Part III. General Study Design Recommendations

Note: This is an excerpt from "*Guidance for Pre- and Post-Construction Monitoring to Detect Changes in Marine Bird Distributions and Habitat Use Related to Offshore Wind Development".* The full guidance document is available at www.nyetwg.com/avian-displacement-guidance

Developed by the Avian Displacement Guidance Committee of the Environmental Technical Working Group, with support from the Biodiversity Research Institute

Citation: Avian Displacement Guidance Committee. 2024. Guidance for Pre- and Post-Construction Monitoring to Detect Changes in Marine Bird Distributions and Habitat Use Related to Offshore Wind Development. Report to the Offshore Wind Environmental Technical Working Group. 100 pp. Available at www.nyetwg.com/avian-displacement-guidance.

Photo credit: Nicholas Doherty

Part III. General Study Design Recommendations

4.0 Key Research Questions

4.1 Key Research Questions to Examine Displacement, Attraction, and Avoidance

Several key research questions focus on understanding potential displacement, attraction, and macro- to meso-scale avoidance of marine birds at OSW development projects (Table 1). These questions are focused on the scale of the individual OSW facility (e.g., extent of wind facility footprint and immediately adjacent areas), such that a project developer might endeavor to answer them as part of pre- and post-construction monitoring efforts.

These questions about changes in habitat use by marine birds were identified as key questions from previous efforts, including the development of a scientific research framework for understanding offshore wind's effects to birds and bats in the eastern U.S. (Williams et al. 2024) and compilation of research needs and data gaps for offshore wind environmental research in the U.S. Atlantic (Regional Synthesis Workgroup 2023). The choice of research question(s) may inform the selection of focal species (Section 5), or conversely, specific taxa of interest that are known to be present at an offshore wind project site may inform the selection of research question(s). The highest priority research questions at a particular site will vary, and there are several sources of variation that should be considered when identifying which research questions to address, including differences among species, seasons, individuals, ages, sexes, stages of the annual cycle, environmental conditions (such as weather and visibility), and facility operating conditions. It is important to incorporate data collection focused on potential causal mechanisms of responses and variation in these responses, regardless of the specific question of interest, so that site-specific data can be effectively used to inform a regional scale understanding of effects and impacts to marine birds from OSW development.

Table 1. *Potential research questions related to marine bird displacement, attraction, and macro- to meso-scale avoidance of offshore wind energy development that can be addressed at the spatial scale of an individual wind facility. "Type" distinguishes between questions focused on changes in distributions and habitat use (D) and changes in movement behavior such as macro- to meso-scale avoidance (M). Potential study methods are defined in Section 6. Sources of variation to consider when examining these questions (e.g., covariates to include in analysis where possible) include species, season, individual, age, sex, stage of annual cycle, environmental conditions such as weather, and facility operating conditions.*

Research Question	Type	Project Phase
Are changes in distributions and habitat use (e.g., displacement/attraction) of marine birds occurring, and if so, what is the magnitude and distance from the offshore wind facility at which they occur?	D	Pre-construction, Operations
Do the occurrence, magnitude, and distance of changes in habitat use vary temporally (e.g., does habituation occur)?	D	Pre-construction, Construction, Operations
Are there changes in foraging or roosting activities of marine birds in relation to the wind facility?	D	Pre-construction, Operations
Is there nocturnal attraction of marine birds (e.g., to offshore wind-related lighting)?	M	Pre-construction, Construction, Operations
Are macro-scale changes in movement behavior (e.g., macro-avoidance) of marine birds occurring, and if so, at what magnitude and distance from the offshore wind facility does this behavior extend?	M	Pre-construction, Operations
Are meso-scale changes in movement behavior (e.g., meso-avoidance) of marine birds occurring, and if so, at what magnitude and distance from the turbines does this behavior extend?	M	Operations

4.2 Using Site-Specific Data to Inform Regional-Scale Questions

The above questions are relevant to the spatial scale of the individual wind facility. However, site-level research should also contribute to a broader regional understanding of displacement, attraction, and avoidance, and the factors that might contribute to the magnitude of these effects. Many fundamental questions about the effects of OSW on marine birds require data from multiple wind facilities. Understanding the potential for cumulative effects of displacement, for example, requires an understanding of variation in displacement effects in relation to site-specific characteristics and conditions.

Questions such as the following require data from multiple wind facilities, including the reporting of specific OSW project characteristics, and/or require a range of data on populations of interest beyond what can be collected by developers at and around individual wind facilities, and are thus outside the scope of this document:

- How do aspects of OSW areas, such as wind facility size and shape and turbine size and spacing, affect the displacement, attraction, and avoidance behaviors exhibited by marine birds?
- How do these effects vary geographically (in relation to distance to shore, water depth, or other variables)?
- How are displacement, attraction, and avoidance exhibited by marine birds at an OSW influenced by the proximity to, and layout of, other OSW facilities in the region?
- What are the causal mechanisms driving changes in behavior (e.g., changes in prey and oceanographic characteristics)?
- Do displacement, attraction, and avoidance of marine birds at offshore wind developments have population-level effects on fitness via changes in energetics or demography?

For data collected at the individual OSW project scale to be most useful in answering regional-scale questions, as well as informing larger meta-analyses, **studies of individual wind facilities should consistently include key ancillary and covariate data, as well as OSW project data[3], in their analysis and reporting on effects.** Explicitly considering environmental, facility, and individual covariates can also help to inform the interpretation of site-specific results when considered in conjunction with data from other sites. For example, data on number of turbines in a wind facility, distance between turbines, vessel activity, and turbine operational status (e.g., when turbine blades are spinning vs. stationary) can help to inform understanding of whether birds respond differently to wind facilities based on these factors (though some data, such as operational status can be commercially sensitive data, depending on the timescale at which data are summarized). In addition to the ancillary data (age, sex, weather conditions, etc.) discussed above, covariate and site-level data to be consistently reported should include (but not be limited to):

[3] Project data is also available in permitting documentation and should eventually become available via the U.S. Wind Turbine Database (https://eerscmap.usgs.gov/uswtdb/). However, difficulties with accessing such data in the European context, especially for older wind energy projects, suggests the importance of also reporting this type of information alongside environmental monitoring results.

- Location information for the wind facility, including latitude and longitude of the centroid, and distance from shore; and
- Wind facility characteristics, including the number and size of turbines, size of the project footprint, and turbine spacing.

Section 8 provides general data sharing recommendations. Section 10.7 and Appendix C include additional specific details on reporting needs. It is beneficial for the entire industry if data collected at the spatial scale of an individual wind energy facility are also useful at a broader regional scale to inform future monitoring and effects minimization. Regional-scale strategic planning is required to identify priorities, improve coordination, and ensure standardization (Section 12). While this is outside of the scope of this effort, the Regional Wildlife Science Collaborative for Offshore Wind (RWSC; rwsc.org) is working to develop science plans to meet these needs.

5.0 Identifying Focal Taxa

Focal species should inform study design and data collection methods, even for study methods that collect information on multiple species simultaneously (e.g., observational surveys). The choice of focal species for understanding displacement, attraction, and avoidance at site-specific scales will depend on research questions of interest (Section 4), characteristics of the particular wind project(s) and location(s) being investigated, and species-specific risk inferred from existing information (see Appendix C and Lamb et al. 2024 for a summary of findings from existing displacement, attraction, and avoidance studies), along with other considerations. Consultation with federal agencies, as well as coordination with other OSW developers in the region of interest, is important to ensure that selection of focal species at individual projects aligns with regional needs. For observational surveys in particular, information on one or more focal species should be used to inform aspects of survey design, such as spatiotemporal coverage and buffer size, but data should be collected on all species observed. Existing data on these focal species should also be used in power analyses during study design to help ensure that research will adequately detect effects (Section 7). Factors to be considered when choosing focal species include exposure, sensitivity to effects, population sensitivity, and uncertainty in our understanding of responses. Definitions for these terms are described below. These considerations can be implemented in a decision tree (Figure 2) to help select focal taxa for study that will best contribute to a broader understanding of offshore wind effects and inform resource management and other decision making. As explained in Section 4.1, the choice of focal species may inform research questions or vice versa. In addition, the degree to which the answer to the research question for a particular species is being addressed by other researchers and OSW developers, the influence and implications of results, and applicability of results across broader taxa, should be considered. This type of coordination should be facilitated by regional science collaboratives and other mechanisms (Section 12).

We also recognize that species of particular conservation and regulatory interest, such as endangered species, may be considered high priority regardless of the additional considerations and decision tree described below. However, studies of species with low exposure (e.g., due to rarity) are prone to having low statistical power to detect effects. When studying endangered species, extreme care is needed during study design to help ensure adequate sample sizes such that studies will be able to detect effects, should they exist.

