stages of development that are focused on the detection and identification of birds in monitoring data obtained from cameras, radars, or other passive monitoring equipment. AI technologies include detection, classification, and tracking algorithms for imagery from digital aerial surveys, camera and radar systems, and other data types.

3.7.2 Uncertainties and Bottlenecks

To successfully develop AI programs for both classification and detection, a substantial amount of training data must be stored, hosted, and analyzed. As a result, human input for training as well as validation can be costly. In addition, the ability to develop algorithms for species identification and to subsequently evaluate error rates was identified as a very complex process and a bottleneck to successful deployment of AI.

SMEs also indicated substantial limitations relating to environmental and biological sources of variability as well as nuances of detection and identification. To successfully replace human observers, AI must be able to reliably detect birds from imagery, distinguish between biotic and abiotic targets, and differentiate bird species. Specifically, it must quantify the characteristics that distinguish species to recognize individuals of the same species in a wide range of body poses, shapes, life history stages, and other circumstances, and do so in a wide range of weather conditions that may affect detectability as well as identification. However, successful AI can greatly reduce the cost and labor to manually review imagery.

3.8 Habitat and Prey Monitoring Technologies and Methods

3.8.1 Description

Habitat and prey monitoring is intended to characterize the distribution, abundance, and characteristics of birds’ prey and the habitat-based drivers of prey distributions, abundance, or availability that may in turn impact birds. Data obtained from habitat and prey monitoring can inform understanding of phenological shifts in bird distributions through time, health and body condition, and indirect impacts of climate change on birds, for example. Technologies identified by SMEs for use in habitat and prey monitoring include underwater imagery, active acoustics (e.g., echosounders), midwater- and bottom-trawls, ambient acoustic sensors above and below water, remote sensing, and oceanographic modeling to develop prey-environment relationships, among other technologies.

3.8.2 Uncertainties and Bottlenecks

Species identification of prey taxa can be a challenge and is not possible using active acoustics alone. Additionally, underwater biomass may not always be correlated spatially or temporally with biomass near the water's surface, which is where prey are available to be detected and captured by marine bird species. There are systematic, long-term, and large-scale sampling datasets using midwater and bottom trawls (e.g., National Oceanic and Atmospheric Administration Northeast Fisheries Science Center seasonal bottom trawl: www.fisheries.noaa.gov/inport/item/22557), but these trawls focus on obtaining data on commercially fished species rather than forage fishes. Benthic fish species that burrow into sediments, such as sand lance, may also be important prey species for marine birds and are poorly sampled using these methods (Suca et al. 2021). SMEs identified a particular lack of prey monitoring at similar spatial and temporal scales to that at which marine birds make their foraging decisions, which limits our understanding of bird-prey relationships.

Limitations were also identified for remote sensing opportunities to better understand prey distributions. While prey populations may exhibit relationships with remotely sensed data such as sea surface temperature, eddy presence, and chlorophyll *a*, it has proved challenging to validate predictions of distributions derived from these environmental variables. In addition, due to the highly dynamic nature of marine environments, dynamic spatial modeling is important to understand risk and distributions of prey through time (Maxwell et al. 2015), but these models are extremely data-intensive.

3.9 Models

3.9.1 Description

Models include any mathematical representations of bird or ecosystem characteristics. Modeling techniques provide statistical representations of underlying data to inform many aspects of bird behavior, distribution, and demography. SMEs discussed behavioral movement models (such as hidden Markov and state-space modeling), individual-based models, energetics models, population models, and ecosystem-based modeling.

3.9.2 Uncertainties and Bottlenecks

The primary bottlenecks identified by SMEs included limitations based on data and limitations in the review and standardization process. Models typically require extensive underlying data that can be difficult to obtain, especially in a standardized manner with sufficient temporal sampling (if applicable). There are often limitations to the demographic data available to inform population models, for example, and distribution models are often limited to describing specific life history stages such as the breeding season. Lastly, multiple data sources may be available (e.g., tracking data and observational survey data) but are difficult to combine into singular models; models that could better integrate these disparate data sources could be powerful for informing the understanding of bird behavior and distributions.

3.10 Passive Acoustics

3.10.1 Description

Passive acoustic monitoring for birds involves the deployment of full-spectrum acoustic sensors with microphones that record sounds, including bird calls. These recordings can be used to identify the species present at a site, including nocturnal migrants that emit “flight calls,” short vocalizations during migratory flight. Recording can occur any time of day or night, though subsampling is often required due to data storage limitations. Recordings typically must be manually downloaded from recording systems and manually reviewed to identify calls to species level, though there are filters that can help to detect bird calls and separate them from other sources of sound in the environment.