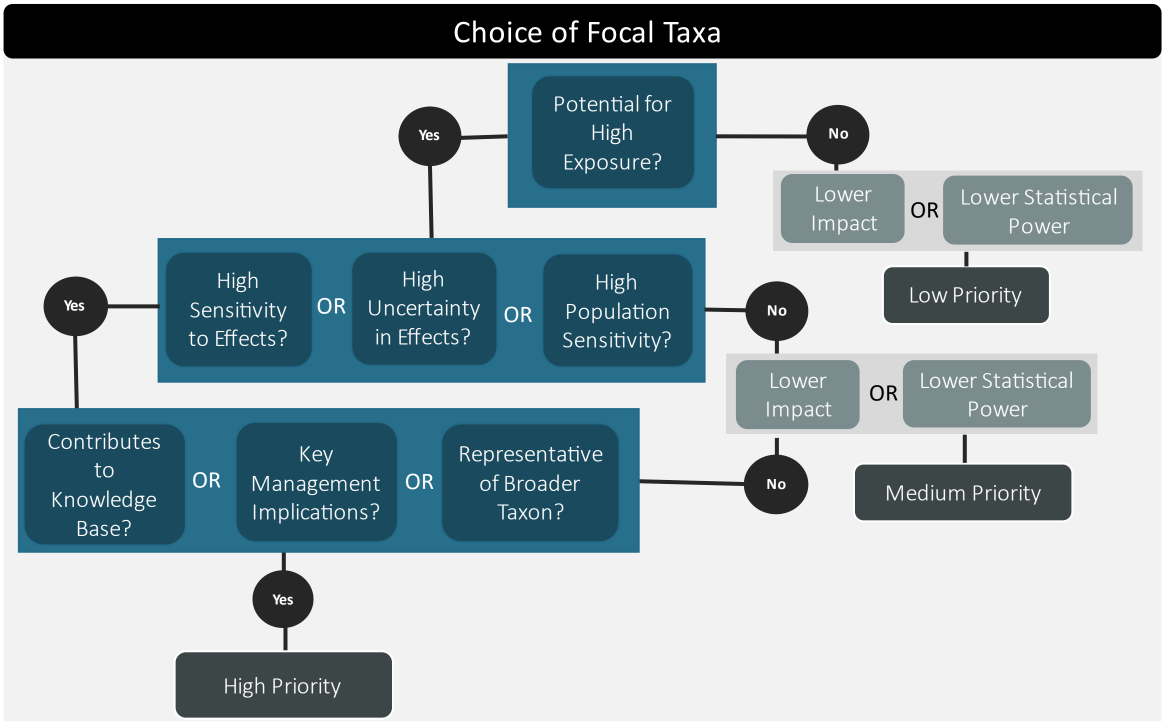

Figure 2. *Decision tree to inform the choice of focal species for displacement, attraction, and macro- to meso-scale avoidance studies at offshore wind development sites. Definitions for the terms used in this figure are described below.*

5.1 Understanding Exposure

Exposure can be defined as the frequency and duration of contact or co-occurrence between an offshore wind stressor or activity and an environmental receptor (i.e. an individual animal, group, population, or community) that may allow the stressor to act on the receptor in some way (Goodale & Milman 2016). Exposure relates to the abundance, distribution, and behavior of species in the focal geography, which dictate the potential for them to be exposed to offshore wind energy development. In the case of avoidance, displacement, and attraction, the key offshore wind stressor is the presence of offshore wind structures, as well as vessel traffic (Dierschke et al. 2016). Exposure can be assessed in multiple ways but should be informed by existing regional information on the abundance and distribution of species, including modeled seasonal relative abundance of species (Marine-life Data and Analysis Team, or MDAT; Winship et al. 2018), existing survey data for the area of interest from the Northwest Atlantic Seabird Catalog, and available tracking data (such as those archived in Movebank), as well as site-level information collected during the site assessment process and consultation with regional experts. Exposure is a particularly important factor to consider as it is directly related to the statistical power to detect effects.

5.2 Understanding Sensitivity and Uncertainty

After exposure, the sensitivity of a species or taxon to OSW effects (or our lack of understanding as to whether such a sensitivity exists) could be considered as a second tier of decision-making considerations (Figure 2). Sensitivity can be defined as the properties of an organism or system that influence relative susceptibility to a stressor (Goodale & Stenhouse 2016). This can include sensitivity to OSW stressors, as well as population-level sensitivity to perturbation generally, which together dictate species vulnerability.

Population Sensitivity – Population sensitivity can be defined as the properties of the global or regional population of a species related to demography (e.g., survival, reproduction) and conservation status that informs the degree to which pressures from OSW development could influence the size of the population. Population sensitivity encompasses species-level information, including conservation status, population size, and the proportion of the population present in the region. Conservation status can be defined at a range of scales, including information from the IUCN Red List, federal and/or state regulatory assessments (e.g., under the Endangered Species Act, Migratory Bird Treaty Act, or state environmental protection laws), and nonregulatory assessments (e.g., Species of Greatest Conservation Need, Birds of Conservation Concern, regional conservation status). This could also take into consideration species that are not currently listed under any of these assessments, but show population declines or are suspected to be impacted in a significant manner by other emerging threats. Species with higher population sensitivity are often considered to be a higher conservation priority for understanding effects of anthropogenic activities, including OSW.

Sensitivity to OSW Stressors –Sensitivity to OSW effects includes the expected response of receptors to OSW stressors at the individual/local scale. Effects may occur inside or outside of the lease area and may carry over to other parts of the annual cycle.

Vulnerability **–** Vulnerability combines individual sensitivity to a particular effect and population sensitivity, encompassing the degree to which a receptor or system is expected to respond to their exposure to a stressor. Existing avian vulnerability frameworks (e.g., Furness et al. 2013, Robinson Wilmott et al. 2013, Kelsey et al. 2018) provide a model for understanding vulnerability as a combination of site-specific exposure to offshore wind stressors (above) and sensitivity to those stressors, including predicted individual response as well as population sensitivity. Understanding of sensitivity to displacement, attraction, and avoidance effects is informed by studies of behavioral changes at existing offshore wind facilities (primarily in Europe), as well as studies focused on disturbance from boat and/or helicopter traffic and on other industries (primarily offshore oil and gas and land-based wind). An understanding of species-level information, such as habitat flexibility based on diet, is also important for predicting sensitivity.

Existing publicly available literature in relation to marine bird response to OSW development is summarized in Appendix C. The species discussed in this summary represent those for which we have the best understanding of potential effects of OSW structures, recognizing that many factors, including wind facility characteristics, location, stage in the annual cycle, and turbine operational status, may introduce variability in these responses (Lamb et al. 2024). As avoidance and attraction represent opposite responses, we should consider both in relation to sensitivity to response (and indeed, some recent work suggests that both avoidance and attraction behaviors may be occurring within the same populations, or even within the same individuals; Peschko et al. 2021, Johnston et al. 2022). In regard to understanding potential disturbance from boat traffic, a vulnerability index was developed for Northwest European seabirds (Fliessbach et al. 2019), and there is additional literature available to inform our understanding of these effects, with some species, like Red-throated Loons, exhibiting a negative response (Schwemmer *et al*. 2011), while other species, like Northern Gannets, may be attracted to vessels from a considerable distance (10+ km; Bodey et al. 2014).

In general, species with higher suspected sensitivity to OSW effects may be higher priorities for understanding those effects, both from a conservation standpoint (if such effects are expected to potentially reach the point of causing population-level impacts) and from the standpoint of having sufficient power to detect change (since a large effect size will generally increase statistical power, all else being equal).

High Uncertainty in Effects – For some species that have been well studied in other geographies in relation to OSW development, we can get a sense of relative sensitivity to displacement, attraction, and avoidance response (recognizing that these responses may still vary with location and a range of other factors). For other species not present in areas for which OSW responses have been examined to date, we may have a more limited understanding of potential effects. However, recent avian vulnerability assessments for the Atlantic and Pacific U.S. (Robinson Willmott et al. 2013, Kelsey et al. 2018) have attempted to predict vulnerability of avian taxa to displacement (as well as collisions) based on factors such as habitat flexibility, drawing heavily from data on related species where available. There may also be other sources of uncertainty in potential response related to stage in the annual cycle (e.g., non-breeding birds may respond differently than during the breeding season). Thus, in addition to high sensitivity, high uncertainty in that sensitivity by taxon or life history stage may warrant additional research.

5.3. Additional Considerations for Selection of Focal Taxa

There are several additional factors that should be considered when selecting a focal species for study (Figure 2). Species or taxa could be considered as potentially higher priority for study if they are representative of broader taxa, contribute to a regional knowledge base, or have key management implications, as discussed below:

Representative of Broader Taxa – There may be a benefit to focusing on species for which findings may be applicable to a broader taxonomic group. This may be particularly important in cases where the species of interest, due to population sensitivity, is rare (leading to low statistical power to detect effects) or difficult to study (e.g., limited methods available). In these cases, it may be beneficial to consider choice of focal species based on the degree to which a species may adequately represent broader taxa, based on similarities in ecological niche, morphology, and behavior. However, umbrella and surrogate species should be approached with caution, as even closely related species may have substantially different responses to disturbance (Caro et al. 2005, Murphy et al. 2011).

Contribute to a Regional Knowledge Base – It is generally valuable to use a strategic lens for selecting focal species, with coordination among OSW developers funding pre- and post-construction studies, particularly in the same geography, as well as others conducting research in the region. While replication of studies across ecological and project gradients (e.g., different turbine sizes, distances to shore, and other site characteristics) can help inform regional-scale research questions (see Section 4.2), studies should meaningfully contribute to our knowledge base around the effects of OSW development on marine birds, which may at times lead to prioritization of less-studied taxa to broaden our base of knowledge. As a coordinating body, the RWSC has a database of ongoing research for which all site-level studies should be contributing; this database, in addition to participation in RWSC bird and bat subcommittee meetings and requests for subcommittee feedback, can help to inform multiple aspects of the study design process.

Key Management Implications – It is beneficial to consider the degree to which the findings of research would influence future decision making. For example, those species for which there would be a clear nexus for adaptive management may be prioritized as focal species. This may be interrelated with population sensitivity, especially in the U.S. regulatory context, as taxa with higher population sensitivity may also be more heavily protected under federal regulation and thus require more potential management actions. Species with high sensitivity or great uncertainty in effects may also be "high leverage" species for informing the siting and adaptive management of future wind energy projects. In addition, this category may also encompass species with significant cultural and/or indigenous value.

6.0 Choosing Appropriate Methodologies

6.1 Selecting Study Methods

The choice of study method(s) for displacement, attraction, and avoidance studies should depend, first and foremost, on the research question of interest (Section 4) and the focal taxon (Section 5). There are several general methods available to answer the research questions outlined in this document, including:

- Observational surveys involve the counting and identification of wildlife present in or above an area of ocean via direct visual observation by surveyors, collected from either a vessel or aircraft moving through the area in a systematic manner. Observations can occur while surveyors are physically present on the observation platform or by reviewing camera footage acquired from the survey platform.
  Specific Methods: digital aerial surveys, including concurrent use of LiDAR, and boat-based surveys, including use of supplemental technology such as laser rangefinders (Largey et al. 2021; Harwood et al. 2018).
- Individual tracking involves the capture of wild, free-living individuals and the attachment of devices that record coarse or fine-scale locational information, and sometimes behavioral information and/or environmental conditions. Depending on the type of device, information is logged and retained on the device or transmitted to receivers on the ground or via satellites. Ancillary data loggers such as wet-dry sensors, time-depth recorders, and altimeters can also be incorporated into tracking efforts to collect ancillary data and inform interpretation of data.
  Specific methods: GPS, satellite telemetry, automated radio telemetry.
- Radar studies involve the use of electronic instruments with a rotating antenna to emit radio waves, which reflect off nearby objects and generate an image of the surroundings. These include marine radar (horizontally or vertically oriented) that are often used in navigation by ships at sea but can also be used to detect animals in the airspace for several kilometers around the radar unit. 3-D radars may use a combination of S-band and X-band horizonal and vertical radars, depending on the model, to provide 3D images of bird flight trajectories over similar ranges as traditional marine radars. Finally, Next Generation Radar, also known as WSR-88D weather surveillance radar, are land-based S-band units operated by National Weather Service designed to detect precipitation in the atmosphere but also regularly detect "bioscatter," or reflectivity of the electromagnetic energy caused by biological entities in the atmosphere, such as birds, bats, and insects. We also briefly consider systems that include integrated radar and cameras (see remote visual imagery, below).
  Specific methods: marine and 3D radar, including integrated radar/camera systems, and weather surveillance radar.
- Behavioral observations consist of recording of a focal animal's behavioral activity and changes in that activity related to features of its environment (e.g., turbines), noted directly by an observer present in the environment, at repeated intervals or within a specific timeframe and/or study

area (see Rothery et al. 2009, Krijgsveld et al. 2011, as examples).
Specific methods: human observers that may use supporting technology such as spotting scopes, cameras/binoculars, and laser rangefinders.

- Remote visual imagery involves the use of technologies to gather information and/or document activity (e.g., presence, flight behavior, flight patterns) without the presence of human observers. For the purposes of this discussion, we consider this category to include photographic, video, thermographic, and infrared cameras placed on offshore wind infrastructure or vessels, as well as imagery retrieved from satellites.
Specific methods: photographic/video cameras, thermographic and infrared cameras, satellite imagery.

We present detailed guidance for conducting observational surveys in this document. There may not be equally detailed guidance available for other study methods noted above; this need has been identified by the RWSC in their science plan and is also suggested as a next step in Section 12 of this document. Several additional study methods besides those listed above have been used at OSW facilities, such as visual aerial surveys and passive acoustic monitoring. These are not suggested methods for the key questions outlined in this document. Visual aerial surveys are unsafe for human observers, cause disturbance of some bird species, and are not feasible to conduct in the same manner pre- and post-construction, since flights need to be conducted within the altitude of the rotor-swept zone of turbines. Passive acoustics typically have limited geographic range and cannot provide reliable estimates of the number of individuals detected in acoustic data. As a result, this technology is more suited to questions focused on the micro scale, including topics such as species presence. Likewise, many cameras are designed to provide micro-scale information on collisions and micro-avoidance, which are outside the scope of this document. However, some systems can also provide meso-scale or even macro-scale information (in the case of satellite imagery), and these systems are thus included in this document.

In some instances, a focal taxon may be selected before a research question, or vice versa. Regardless, once these decisions have been made, it is often necessary to review the available general study methods for the question and taxon of interest and select one or more methods to pursue. General methods to address each research question have been noted in Table 2.

Selection among study methods should be informed by the taxon of interest. These considerations include the following:

- **Taxonomic breadth** – The degree to which the study focuses on an individual species response versus gauging the response of a larger suite of species or the community. Some methods are better designed at collecting information on multiple species/groups simultaneously (e.g., observational surveys), while others target individuals (e.g., tracking).
- **Activity patterns** – Some methods are limited in their ability to collect quality data during particular time periods and conditions. For example, not all methods can collect information on species at night, so diurnal vs. nocturnal exposure/activity of focal taxa is an important consideration in the selection of methods.
- **Scale of expected response** – The spatial extent of expected response to the OSW facility (based on the literature; see Section 5) will inform the degree to which different methods are suitable. For example, behavioral observations generally occur from a fixed platform with limited spatial range, and thus may be unsuitable for species where macroscale response is expected.

- **Activity type** – How birds are likely using the area (e.g., transit versus foraging), as well as the ecology of foraging (primarily in flight, or spending long periods on the water's surface), will also influence the choice of study methods. Radar, for example, cannot be used to monitor birds at or near sea level (due to wave clutter), and therefore would be a poor choice for species that spend a significant amount of time on the surface.
- **Body size** – Particular methods may be better suited for smaller versus larger-bodied species. Some methods may have limitations relating to the ability to detect or identify small-bodied species at the desired distance away from the observation platform. Body size also affects the capacity of tracking methods to answer some types of questions, due to limitations on what types of tags can be deployed.

These considerations should be used to further narrow the suite of potential methods for the research question of interest (Figure 3) to identify one or more general methods to pursue.

Table 2. Potential pre- and post-construction study methods for examining key displacement, attraction, and macro/meso-scale avoidance questions for marine birds at offshore wind facilities. Additional details on each general type of study method are described below. Definitions of terms, including avoidance and displacement, are included in Section 1.1 and in the document glossary (Appendix B).

Research Question	Potential Methods
Are changes in distributions and habitat use (e.g., displacement/attraction) of marine birds occurring, and if so, what is the magnitude and distance from the offshore wind facility at which they occur?	• Observational Surveys • Individual Tracking
Does the occurrence, magnitude, and distance of habitat change vary temporally (e.g., does habituation occur)?	• Observational Surveys • Individual Tracking
Are there changes in foraging or roosting activities of marine birds in relation to the wind facility?	• Observational Surveys • Individual Tracking • Behavioral Observations
Is there nocturnal attraction of marine birds (e.g., to offshore wind-related lighting)?	• Remote Visual Imagery • Individual Tracking • Radar
Are macro-scale changes in movement behavior (e.g., macro-avoidance) of marine birds occurring, and if so, at what magnitude and distance from the offshore wind facility does this behavior extend?	• Individual Tracking • Remote Visual Imagery • Radar
Are meso-scale changes in movement behavior (e.g., meso-avoidance) of marine birds occurring, and if so, at what magnitude and distance from the turbines does this behavior extend?	• Individual Tracking • Behavioral Observations • Radar • Remote Visual Imagery

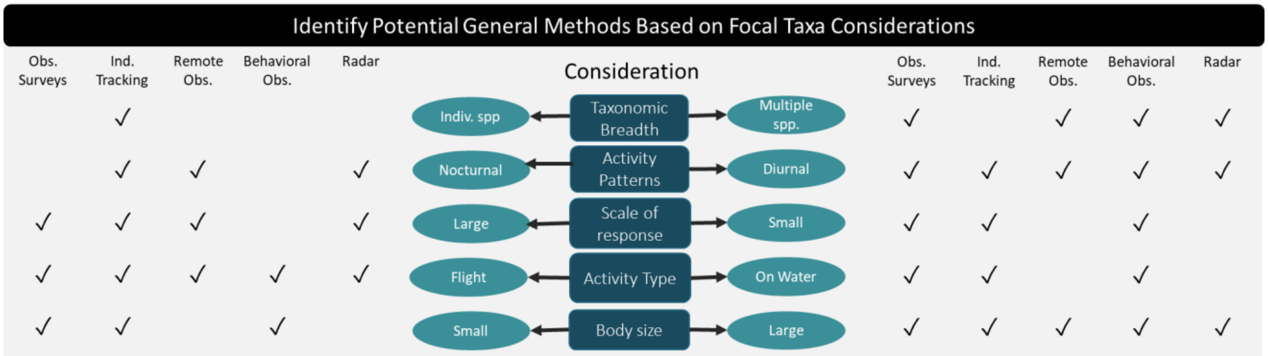

Figure 3. Taxa-related considerations that inform the selection of general study methods (in combination with the choice of research question, as described in Table 2.

In addition to the influence of research question (Table 2) and considerations based on focal taxa (Section 5; Figure 3), the selection of overall study method(s) may also be influenced by the following:

- Collection of Ancillary/Covariate Data – Some methods lend themselves to collection of specific types of ancillary data, such as physiological data (e.g., tracking) or prey sampling (e.g., observational surveys). Ancillary data collection should be considered depending upon the specific taxa, research hypotheses of interest, and the degree to which site-level data could contribute to larger-scale research questions.
- Sampling Bias – There are multiple aspects of sampling bias that should be considered when choosing among methods. These relate to:
    - Detectability (e.g., differences in the ability to detect species based on platform, environmental/weather conditions, or other factors),
    - Availability (e.g., the degree to which birds are available to be sampled), which can relate to the speed of information collection, knowledge of behavior, and other considerations,
    - Ease of species identification and associated limitations, and
    - Representativeness (e.g., the degree to which the sample is representative of the broader population) which relates to sample size/statistical power concerns, the degree to which data are collected at the group level (e.g., surveys) or individual level (e.g., tracking), and whether the study method allows for information to be collected on species absence as well as presence.
- Spatial and Temporal Scale – Some methods collect "snapshots" of data in time, while others collect longitudinal information, and the preferred option will vary depending upon the question of interest. Likewise, methods vary in their spatial coverage and locational accuracy depending on design, platform availability, and other factors.
- Environmental Conditions – Some methods may be limited by weather or other environmental conditions in ways that may hinder their ability to answer particular questions. For example, surveys are restricted to lower sea states, compared with tracking which collects information regardless of conditions.
- Logistics and Feasibility – There are many logistical challenges to be considered in the choice of method for offshore study of marine birds. These include, but are not limited to, platform availability (which is important for methods such as radar, behavioral observations, and some types of remote imagery), deployment of data collection devices (tracking, radar, camera

systems), feasibility of data collection at different stages of the annual cycle (for example, there may be differences in accessibility or capture feasibility for breeding vs. nonbreeding periods), and logistics related to information transfer (applicable to all methods to greater or lesser degrees). Additional constraints include cost and health and safety considerations, which will likely be dependent upon individual study designs and those conducting the research. Given this variation, these are difficult to categorize at this broad methodological level but are touched on briefly for various methods in Section 6.2.