3.10.2 Uncertainties and Bottlenecks

Passive acoustic detectors require a platform for deployment. Turbine operational noise makes deployment of passive acoustic detectors for birds difficult on these platforms. In addition, passive acoustic detectors can have quite limited detection ranges. As detection ranges and call rates are poorly understood, passive acoustic data provide evidence of species presence at a site, but cannot provide definitive absence data, and are not suited to obtaining information on abundance or densities of species of interest.

3.11 LiDAR

3.11.1 Description

LiDAR (Light Detection And Ranging) is a type of remote sensing that uses a laser to measure distances to objects, including particles in the air. Doppler LiDAR systems are deployed on buoys during offshore wind site assessment processes to estimate wind speeds and directions. The LiDAR laser also bounces off other objects in the atmosphere, including birds, and thus can be used to estimate the flight height of birds that pass through the vertical laser beam.

3.11.2 Uncertainties and Bottlenecks

LiDAR limitations are similar to those identified for radar systems, including requiring a platform for deployment and issues involving clutter and filters. Additionally, LiDAR capabilities for wildlife monitoring are currently not well understood, but may be limited for detection of small-bodied birds. Airborne LiDAR (in which the system is pointed downward from an aircraft to detect the flight height of birds below the plane, rather than pointing upwards into the sky) is also costly to deploy.

4 Limitations Associated with Monitoring Platforms

SMEs identified a range of platforms that could host the above monitoring systems, including offshore wind turbines, buoys, and substations, as well as unoccupied aerial systems (UAS; or drones) and birds themselves. SMEs did not discuss platforms as technologies in and of themselves but did identify bottlenecks and limitations associated with the deployment of the above bird monitoring systems on these platforms.

4.1 Turbines

Turbine installations have multiple opportunities for the inclusion of bird monitoring technologies such as cameras, radars, and receiving stations (e.g., Motus). The primary limitations identified by SMEs were mounting logistics, maintenance, and technology-specific bottlenecks. There were many logistical limitations identified for installations and mounting of technologies on turbines, including reliable power sources, a lack of standardized holes or ports for installation, complex cabling systems, and limited space for installation. Not all turbines are expected to have dedicated space for technology installation. The timeline for turbine development and installation also occurs on a different timeline than the availability or development of bird monitoring plans; if turbine engineering specifications are defined multiple years prior to construction, then monitoring plans must be defined on a similar timeline, which is not only difficult to do but increases the likelihood of using outdated technologies.

Additional limitations include data management concerns, particularly relating to difficulties with both transmitting data remotely and with manual retrieval, as well as concerns relating to potential voiding of turbine warranties by adding monitoring systems or altering turbines to host such systems. SMEs indicated that there are stringent health and safety certifications required for access to turbines, and there will likely be limited visits to technology installations conducted by OSW employees. It is also likely that bird technology maintenance will be secondary to turbine maintenance and operations. However, remote transfer of data using turbine systems elicited concerns about cyber security. Turbine noise, electromagnetic interference, and presence as line-of-sight metal objects were also indicated to impede bird monitoring systems in various ways.

4.2 Buoys

Buoys are a platform of opportunity for additional deployment of bird monitoring technologies in and around OSW lease areas, and are one of the only platforms reliably available in wind lease areas prior to construction. Bottlenecks in the use of buoys as bird monitoring platforms that were identified by SMEs primarily focused on installation and operations of monitoring systems. First, buoys have very limited space and power access. Second, because buoys move, it is necessary to consider system stabilization requirements to use cameras or radars on buoys. And third, once a buoy is deployed, there is often very limited access for maintenance and data downloads, suggesting the importance of fully remote system health checks and data acquisition or, at minimum, a capacity for line-of-sight data transfer.

4.3 Offshore Substations

Offshore substations (also known as electrical service platforms) export turbine-generated power to shore through underwater cabling. SMEs identified that these substations may be more accessible than turbines for routine access and maintenance, but technologies deployed on substations will not be able to provide data on turbine-specific interactions such as collision and avoidance. SMEs also identified similar logistical limitations for deployments of bird-specific sensors or technologies on substations as on turbines, noting issues such as electrical limitations, the space required for some monitoring devices (for example, radar), and possible physical or electrical interference with other installed systems on the substation. As with turbines (above), they also identified potential concerns about substation warranties and timing of substation design relative to the timing of ecological discussions. Designs for these substations are put in place well in advance of deployment, and the addition of bird sensors may become increasingly difficult and expensive after the design is complete.

4.4 Drones and Unoccupied Aerial Systems

Drones and UAS include both fixed-wing and rotor-based aerial platforms. UAS typically have RGB or thermal cameras installed, though other technology installations such as LiDAR are possible. UAS are not routinely used in bird research relating to OSW energy development, though several limitations were identified that could improve the utility of UAS for bird monitoring and research.