- **Invasiveness** – As always with wildlife research, it is recommended that the least invasive option be used that is available to answer the study question (e.g., implanted transmitters may be needed to answer some research questions whereas less invasive tagging techniques such as bands may be sufficient to answer others).

These considerations are discussed below (Table 3) for each of the five general methods categories (observational surveys, individual tracking, radar, behavioral observations, and remote visual imagery). Strengths and limitations of specific methods (e.g., GPS tracking) are further discussed in Section 6.2.

Table 3. *Key considerations when choosing among the five major categories of study methods for examining displacement, attraction, and macro- and meso-scale avoidance of marine birds at offshore wind energy development projects. Considerations and methods categories are described in text (this section). Additional strengths and limitations of specific methods can be found in* *Section 6.2*.

Methods Considerations	Observational Surveys	Individual Tracking	Radar	Behavioral Observations	Remote Visual Imagery
Collection of Ancillary/ Covariate Data	-Can record behavioral information (particularly boat surveys) and flight heights -Can collect environmental data including SST, salinity, and prey data simultaneously (boat surveys)	-Can provide detailed information on movement behavior -Must infer behavior from movement patterns (unless ancillary data loggers are used) -Can collect information on body condition and diet (e.g., morphometrics, tissue samples, feces) at time of capture and/or recapture -Can integrate sensor types (e.g., temperature, pressure, accelerometer, magnetometer, energetics)	-Can provide flight behavior data such as flight height and speed (depending on the radar unit)	-Can record behavioral information such as foraging, roosting, interactions among individuals -May allow for ad-hoc collection of diet information (e.g., feces, pellets)	-Some types of systems may record temperature -Satellite imagery can also provide environmental covariate data, though potentially at different spatiotemporal resolutions than animal observations
Sampling Bias	-Difficulty in detecting small/dark species and distinguishing among visually similar species -Availability bias for species that dive -Provides both presence and absence information	-Limitations regarding capture and deployment feasibility for some species, age/sex classes, etc. (see below) -Typically small sample sizes and few capture locations, which may affect representativeness of sample -Data points represent only presence information.	-No species/taxa identification (unless paired with another method) -Target discrimination can be difficult -Detectability varies with body size and wavelength, as well as weather and interference from other objects -Cannot sample animals at/near sea level	-Observation range is limited by multiple factors including optic quality, vantage point location, height above water, weather -Difficult to observe avoidance behaviors at multiple spatial scales from the same position (e.g., would require positioning outside of the wind facility to observe macro-avoidance)	-Taxonomic classification to species may be difficult, with a tradeoff between field of view and image resolution, as well as poor resolution for most nighttime camera options -Difficulty in detecting small/dark species and distinguishing among visually similar species -Typically small sampling volume (for camera systems)

Methods Considerations	Observational Surveys	Individual Tracking	Radar	Behavioral Observations	Remote Visual Imagery
Spatial and Temporal Coverage	-Provides a snapshot of information during daytime only -Spatial coverage dictated by survey design -Post-construction coverage may be affected by turbine locations/height, depending on survey method	-Provides longitudinal data (repeated observations over time) -Spatial coverage may be unpredictable -Necessary temporal resolution will be question-dependent (e.g., attraction to lighting requires finer resolution than displacement) and may not be possible for all taxa or questions of interest	-Spatial coverage limited to range around platform locations but good coverage at the scale of <10 km (for marine radar; Gauthreaux & Belser 2003) and dozens of km for weather radar -Can record continuously regardless of time of day -Not suitable for micro-scale monitoring of movements due to interference from turbines	-Provides a snapshot of information during daytime only -Spatial coverage limited by number of observers and platform locations	-Spatial coverage is limited by platform locations and tradeoff with image resolution (for camera systems) -High temporal coverage may be possible
Environmental Conditions	-Limited to good weather conditions -Glare, sea state, and observer visual acuity impact accuracy, though variable	-Generally not affected by environmental conditions	-Clutter and backscatter from the water surface, turbines, and other major landscape features -Some models can operate in bad weather, but performance decreases with rain/snowfall	-Limited to good weather conditions	-Can monitor across a range of conditions in some cases, but typically limited to clear weather conditions -Cloud cover blocks satellite views
Logistics and Feasibility	-Appropriate survey platform for wildlife viewing that meets industry health and safety standards	-Limitations regarding tag weight and body size and capture feasibility (e.g., by age class, sex, timing in annual cycle) -Difficulty in capture/recapture during particular times of year/locations -Can be challenging to predict whether tagged individuals will use area of interest - Many species do not retain tags across multiple years as they are lost during molt. So, it may be difficult to obtain data from the full annual cycle	-Requires stable platform free from obstruction and may require gyro-stabilization, as well as power supply (for marine and 3D radars) -Some systems lack remote data transfer -Generally high level of post-processing	-Access to platforms in or near the wind facility may be challenging due to health and safety regulations, operator guidelines, access limitations, etc.	-Requires stable platform and power supply (for camera systems) -Some systems lack remote data transfer -Generally high level of post-processing
Invasiveness	-Some disturbance from boats; typically, little or none from digital aerial surveys so long as flight heights >~500m are maintained (see Section 10.4)	-Handling of birds during capture, potential disturbance at breeding sites -Potential for tag effects	-Non-invasive for animals	-Non-invasive for animals	-Non-invasive for animals

6.2 Considerations for Specific Methods

Once the general method(s) has been selected (e.g., individual tracking), specific methods within those broad categories must be considered for research (e.g., GPS vs. automated radio telemetry). This section details additional strengths, limitations, and additional considerations for each specific method. Cost and health and safety are highly dependent upon individual study designs and must be addressed on a per-project basis; as such, are not explicitly addressed in the below tables as a strength or limitation but noted in some cases in the "other considerations" sections. For examples of studies using each of these study methods, see Appendix C.

6.2.1 Observational Surveys

Strengths and limitations of digital aerial and boat-based observational surveys are detailed below. As mentioned in Section 6.1, we do not recommend the use of visual aerial surveys.

BOAT-BASED SURVEYS	
Strengths:	Limitations:
• **Longer survey window**. Better than aerial surveys at detecting episodic events (such as migration flights) that require a longer survey period. • **Covariate data.** Allow collection of contemporaneous environmental covariate data (e.g., water sampling, proxies for fish abundance, real-time bathymetric data, species composition of forage fish schools, eDNA, multibeam side scan sonar, etc.) to accompany avian observations. • **Other local data**. Can collect local-scale data such as foraging behavior, foraging hotspots, etc. • **Image collection**. Produce an archive of data, assuming a long-lens camera is used (requires an extra observer). • **Species identification**. Observers on boats may be able to detect and identify smaller species than aerial surveys. Diving birds are assumed to be more likely detected than via aerial surveys due to slower speed. • **Speed of accessing data**. Observational data from vessels is generally available more quickly than digital aerial survey results. • **Strip Width**. For highly detectable species, effective survey strip width centered on track line is larger from a boat than from a plane. • **Assessment of biases.** Multiple observers easily incorporated to include an assessment of detection biases.	• **Double counting**. The longer time scale of the surveys may lead to higher instances of double-counting individuals, which violates analytical assumptions. • **Flight height**. Assessments of bird flight height from shipboard observers can be highly inaccurate as well as uncertain. Can use a laser rangefinder to help improve accuracy but requires a dedicated extra observer. • **Weather-dependent**. Poor conditions lead to more cancellations than digital aerial surveys, which can lead to increased permitting/consenting risk if projects require a certain number of surveys in specific time periods. • **Platform effects**. More likely to cause platform effects on animal movements (including both avoidance and attraction) than aerial surveys, especially if a fishing boat is used as the survey platform. • **Lack of QA/QC post-survey**. Cannot be validated after the event to assess reliability of counts and species identified (though species ID can be verified for a subset of animals if long-lens camera is used). • **Avoiding hazards.** May be unable to follow same survey design pre- and post-construction. • **Coverage.** Effective strip width for smaller/darker species and species on the water can be quite narrow and varies with weather conditions (e.g., sea state).
Other Considerations: Not as economical as digital aerial surveys for covering large areas located far offshore. More man-hours at sea compared with digital aerial surveys.	

<table>
<tr><th colspan="2">DIGITAL AERIAL SURVEYS</th></tr>
<tr><td>Strengths:</td><td>Limitations:</td></tr>
<tr><td>

Covering large areas far offshore. Survey planes fly higher and faster than visual aerial surveys and are much faster than boat surveys, thus particularly well suited for surveying larger areas located farther offshore.
Survey Speed. The rapid survey flight speed captures a quick snapshot of bird distributions, reducing any risk of double counting.
Survey Altitude. The high flight altitude reduces disturbance to birds at the surface.
Flight height data. Estimated flight heights can be calculated, though there is uncertainty around estimates depending on method, and may require additional data collection (e.g., use of LiDAR).
Image collection. An archive of data is produced for future reference, allowing robust quality assurance and quality control (QA/QC) procedures.
Location accuracy. Geospatial accuracy of individuals captured in the data as compared with estimated from human-observer estimates of distance and angle.
Avoiding hazards. Digital aerial surveys are typically conducted at a high enough altitude to be flown safely over turbines (though this may require refinements of cameras and camera configurations as turbines get taller).

</td><td>

Availability and behavior. Due to the rapid survey speed, the availability of diving birds to be detected may be lower, and the opportunity to gather behavioral data is reduced compared to boat-based surveys.
Substantial data review time. Substantial imagery review time is required to locate and identify animals. There have been several attempts to develop automated detection and identification algorithms, but there has been limited success for most species to date due to challenges associated with repeatability across surveys. Deep learning neural networks, for example, while effective for a single survey, have been less successfully applied across surveys and conditions. USFWS and BOEM are currently exploring digital approaches and deep learning algorithms.

</td></tr>
<tr><td colspan="2">Other Considerations: Not as economical as boat surveys for covering smaller areas closer to shore. Fewer man-hours at sea compared with boat-based surveys. For safety reasons, need to fly all surveys at >152 m (500 ft) above highest point of planned or existing offshore structures.</td></tr>
</table>

6.2.2 Individual Tracking

Tracking methods have varying accuracy and precision in their location estimates. In this context, **precision** describes the dispersion of calculated positions if the device is stationary (e.g., how much uncertainty there is in the estimated location of the tagged animal), while **accuracy** is a measure of conformity between estimated and true positions (e.g., how close the estimated position is to the true position of the animal; Garrido-Carretero et al. 2023). Key tracking methods include automated radio telemetry, GPS telemetry, and satellite telemetry. Archival geolocators are also used in avian distribution studies; they are not recommended as the primary tracking technology for displacement, attraction, and avoidance studies of marine birds due to their lower spatial accuracy and precision, but they can provide auxiliary behavioral information when used in conjunction with other tag types (e.g., wet-dry sensor can inform estimates of dive activity). There are a variety of movement modeling approaches that can be used to estimate locations and habitat use areas from tracking data, as well as to differentiate behaviors (e.g., foraging vs. migrating; Baldwin et al. 2018, Gulka et al. 2023, Green et al. 2023).

<table>
<tr><th colspan="2">GPS TELEMETRY</th></tr>
<tr><td>Strengths:</td><td>Limitations:</td></tr>
<tr><td>
Flexibility. Wide variety of tags and associated capabilities (i.e., power management, data collection regimes) available. In some cases, remote download either to a base station or via GSM network is available such that data can be transferred remotely.
Spatial coverage. Can provide unbiased location information.
Flight height. Can provide good-quality flight height data, although the accuracy of altitude estimates varies and can impact tag weight and battery life. Uncertainty in estimates also relates to the temporal resolution of GPS fixes (Schaub et al 2023). Add-on pressure sensor can improve altitude estimates but requires pressure measurements for calibration and adds to tag weight.
Flight speeds. If sampling is frequent enough, can estimate or instantaneously measure (e.g., Fijn and Gyemisi 2018) flight speeds.
Other behavior. Can often differentiate between general behavior types (e.g., flying vs roosting) based on movement patterns, and can refine estimates with addition of ancillary data (e.g., from TDRs or wet-dry sensors).
Lower location error than satellite telemetry. Generally higher precision and accuracy than satellite and radio telemetry, generally <25m (Acacio et al. 2022, Lui et al. 2018), allowing for fine-scale estimation of movement and habitat use. Accuracy and precision increase with fix rate (Acacio et al. 2022).
</td><td>
Weight. Many GPS units are heavy enough that they cannot be safely carried by smaller marine bird species.
Recapture. While larger tags do not require the recapture of the tagged individual to access data, smaller tags either do, or require remote download via a nearby base station, both of which limit the tags' utility in the non-breeding season. Smaller GPS units with remote download capabilities are currently in development but are still limited in what species can carry them and/or can only log data for a limited number of point locations.
Temporal coverage. Due to tag attachment limitations, may be difficult to get data from a full annual cycle or across multiple years.
Tradeoffs between resolution of location information and auxiliary data and battery life. The finer the resolution of information collected, the greater the required battery power. Some tags have solar panels allowing for additional data collection, but many are limited in the total number of locations tags can collect.
Sample size. Cost per tag may limit sample sizes.
</td></tr>
<tr><td colspan="2">Other Considerations: More expensive per tag than automated radio telemetry. The use of GSM cell network for data transfer requires that data transmission costs for the life of the tags need to be budgeted for during project development.</td></tr>
</table>

AUTOMATED RADIO TELEMETRY	
Strengths:	**Limitations:**
• **Weight**. Automated radio transmitters are one of the only options for offshore tracking of small-bodied species. • **Sample sizes**. Automated radio transmitters are relatively inexpensive as compared to other tag types, allowing for large sample sizes. • **Collaborative network**. The Motus Wildlife Tracking System is centralized to share data among users, and guidance on the offshore deployment of receiver stations exists (Loring et al. 2023a).	• **Spatial coverage**. Limited by the network of receiving towers. Expansion of telemetry stations on offshore wind energy infrastructure (e.g., turbines, buoys) would help improve offshore coverage and could allow for development of a regional-scale monitoring network in the offshore environment. • **Temporal coverage**. Due to tag attachment limitations, may be difficult to get data from a full annual cycle or across multiple years. • **Three-dimensional location estimation**. Tags do not provide actual location estimates, though modeling efforts via triangulation of detections from multiple antennas/receivers is ongoing (Loring et al. 2023b). More precise estimates may require integration with pressure sensors or accelerometers. • **Frequency**. Two different radio frequencies are used and not all stations can detect both. • **Logistics/safety restrictions**. Gaining access to offshore wind energy infrastructure for station deployment and maintenance is challenging due to cost, safety, and access limitations.
Other Considerations: Monthly data fees must be paid by owners of receiving stations if the stations are equipped with remote connectivity. Tags are relatively inexpensive compared to other telemetry approaches (though this does not include the cost of receiving stations).	

SATELLITE TELEMETRY	
Strengths:	Limitations:
• **No recapture**. Tagged individuals do not have to be recaptured to access data, as data are transferred in real-time via the Argos system. • **Flexibility**. Wide variety of tags and associated capabilities. • **Spatial coverage**. Can provide unbiased location information at fair spatial resolutions. • **Flight speed and behavior**. If sampling is frequent enough, can estimate flight speeds and/or differentiate between general behavior types (e.g., flying vs roosting) based on movement patterns.	• **Tag size**. Satellite tags require a battery source and are therefore larger and heavier than other tag types, so limited to large-bodied species, and may require surgical implantation in some species. • **Temporal coverage**. Due to tag attachment limitations, may be difficult to get data from a full annual cycle or across multiple years. • **Increased location error compared to GPS telemetry**. Spatial accuracy and precision not suitable to investigate at finer scale than macro-avoidance. Error varies depending on number of satellites involved among other factors, but generally have a precision of >250 m at best (range of field tests: 500m-15 km; Boyd and Brightsmith 2013, Irvine et al. 2020). • **Tradeoffs between resolution of location information and auxiliary data and battery life**. The finer the temporal resolution of information collected, the greater the required battery power. Some tags have solar panels allowing for additional data collection, but many are limited in the total number of locations tags can collect.
Other Considerations: More expensive per tag than automated radio telemetry. The use of satellite telemetry services (such as the Argos system) requires that data transmission costs for the life of the tags need to be budgeted for during project development.	

6.2.3 Radar

There are multiple types of radar that can be used in studies of marine birds at OSW facilities (see review in Nicholls et al. 2022 for specific technologies). In general, these include (1) marine (surveillance) radar, typically used by vessels for marine navigation that can also be used to map the trajectories of individuals or flocks of birds, (2) three-dimensional (3D) radar systems, which generally integrate multiple marine radar units in horizontal and vertical planes, and (3) weather surveillance radar systems that can assess and map biomass in the atmosphere. Generally, radar used to monitor birds must use either X-band (3 cm) or S-band (10 cm) wavelengths to detect objects in the atmosphere; the different wavelengths affect the radar's ability to detect different size objects (e.g., there is a greater chance of missing objects that are smaller than the radar's wavelength) as well as affecting sensitivity to clutter (e.g., precipitation and other moisture in the atmosphere). One of the key limitations of radar systems is the inability to identify species; as such, integrating radar with use of visual observers (Skov et al. 2018) or camera systems (which combine a marine radar or 3D radar unit with a camera system to inform species identifications) are increasingly being used at offshore wind facilities (see Tjørnløv et al. 2023 for example of integrated radar/camera system). Due to generally similar strengths and limitations, marine and 3D radars are discussed jointly below.

MARINE AND 3D RADAR	
Strengths:	Limitations:
• **Coverage**. Relatively large-scale coverage as compared to some other study methods (multiple km). • **Movement data**. Can provide data on passage rates, flight speed, and flight direction, as well as macro- to meso-avoidance (e.g., Leemans et al. 2022). • **Altitude data**. Good altitudinal distribution data if a vertical unit or 3D radar is used. • **Effective in low visibility**. Can monitor avian activity during hours of darkness, as well as in some periods of low visibility (e.g., light mist, fog), so close to 24-hr data collection is possible. • **Effective at lower altitudes**. Can survey lower altitudes than weather radar.	• **Coverage**. Lower spatial coverage compared to weather surveillance radar (generally <10 km). • **Species identification**. Cannot provide species identification or taxa-level identification without addition of supplemental technology or visual observers. • **Appropriate platform**. Requires a stable platform, free of obstructions, for detector deployment, and may require gyro stabilization offshore, which can be expensive. • **Only suitable for studying birds in flight.** Susceptible to clutter from water, turbines, and other landscape features that prevent detection of birds, including birds at or near the water's surface. • **Weather.** Limited detection during rain; more clutter issues in high seas. • **Abundance estimation**. Target discrimination can be difficult (sometimes cannot differentiate between individual birds and flocks of small birds). • **Lack of remote data download**. Many systems lack the ability to send data remotely, meaning issues may go a long time without being noticed. Additionally, accessing the system for manual data download is expensive and potentially dangerous. • **Weatherization**. Challenges with maintaining equipment in offshore environment. **Logistics/safety restrictions**. Gaining access to platforms for device deployment and maintenance in or near the wind facility can be challenging due to cost, safety, operator guidelines, access, etc.
Other Considerations: Systems can be expensive to deploy. These radars can be integrated with camera systems, which are discussed in Section 6.2.4, below.	