SMEs indicated that the primary reasons that UAS are not routinely used in bird research are 1) limitations on flight duration, and 2) altitude regulations. Flight duration, which is limited by battery size and power availability, is typically low for most rotor-based UAS. Flight altitudes are currently limited in United States airspace by the Federal Aviation Administration. Low flight altitudes could impact or alter the behavior of nesting and staging birds, and altitude limitations for both rotor-based and fixed-wing systems could impede the ability to detect birds that fly above regulated limits or the ability to fly the platforms in the vicinity of turbines. Environmental factors such as wind speed and precipitation also limit the use of UAS in marine environments. The size and payload of UAS was also identified as a bottleneck, as multi-system monitoring or installation of heavy technology is not currently possible on most UAS.

4.5 Birds

Birds can serve as a technology deployment platform to measure behavior, distribution, and other information of interest. Many of the limitations and bottlenecks of bird-borne deployments are discussed in the tagging section (Section 3.1, above). SMEs reiterated the need for smaller tags, long-lasting power sources (particularly when solar tags are not an option, for example if tag deployment occurs on the underside of the tail or if animals are nocturnal), and safe and effective long-term tag attachment methods. Additional uncertainties and bottlenecks identified by SMEs related to permitting and access restrictions for use of birds as technology platforms, as well as the potential for sampling bias.

Access restrictions include permitting requirements, such as specific limitations put in place for species that are endangered or are under other state or federal protections. Logistical limitations may also prevent tag deployment at certain time periods or locations, such as during chick rearing or when there are geographic limitations impeding researcher access to nesting sites. This can lead to reduced sample sizes or biases in temporal or demographic coverage. Individual and cohort behaviors can also impact the ability of researchers to capture and tag birds. Subadults, for example, are notoriously more difficult to capture and monitor than their adult counterparts.

5 Potential Solutions

5.1 General Solutions

There was broad agreement among SMEs about the top priorities and potential solutions to many of the technology-specific bottlenecks identified above. SMEs indicated that engaging with wind energy projects and turbine manufacturers as soon as possible, preferably several years prior to construction, is important to streamline and facilitate the operationalization of turbine- or platform-based monitoring at OSW sites. SMEs also focused on the importance of standardization and flexibility in platforms and technologies, including designing systems to be able to operate on different countries' electrical systems and a common need for front-end engineering for common scientific research needs on platforms.

Identifying how technologies can complement each other and increasing the rapidity of technology prototyping to the scale of months, rather than years or decades, could help facilitate better adoption of monitoring technologies, including on OSW structures. SMEs recognized that it is not feasible to prioritize every monitoring method and suggested that it could be worthwhile to prioritize further development of technologies that are able to inform potential mitigation strategies as well as documenting effects. It was also suggested that the development of government requirements for data sharing protocols, standards, or platforms could help to drive collaboration and innovation. Ultimately, a combination of prioritization, cross-sector coordination and streamlining, and acceleration of development and testing timelines were recommended to improve bird monitoring technologies.

5.2 Systems

5.2.1 Tags and Other Bird-Borne Sensors

SMEs suggested that R&D priorities for tags and other bird-borne sensors include:

- Increased reliability
- Improved accuracy of altitude measurements
- Further miniaturization of tags and improved battery life relative to tag size
- Improved waterproofing across all tag types
- Remote download capabilities

Tag integration was highlighted as a potential solution to some existing technological limitations, for example by improving integration of altimeters or pressure sensors with other tag types to obtain more reliable altitude data. The combination of solar power and battery operation in tags could allow for tracking of nocturnal movements, and the inclusion of mortality sensors into a broader array of tag types could increase functionality. Lastly, SMEs noted that the use of a common Motus frequency with a consistent, well documented power output for Motus tags could improve functionality for that specific technology.

5.2.2 Radar

SMEs suggested several R&D priorities to improve radar technologies, including:

- Improved filtering and/or masking of clutter, and
- Understanding of the limitations of radar systems, specifically in rain and strong winds.

Standardization was also mentioned multiple times, particularly for coordination of simultaneous data collection, as well as a suggestion to adopt state-of-the-art target discrimination systems to improve radar performance. Standardization of data management processes was recommended, including the development of a public database for storing and sharing radar data. A need was also identified for radar practitioners to communicate radar system capabilities and limitations more clearly, including limitations surrounding bird flocks and wind turbine shadows, for example. SMEs suggested integrating radar with thermal or camera imaging systems, as well as possible integration of tracking and radar, in order to address some of the limitations (specifically around species identification) of radar-only systems.