WEATHER SURVEILLANCE RADAR	
Strengths:	Limitations:
• **Coverage**. Large-scale coverage. • **Flight height data**. Can provide flight height data within the detection cone of the radar. • **More effective in precipitation**. Performs better than marine radar in poor weather conditions.	• **Spatial coverage**. Limited by existing network of weather radars and therefore may not overlap with some offshore study areas. Additionally, detection range increases in altitude with distance from the radar, meaning that the monitored airspace at many offshore wind lease areas is above rotor-swept height. • **Target discrimination**. Target discrimination is generally not possible, so radar provides a measure of biomass in the airspace rather than allowing tracking of individual birds or flocks.
Other Considerations: Data are collected by the federal government and can be accessed without an up-front cost.	

6.2.4 Behavioral and Remote Visual Imagery

Behavioral observations from fixed platforms and remote visual imagery, while different methods, have similar limitations and therefore have been combined for the purposes of comparing strengths and limitations. Remote visual imagery methods include photography/video, thermographic, and satellite imagery.

OBSERVERS ON PLATFORMS	
Strengths:	Limitations:
• **Availability, affordability, portability**. The use of optics (binoculars, spotting-scopes) allows for a relatively cheap, site-specific, and fast means to collect fine-scale data. • **Fine-scale behavior/movement data**. Useful for observing behaviors such as foraging, roosting, and inter- and intra-specific interactions within OSW project footprints. In certain cases, may allow for ad-hoc collection of diet data, such as pellets/feces present on platforms. • **Good species identification**.	• **Limited range**. Observation range is limited by factors including optic quality, weather, and height above water. Unless positioned on the outside edge of the OSW facility, it can be hard to observe avoidance behaviors. • **Weather-dependent**. Poor conditions lead to cancellations, which can lead to increased permitting/consenting risk if projects require a certain effort in specific time periods. • **Logistics/safety restrictions**. Gaining access to observation platforms in or near the wind facility can be challenging due to cost, safety, operator guidelines, access, etc.
Other Considerations: Possible health and safety concerns for human observers on offshore platforms.	

SATELLITE IMAGERY	
Strengths:	Limitations:
• **Detection**. Used to detect whales, and resolution sufficient to detect larger birds on the water and in aggregations in staging areas.	• **Species Identification**. Resolution not adequate for identifying many species. Limited utility for smaller, darker species with inferior detectability. • **Substantial data review time**. Possible high level of post-processing of datasets. • **Weather condition limitations**. Not usable in low visibility conditions with cloud cover.
Other Considerations: Government agencies can utilize the WorldView-3 and -4 platforms at no cost. Does not require man-hours offshore.	

VISUAL PHOTOGRAPHY / VIDEO	
Strengths:	Limitations:
• **Fine-scale monitoring**. Useful for examining meso-scale interactions with turbines as well as providing flight behavior data (i.e., flight patterns, flight height). • **Collision detection**. Not relevant to the scope of this document, but one of the only available technologies that can be deployed long term to detect micro-avoidance behaviors and collisions with turbine blades. • **Species identification**. Provides detailed imagery of individual birds.	• **Logistics/platform restrictions**. Photo/video systems require a stable platform and power source for device deployment. • **Tradeoff between field of view and image resolution**. Species identification can be difficult for smaller birds farther from the camera; to achieve better resolution, the field of view must become so narrow that only a small fraction of airspace is monitored, causing low sample sizes. • **Lack of remote data download**. Many systems lack the ability to send data remotely, meaning issues may go a long time without being noticed. Additionally, accessing the system for manual data download is expensive and potentially dangerous. • **Substantial data review time**. Possible high level of post-processing of datasets. • **Weatherization**. Challenges with maintaining equipment in offshore environment. • **Weather condition dependent**. Challenges in low-visibility conditions. • **Logistics/safety restrictions**. Gaining access to wind facility platforms for device deployment and maintenance can be challenging due to cost, safety, operator guidelines, access, etc.
Other Considerations: These systems can be integrated with marine and 3D radar units, which are discussed in Section 6.2.3, above. Minimal man-hours offshore as compared with observers on platforms.	

THERMOGRAPHIC PHOTGRAPHY/VIDEO	
Strengths:	Limitations:
• **Effective in low visibility**. Can monitor avian activity during periods of low visibility/complete darkness. • **Collision detection**. Not relevant to the scope of this document, but one of the only available technologies that can be deployed long term to detect micro-avoidance and collisions with turbine blades.	• **Limited range**. Thermal imaging cameras typically have a short range, limiting effectiveness. • **Species identification**. Lack of clear imaging/ color as well as poorer resolution than visual camera systems, making species identification difficult. • **Logistics/platform restrictions**. Requires a stable platform and power source for device deployment. • **Lack of remote data download**. Many systems lack the ability to send data remotely, meaning issues may go a long time without being noticed. Additionally, accessing the system for manual data download is expensive and potentially dangerous. • **Substantial data review time**. Possible high level of post-processing of datasets. • **Weatherization**. Challenges with maintaining equipment in offshore environment. • **Weather condition limitations**. Challenges in low visibility conditions. • **Logistics/safety restrictions**. Gaining access to wind facility platforms for device deployment and maintenance can be challenging due to cost, safety, operator guidelines, access, etc.
Other Considerations: Integrated photographic and thermographic systems can help to address the respective limitations of both types of systems. These systems can also be integrated with marine and 3D radar units, which are discussed in Section 6.2.3, above. Minimal man-hours offshore as compared with observers on platforms.	

6.3 Summary: Choosing Appropriate Methods

The above process of selecting a research question, focal taxon or taxa, general study method, and specific study method is summarized in Figure 4. Aspects of Figure 4 may be cross-walked to relevant portions of Sections 4-7 of this guidance document.

Additional discussion of study design choices for examining the key research questions relating to displacement, attraction, and avoidance are examined below specifically for observational surveys. This includes recommendations on study protocols, sampling design, and effect quantification considerations where appropriate. We know of no similar guidance for using the other general study methods (tracking, radar, behavioral observations, and remote visual imagery) to assess OSW effects on marine birds. However, several recent reviews (Dierschke et al. 2016, Cook et al. 2018, Largey et al. 2021) provide guidance on appropriate study methods and may be useful references. Additionally, many of the below recommendations on data consistency, reporting, and data transparency are broadly applicable to all study methods discussed in this guidance.

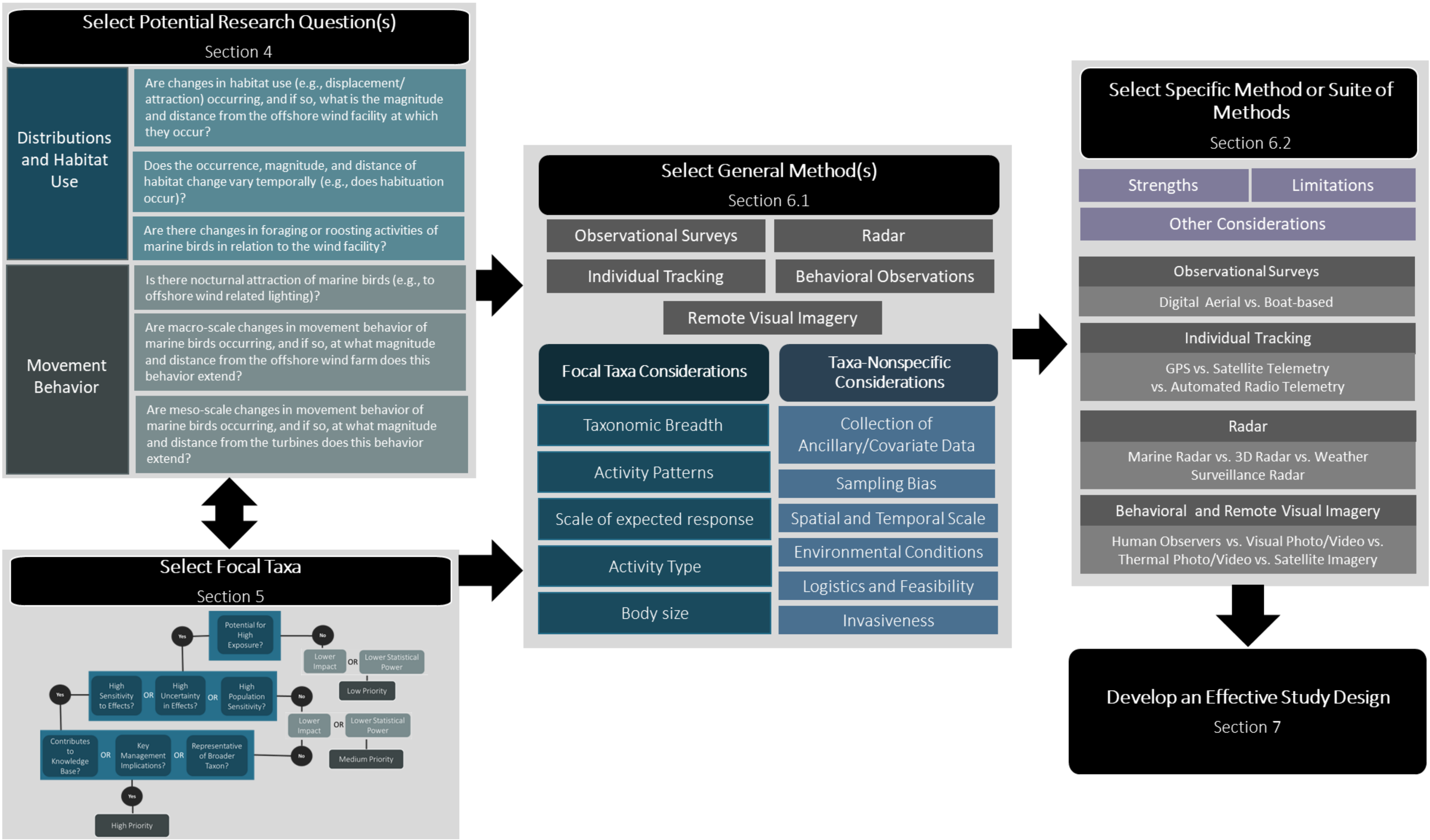

Figure 4. *Detailed decision tree that walks through the process of selecting a research question, focal taxa, and study method. Additional details are provided in Sections 4.0-6.2, above.*

7.0 Developing an Effective Study Design

Once research questions, focal taxa, and methods have been identified, further study design choices should focus strongly on maximizing statistical power to answer the study questions. **A study plan should be developed for all pre- and post-construction monitoring of marine birds that clearly articulates: (1) the study objectives, research questions, focal taxa, and testable hypotheses, (2) a study design, including data collection methods, sample sizes, and analytical approaches, informed by power analyses, and (3) data sharing and coordination plans**. There are existing regional resources that provide high-level recommendations for study plan development (Regional Synthesis Workgroup 2023, ROSA 2021, Mackenzie et al. 2013), and further relevant guidance may become available through RWSC and other relevant efforts in the coming years. **Study plans should be developed and assessed in consultation with subject matter experts (building on existing efforts where possible) and in coordination with other OSW developers conducting similar monitoring in the region of interest (see Section 12 for further recommendations on coordination of research activities). A rubric for assessing study plans can be found in Appendix D.**

These recommendations are intended to apply broadly across research questions identified in Section 4, with more detailed recommendations specific to observational surveys in Section 10.

7.1 Study Objectives

A study plan should be developed that clearly articulates the objectives and intended outcomes, including selection of clear research questions (see Section 4), focal taxa (see Section 5) and identification of how resulting knowledge will improve our understanding and decision-making. Testable hypotheses should be developed based on existing conceptual frameworks of potential effects from OSW development on marine birds (see NYSERDA 2020, Williams et al. 2024), and include supporting documentation from published literature and reports (see Appendix C).

7.2 Study Design

7.2.1 Statistical Power and Effect Size

We recommend that the study design process should (1) evaluate whether expected data types and sample sizes are sufficient to detect a reasonable level of observable effect, and (2) ensure that planned data collection can most effectively address the articulated research questions and/or hypotheses (Regional Synthesis Workgroup 2023). While aspects of study design should be reassessed throughout the life of a study, effectiveness of a proposed study design (including the proposed sample sizes) should be evaluated during planning using the metric of statistical power, which can estimate the probability of detecting an expected effect at a particular significance level. Maslen et al. (2023) outlines the main steps of a power analysis:

1) *Specify analytical approaches and testing procedures*. Analytical approaches should capture key properties of the data that are expected to be collected, including sample sizes (e.g., number of observations) based on best available information from the location of interest (e.g., site assessment data), or at minimum from the literature. Statistical testing procedures should be based on questions, hypotheses and data.
2) *Decide on a measure and value of effect size that is ecologically meaningful*. The choice of metric for effect size should be informed by the specific study question and the ecological system or population of interest (Osenberg et al. 1997). In many types of power analyses,

effect sizes must also be selected (i.e., the expected percent decrease in density within an OSW project footprint following construction of the facility). We recommend selecting a range of reasonable effect sizes from existing literature, to assess the influence of this value on statistical power. Using existing data to the degree possible, the choice of effect size value should take into consideration taxonomy, sources of variability including temporal (e.g., seasonal, annual, and longer-term fluctuations) and spatial variability (ROSA 2021), and the biological relevance of the selected value (Osenberg et al. 1997). These factors are discussed in detail in the following sections on spatiotemporal scale considerations, data collection, and data analysis.

3) *Estimate power, either analytically or using a simulation approach* (e.g., generating data under the assumed observation process, then applying the analytical approach and testing procedure to each simulated dataset and recording the proportion of times the null hypothesis is rejected). This estimation should also carefully consider the effects on decision making that may result from both Type I error (e.g., detecting an effect when there is none) and Type II error (e.g., not detecting an effect when there is one; Leirness & Kinlan 2018, Fairweather 1991). Given the uncertainty of potential effects from OSW development, as well as the conservation status of many marine bird taxa, a precautionary approach is generally recommended for the conservation and management of ecological populations (in which researchers strive to minimize errors of omission, or Type II error; Hoenig & Heisey 2001).

Note that, while we use the language of frequentist statistics to discuss aspects of power and error, this should not be interpreted as an endorsement of frequentist methods; in many cases, Bayesian approaches may be better suited to effects studies (additional recommendations on analysis are included in "Data Analysis," below).

Statistical power generally increases with increasing sample size, increasing effect size (e.g., the magnitude of expected change/response), and decreasing variability (Cohen 2013). Thus, we recommend the following:

- **We encourage the choice of focal species with relatively high potential exposure (Section 5).** Studies of species that are uncommon or lower in abundance at a site will likely result in a large number of zeroes in the data and/or low sample sizes, which negatively affect statistical power (Vanermen et al. 2015b; LaPeña et al. 2011). While this should not preclude the study of species that are lower in abundance at a site relative to other species or locations, it is important to recognize that focusing on lower-abundance species will typically require additional sampling effort (within or across study methods) and/or coordinated efforts at a larger spatial scale (e.g., meta-analysis across projects) to achieve adequate statistical power.
- **Selection of focal species with expected greater magnitude of response will increase the chance of detecting that response if it occurs (Section 5).** Small effect sizes may be difficult to detect even with high intensity data collection (Donovan & Caneco 2020; Leirness & Kinlan 2018). **For species where potential effect size is unknown, effect size should be treated conservatively (e.g., smaller magnitude of response, higher uncertainty) such that the study is designed with a greater chance of detecting effects, should they occur.**
- Study design should include explicit consideration of, and measurement to control for, potential sources of variation **that may affect the detection of effects and level of response, and/or**

interpretation of results. Statistical power is greatly affected by the level of variation in the system (Vanermen et al. 2015b). As such, understanding and accounting for as many sources of variability as possible, particularly environmental and biologically relevant variability, is key for increasing statistical power (Maclean et al. 2013, Vanermen et al. 2015b). In particular, this should include data that may influence and help control for sources of variation, including: (1) environmental conditions (e.g., oceanographic conditions, weather) collected simultaneously with response data, when possible, (2) biological parameters (e.g., body condition, age, sex), (3) external factors (e.g., OSW facility/site characteristics, other anthropogenic factors), and (4) seasonality or other sources of predictable spatiotemporal variation (e.g., study designs should ensure sufficient sample sizes specific to the season in which effects are expected to occur).

7.2.2 Spatial and Temporal Scale

The spatial and temporal scale of the study can influence statistical power (Maclean et al. 2013). Thus, studies should be designed with appropriate spatial and temporal scales for the question(s) of interest. We strongly recommend that existing data (e.g., site assessment data) and available literature are used to inform power analyses regarding choices related to spatial and temporal scale during study design (Mackenzie et al. 2013). While existing data can inform these decisions, consideration should be given to potential changes and uncertainty over space and time in datasets, and testing various scenarios within a power analysis framework can help identify and clarify the influence of different study design decisions on statistical power. Specifically, we recommend that:

- The spatial extent of the study should be chosen based on the spatial scale of the question and available knowledge of response distance for focal taxa. The spatial scale of the question relates to the focus on displacement and macro-avoidance (large scale), or meso-avoidance (smaller scale) and should also incorporate knowledge of potential response distances from existing studies (see Appendix C and Lamb et al. 2024). It should be noted, however, that while it is important to focus data collection on the scale perceived to be most relevant, this should not be at the expense of overlooking potential responses at other spatial scales (Cook et al. 2018).
- The spatial scale of the study, including overall spatial extent and spatial coverage (i.e., percent of the study area surveyed) should include consideration of statistical power. Understanding how spatial scale affects statistical power is important, as it can influence both effect sizes and the amount of uncertainty. Too large or too small of an overall study footprint can decrease statistical power, and as such the spatial scale used should be equivalent to that at which responses are anticipated to occur (Maclean et al. 2013). In the case of observational surveys, increasing spatial coverage may increase power. For example, LaPeña et al. (2011) found that a three-fold increase in spatial coverage increased statistical power from 0.55 to 0.84. As such, using power analyses to inform decisions of spatial scale is of the utmost importance.
- Ensure that the temporal scale of the study (e.g., duration and frequency) captures potential scales of response based on best available knowledge and associated uncertainty. This is particularly important for studies directly interested in temporal variation in responses (e.g., habituation), which will require data collection across longer temporal scales, but is relevant for all studies in which there is expected to be potential seasonal variation in responses. Given high levels of variation in marine systems, a conservative approach should be taken (e.g., longer overall temporal scale of study; extending the sampling data collection period) and should be reassessed if additional data becomes available.

- Careful consideration should be given to the temporal scale of the study (including frequency of sampling) in relation to timing in the annual cycle for focal taxa, as this can greatly influence behavioral response. Many seabirds are spatially constrained as central place foragers during the breeding season, and thus, responses to OSW development may be different during breeding than during non-breeding periods (Peschko et al. 2020). This is also particularly important for studies directly examining behaviors such as foraging and roosting.
- The overall duration of the study should include data collected both before and after construction of the wind facility (where possible) to effectively examine changes in responses of individuals or populations. This may not be possible for all study questions, particularly those related to avoidance and attraction, where some methods may be constrained by the presence of platforms offshore during the pre-construction period. Post-construction surveys should be initiated within five years of the completion of pre-construction surveys in order to ensure that all effects surveys (two years of pre-construction surveys and 3 years of post-construction surveys) can be completed within a ten-year period. Given that marine systems are highly variable, this serves to minimize the chance of non-OSW variables (e.g., decadal shifts in marine ecosystems due to climate change) influencing distributions and abundance in ways that could be conflated with OSW effects (Kinlan et al. 2012, Morse et al. 2017, Friedland et al. 2019, 2020a, b). In order to complete two years of pre-construction effects surveys, developers and regulators should coordinate to ensure the surveys are initiated >2 years prior to construction.