5.2.3 Physiological Sampling

SMEs suggested focusing on validating less-invasive sampling methods (e.g., using feathers instead of blood for some analyses) and identifying opportunities for long-term data collection as part of broader monitoring programs.

5.2.4 Cameras

SMEs identified the need to compile information on different camera systems and to compare the benefits and drawbacks of the available systems (a task which will be part of this project's Task #3 efforts to develop a technologies database). SMEs suggested including detailed information on technical specifications for cameras, sensors, and processing. In addition, SMEs mentioned standardizing data formats and mounting options for cameras to streamline collaboration and deployment, and exploring the use of thermographic stereo cameras.

5.2.5 Population Monitoring

SMEs suggested focusing population monitoring in part on connectivity between populations. Additional information and modeling of connectivity could identify populations impacted by OSW. It was suggested that coordination with projects such as the Migratory Connectivity Project (www.migratoryconnectivityproject.org/) or other global scale research could help to improve connectivity models. Tracking and banding data could also be used to further inform connectivity models. There was also interest in long-term strategies such as gathering and standardizing historical data, pursuing full life-cycle approaches to data collection, ensuring standardization across population monitoring projects, and developing protocols for censusing and productivity estimates that use less labor-intensive methods such as remote analysis.

5.2.6 Artificial Intelligence

There were multiple opportunities proposed by SMEs for improving AI technologies, primarily focused on improving collaboration. Collaboration and sharing of algorithms and machine learning approaches could be tied to funding by requiring some form of open-source sharing of methods and results, or by developing a collaborative forum for those working in the AI space. Sharing imagery for use as training datasets could also help support the development of multiple AI technologies.

5.2.7 Observational Transect Surveys

SMEs highlighted possible solutions to survey limitations including replacing surveys with alternative monitoring technologies or increasing collaboration and communication between relevant parties to execute effective surveys. Suggested alternative survey technologies included use of satellite imagery as well as drones to collect aerial imagery. In addition, increased collaboration was recommended on multiple axes: communication between surveyors for multiple taxa could improve survey outcomes particularly when taxa are expected to interact (e.g., foraging birds and whales); collaboration with statisticians could improve the quality of survey design, and therefore the utility of data for modeling purposes; and broad coordination between surveyors could optimize costs and data collection across projects.

5.2.8 Habitat and Prey Monitoring

Possible steps to improve habitat and prey monitoring identified by SMEs include regular collaboration across taxa for survey planning, as mentioned above, as well as improving species identification and validation of prey types from active acoustics data.

5.2.9 Models

Possible solutions to current modeling limitations that were identified by SMEs included developing best practices for applying and evaluating different model types, improving data sharing and centralization, and sourcing species with large tracking datasets as candidates to integrate tracking and survey data.

5.2.10 Other

SMEs noted the importance of coordinating satellite internet or other connectivity options to remotely acquire data from offshore monitoring equipment. SMEs also suggested the need for a properly designed collision and avoidance study to measure actual collisions and validate collision risk models.

5.3 Platforms

SMEs made the recommendation to design a universal science “platform” to more efficiently and effectively deploy monitoring technology on turbines. Standardized technology deployment areas could be engineered into turbine designs and include standardized electrical and network connections, including a parallel network to accommodate wildlife monitoring and keep those data separate from the turbine Supervisory Control And Data Acquisition system. This would facilitate important capabilities such as remote system checks and data streaming. By having a standardized location (or set of locations) and built-in capacity for monitoring technologies on turbines, it was felt that technology developers could design monitoring technologies to meet a common set of specifications, and it would be easier to make monitoring decisions on a different timeline from turbine engineering decisions. To further streamline data collection, maintenance, and data download requirements, it was also suggested to concentrate complementary technologies on a few specific turbines within each wind facility. Ultimately, turbine installations will also simply require working with wind energy companies to increase their comfort with deploying monitoring technologies on turbines.

6 Conclusions and Next Steps

Workshop discussions highlighted a wide range of monitoring technologies, methods, and tools that are available to monitor birds in relation to OSW development. All available technologies and methods have limitations for answering certain types of questions. SMEs provided valuable feedback on these limitations as well as strategies to address them, including recommendations to 1) invest in further R&D to improve and standardize specific technologies, 2) integrate complementary monitoring technologies, and 3) standardize the integration of wildlife monitoring capacity into offshore wind turbine designs (Section 5, above).

The next steps for this project include the development of a technology database, as suggested by SMEs during this workshop, and conducting an additional workshop with turbine engineers, operations and maintenance specialists, and developers of wildlife monitoring technologies to further explore options to integrate monitoring technology with OSW infrastructure and operations. Following these activities, a final report will synthesize project findings and make recommendations for targeted R&D and innovation to improve the efficacy and integration of bird monitoring technologies at OSW facilities.

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