7.2.3 Data Collection Methods

- **Data collection methods should follow** best practices, existing guidelines, and established protocols (when available) for effective and efficient data collection, such as those developed by BOEM (2020), and other regional science entities, such as the RWSC. For surveys, see recommendations in Section 10 of this document.
- **Use consistent data collection methods over space and time (to the degree possible) to a**void introducing methodological biases into study design. These biases are often unnecessary and left unaccounted for in studies and can lead to additional uncertainty. If substantial changes occur in methodology (e.g., switching survey platforms; Section 10), calibration and/or exploration of the effect of these changes may be needed to understand their potential impact on results.
- Data collection processes should include quality assurance and quality control. Quality assurance (QA) represents a set of steps taken to minimize inaccuracies in the data produced, while quality control (QC) occurs following data collection to test whether the quality of the data meets necessary requirements determined by the end user (Campbell et al. 2013). These processes will vary by data type but should follow existing protocols and best practices.

7.2.4 Data Analysis

A clearly defined analysis plan, based on the study's objectives, should be articulated prior to beginning data collection. This should include specific modeling and statistical approaches and tests anticipated to be used. The development of an analysis plan should include the following considerations:

- **Accounting for biases** – Depending on the method, many different types of biases may be introduced during data collection and should be controlled to the degree possible. For example, detectability, availability, and misidentification biases are present in observational survey data. In the case of detectability (e.g., differences in how likely birds are to be detected by observers, related to distance, conditions, etc.), distance sampling data can be used to model species-level distance functions (Buckland et al. 2001) that can be used to correct density and abundance estimates during analysis of boat survey data. Availability bias (i.e., the degree to which birds are available to be observed), which is particularly relevant for diving species, can be considered in analysis of survey data by using information from the literature (Laake et al. 1997, Borchers et al. 2013). Other study methods introduce other sources of bias, such as population sampling bias (Soanes et al. 2013) and capture location bias (Hays et al. 2020) that likewise must be considered during both study design and data analysis. In cases where analytical methods are not available to account for biases, the influence of these biases on results should be carefully explored.

- Choosing the appropriate modeling framework – For any given research question, there are likely multiple modeling approaches, all of which have strengths and limitations for a specific study. The most appropriate modeling framework for the taxon, question, and location of interest should be carefully considered. Data type, sample size, the data distribution, and other data and study characteristics will help dictate the best potential options for modeling frameworks. Comparisons between modeling approaches may also be needed during analysis to identify the best choice for a given study.
- Accounting for autocorrelation – Spatial and temporal autocorrelation is common in ecological data, whereby observations tend to be more similar at some geographic distances and time differences than expected by chance. This can violate statistical assumptions in common modeling frameworks. Autocorrelation can be an issue across different data types, including observational surveys and individual tracking, and there are many methods to account for the effects of autocorrelation (reviewed in Keitt et al. 2002, Dormann et al. 2007).
- Selecting appropriate model complexity – Identification of models of the appropriate complexity is crucial, as models that are too simple can be biased or inaccurate, while overfitted models that are too complex will perform poorly in predicting to areas without data (Mackenzie et al. 2013). Appropriate model complexity can be assessed using model selection and assessments of model fit. Model selection criteria (e.g., Akaike Information Criterion values) can be used to determine the best fit model across potential covariates and balance the predictive quality of the model with parsimony (Maclean et al. 2009). However, these techniques are not always useful when the study is focused on maximizing predictive accuracy. In these cases, model fit must be assessed using robust methods like k-fold cross validation (e.g., leave-one-out approaches) with careful consideration of the predictors included in the model (Diniz 2022).
- Comprehensive identification of covariates – As discussed above, variation has a large influence on statistical power. The inclusion of covariates can help control for variability in response to the underlying environment that is not attributable to OSW development. In particular, it is important that (1) the spatial resolution of covariates is appropriate for the spatial scale of the study and predicted response (i.e., if the expected response/variation is predicted at the scale of a few kilometers, aim to have spatial covariates at that or finer spatial resolutions), (2) candidate variables are not too similar (collinear) such that they cause model instability (which can be assessed via correlations or variance inflation factors; Mackenzie et al. 2013), and (3) a spatial term be considered for inclusion in the model as a proxy for unmeasured covariates. Such a spatial term (generally related to latitude and longitude) can be applied as a global smooth or via spatially adaptive methods, both of which should be trialed and considered in model selection (Mackenzie et al. 2013). Some analyses may benefit from a multi-scale approach to the resolution

of covariates if a species may respond to different covariates at different spatiotemporal scales (McGarigal et al. 2016).

- **Assessment of model performance** – It is important to assess the degree to which model assumptions are reasonable and associated results are defensible (Mackenzie et al. 2013). While evaluation will depend on the model type, assessment must include an examination of the relationship between observed and fitted values from the model.
- **Consideration of synergies and collaboration opportunities** – It is important to consider the collection of community-level data (where feasible, depending on the method, and while also having focal species), as well as the potential to collect information to inform and support regional and community-level assessments that may not directly be used in the study (e.g., tissue sampling during telemetry deployment).

7.3 Data Sharing and Coordination

Study plans should include a clearly delineated process and timeline for sharing study results, including with federal and state agencies, collaborators, and the broader public. This includes publication of scientific papers and reports, as well as raw dataset(s) following QA/QC procedures (Regional Synthesis Workgroup 2023) and associated metadata. Data sharing and coordination are essential components of a study plan to (1) ensure that results are disseminated effectively, (2) reduce potential duplication of effort, and (3) ensure that data can be used to help answer regional-scale research questions. This topic is addressed in further detail in Section 8.

8.0 Data Consistency and Transparency Recommendations

Collection of avian data in relation to offshore wind energy projects should be standardized and conducted in as transparent a manner as possible. Detailed recommendations for the content and format of observational survey data are included in Section 10, but regardless of study method, this expectation for data consistency and transparency includes:

- Coordination with regulatory agencies such as BOEM and USFWS throughout the study design and implementation process to ensure adequacy, timeliness, and scientific robustness.
- Communication and coordination with others collecting similar data to help ensure consistency, as well as with regional entities including the Regional Wildlife Science Collaborative to ensure that data collection can support regional research. Ideally this should occur on a national and even international scale, but at minimum, coordination should occur among those working within the same ocean basin. If there are no publicly available protocols for a specific study type, then development of a project-specific protocol should (1) incorporate expert support to inform study plans, and (2) include publication or dissemination of the final protocol, so that others can reference it and use it for future studies.
- Implementing formal data sharing agreements among data funders, operators, and those analyzing results, if applicable (NYSERDA 2021), to ensure that expectations and intellectual property rights among collaborators are clearly defined at the outset, and that all data that are not commercially sensitive are made available to the public in a timely manner.
- **Standardized public reporting,** including information on data collection methods, spatial and temporal coverage, effect size, uncertainty, and analytical assumptions, as well as sharing of analytical code (when relevant). Sufficient information should be provided so that the study could be repeated from the description. This will also facilitate integration of data into future meta-

analyses and other regional assessments. Key aspects of reporting should be tailored to the data type and study, but should, at minimum, include the following:

  - **Study design information**, including sample size, spatial and temporal scale, response variables, and analytical approaches.
  - **Results**, including effect sizes and associated uncertainty and parameter estimates for all statistical tests (even non-significant ones).
  - **Potential sources of variation**, including information on site characteristics (e.g., latitude and longitude, size of the OSW project footprint, distance between turbines, number of turbines, water depth, and distance to shore).

- Making data publicly available as soon as possible, but within a maximum of two years following collection, if feasible. This includes public access to raw dataset(s) (following QA/QC processes), co-collected environmental covariate data (where relevant), effort data (where relevant), comprehensive metadata (NYSERDA 2021), and code used to conduct final analyses. Prior to data collection, a study plan should be developed that includes a plan to (1) collect, manage, and store data in an appropriate format for seamless integration into a public database (where available), and (2) deliver the data to the publicly available repository or otherwise make the data publicly available. The release of datasets may occur in multiple stages (e.g., initial release to federal agencies vs. fully public datasets) but should occur in a transparent and clearly defined process.
  - For multi-year data collection, subsets of data should be released as they are finalized to ensure that the data can be incorporated in a timely way into broader efforts.
  - Sharing of data summaries or derived data products, such as density maps, is also important (see below) but does not replace making full datasets publicly available to facilitate re-analysis of data, assessments of cumulative impacts, and incorporation of data into future regional analyses. Sharing data with research collaborators likewise does not replace making full datasets publicly available.
  - Recommended databases for housing different wildlife data types are discussed in a recent NYSERDA (2021) report, "Wildlife Data Standardization and Sharing: Environmental Data Transparency for New York State Offshore Wind Energy." Specific suggestions for observational survey data are further discussed in Section 10.
  - Appropriate metadata standards, such as the International Organization for Standardization (ISO) standards finalized in 2003 and endorsed by the Federal Geographic Data Committee[4], should be followed for development of comprehensive metadata for both spatial and non-spatial data types (NYSERDA 2021).
  - Reports, analyses, and journal publications (below) can continue to be pursued after public release of the underlying data. Contracts and data-sharing agreements with researchers and subcontractors should make this expectation explicit prior to the initiation of data collection.
- Contributing derived analytical products to data portals, such as the Northeast and Mid-Atlantic Ocean Data Portals. Summary products, such as maps and modelled estimates of abundance, occupancy, or habitat use, can aid in user interpretation (NYSERDA 2021).
- Publishing study results in primary literature to facilitate scientific review of study methods and results and provide even greater transparency (NYSERDA 2021).

[4] Federal Geographic Data Committee FGDC; https://www.fgdc.gov/metadata/iso-standards