# Appendix C. Literature Review: Macro- to Meso-Scale Changes in Marine Bird Distributions and Habitat Use

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.

# Appendix C. Literature Review: Macro- to Meso-Scale Changes in Marine Bird Distributions and Habitat Use

As an initial step in developing recommendations for pre- and post-construction monitoring of marine birds, we conducted a literature review of existing studies focused on marine bird displacement, attraction, and macro- to meso-scale avoidance, the methods and results of which are summarized in this appendix. This literature review had three inter-related goals:

- Aid in the identification of questions that various monitoring methods (e.g., surveys, telemetry, radar) are designed to answer and the strengths and limitations of each method (informing Sections 4 and 6 of this document).
- Quantify the degree of attraction/displacement expected to occur for various avian taxa during relevant life history stages in the U.S. Atlantic, based on previous studies (informing Section 5).
- Develop recommendations for when to use, and how to design, observational surveys that are intended to detect displacement, attraction, and avoidance (Sections 6–7 and 10).

In addition to the summary presented here, members of the Specialist Committee and support staff have used the database of studies developed during this effort to conduct a quantitative meta-analysis of studies that used observational survey methods (Lamb et al. 2024).

## C.1 Methods

### *C.1.1 Source Identification*

Several recent review papers have examined aspects of displacement, attraction, and macro- to meso-scale avoidance of marine birds at offshore wind facilities, including Dierschke et al. (2016) and Cook et al. (2018), which were used as key resources to identify source documents (*n*=35) for this literature review. Additional potential source documents were compiled via a Google Scholar search (*n*=88) and a search of the Tethys Knowledge Base (*n*=15 additional sources) and via expert elicitation with the Specialist Committee (*n*=6; Figure C1). Google Scholar search terms included: Avian/birds/seabirds + “offshore wind”/”offshore wind farm”/”offshore wind energy”/”marine wind”/”marine wind farm” + displacement/attraction/avoidance. The Tethys Knowledge Base was filtered based on the following filters: Wind energy/fixed offshore wind/floating offshore wind +attraction/avoidance/displacement + birds/seabirds. Following compilation of sources from review papers and online searches, the Specialist Committee reviewed the sources and identified additional potential sources for consideration. Compiled studies primarily drew from the scientific literature, but also included gray literature, where applicable (e.g., government reports and monitoring reports from individual wind facilities in Europe).

Following compilation, source documents were screened for relevance, and studies were included in the literature review if they used empirical data from field studies to directly examine displacement, attraction, macro-avoidance, or meso-scale avoidance of offshore wind facilities by marine birds. Sources that were excluded from further review included those focused on methods development, risk assessments (e.g., from Construction and Operations Plans), monitoring or mitigation plans, and publications on effects irrelevant to displacement (e.g., micro-avoidance, collision risk). Sources were also excluded if their data were redundant with another study. In instances of duplicative data (e.g., multiple monitoring reports from the same OSW project site), the more inclusive study was used. The final list of sources included 24 journal articles and 30 reports, in addition to one conference abstract (Table C1). The initial literature review was conducted in April 2022, with several additional sources added in May 2023.

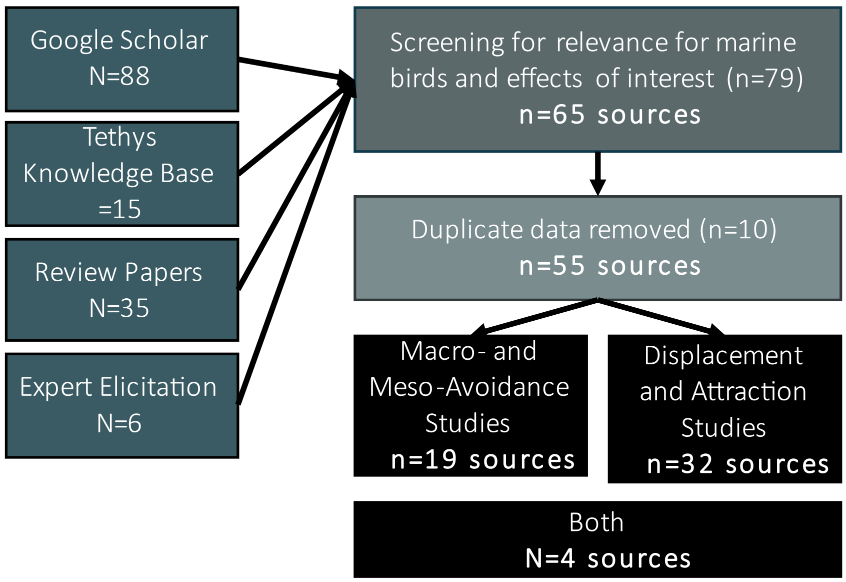


***Figure C1***. *Process for collation of sources for literature review on displacement, attraction, and macro- to meso-scale avoidance of marine birds at offshore wind facilities.*

### *C.2.2 Data Extraction*

Results from the 55 identified sources (Table C1) were manually extracted, including:

- Research question or hypothesis that the study aimed to address.
- Focal species/taxa.
- Species group (e.g., Auks, Gannets, Gulls, Terns, Cormorants, Waterfowl, Loons, Jaegers/Skuas, Tubenoses, All; see Table C3 for list of species included in each group).
- Field study methods (e.g., boat-based survey, visual aerial survey, digital aerial survey, combined survey methods, satellite telemetry, GPS telemetry, geolocator, radar, visual observations, and camera tracking system).
- Stage in annual cycle (e.g., breeding, non-breeding, migration, year-round).
- Distance from study colony (only applicable to telemetry studies conducted during the breeding season).
- Life history stage (e.g., juvenile, adult, all).
- Type of study – definitions modified from Methratta (2021). Options included:
    - Before-after control-impact (BACI) study – A single impact area, defined as the project footprint or project footprint + buffer, is compared with a (theoretically unimpacted) control area both before and after construction of the project in the impact area. Does not include multiple buffers for comparison (see distance-stratified BACI, below);
    - Before-after gradient (BAG) - comparison of impact area + buffer before and after construction to looks at differences in distributions and abundance in relation to distance from the nearest turbine - this may include a stratified gradient (i.e., distance bands);

*Table C1*. *Sources used in literature review on displacement/attraction (D/A) and macro- and meso-scale avoidance (Avoid) of marine birds in relation to offshore wind development. Links to source documents are included in literature cited when available.*

| Citation | D/A | Avoid | Methods |
|---|---|---|---|
| Aumuller et al. 2013 | X | X | Visual Observations |
| Blew et al. 2008 | | X | Radar, Visual Observations |
| Camphuysen 2011 | | X | GPS telemetry |
| Canning et al. 2013 | X | | Boat-based surveys |
| Christensen and Hounisen 2005 | | X | Radar, Visual Observations |
| Clewley et al. 2021 | X | | GPS telemetry |
| Degraer et al. 2021 | X | | GPS telemetry |
| Desholm and Kahlert 2005 | | X | Radar |
| Garthe et al. 2017 | | X | GPS telemetry |
| Gill et al. 2008 | X | | Visual Aerial surveys |
| Goddard et al. 2017 | X | | Digital aerial surveys |
| Guillemette et al. 1998 | X | | Visual Aerial surveys, Visual observations |
| Heinanen et al. 2020 | X | | Digital aerial survey, Satellite telemetry |
| Johnston et al. 2022 | X | | GPS telemetry |
| Kahlert et al. 2004 | X | | Radar |
| Krijgsveld et al. 2011 | | X | Radar, Visual Observations |
| Lane et al. 2020 | | X | GPS telemetry |
| Larsen and Guillemette 2007 | | X | Visual observations |
| Leopold et al. 2013 | X | | Boat-based survey |
| Masden et al. 2009 | X | | Radar |
| Mendel 2012 | X | | Visual aerial survey |
| Mendel et al. 2019 | X | | Combined survey methods |
| Nilsson and Green 2011 | X | X | Radar, Boat-based survey, Visual aerial survey |
| PMSS 2006 | X | | Boat-based survey, Visual aerial survey |
| Percival 2013 | X | | Boat-based survey |
| Percival et al. 2014 | X | | Boat-based survey |
| Perrow et al. 2006 | X | | Boat-based survey |
| Perrow et al. 2015 | | X | Visual observations |
| Peschko et al. 2020a | X | | GPS telemetry |
| Peschko et al. 2020b | X | | Combined survey methods |
| Peschko et al. 2021 | X | X | GPS telemetry |
| Petersen and Fox 2007 | X | | Visual aerial survey |
| Petersen et al. 2006 | X | X | Visual aerial survey, Radar |
| Petersen et al. 2011 | X | | Visual aerial survey |
| Petersen et al. 2014 | X | | Visual aerial survey |
| Pettersson 2005 | | X | Radar, Visual Observations |
| Plonczkier and Simms 2012 | X | X | Radar |
| Rehfisch et al. 2014 | X | | Digital aerial survey |
| Rehfisch et al. 2016 | X | | Combined survey methods |
| Rexstad and Buckland 2012 | X | | Boat-based survey |
| Rothery et al. 2009 | | X | Visual observations |
| Skov et al. 2012a | | X | Radar |
| Skov et al. 2018 | | X | Radar, Camera tracking system |
| Thaxter et al. 2015 | X | | GPS telemetry |
| Thaxter et al. 2018 | | X | GPS telemetry |
| Trinder et al. 2019 | X | | Digital aerial survey |
| Tulp et al. 1999 | | X | Radar |
| Vallejo et al. 2017 | X | | Boat-based survey |
| Vanermen et al. 2015a | X | | Boat-based survey |
| Vanermen et al. 2016 | X | | Boat-based survey |
| Vanermen et al. 2020 | X | X | GPS telemetry |
| Vilela et al. 2021 | X | | Combined survey methods |
| Welcker and Nehls 2016 | X | | Boat-based survey |

- After gradient (AG) - similar to BAG design but only includes data collection after impact (e.g., examines post-construction distributions relative to the wind facility using a gradient sampling design), rather than comparing gradients before and after construction;
- After control-impact (ACI) - similar to BACI design, but only includes data collection after impact. This category includes studies that don't have a pre-defined "control" area but make comparisons between "inside" vs. "outside" of the wind facility;
- Distance-stratified (DS) BACI – BACI study that includes comparison of a control area with locations at multiple distances from the centroid of the "impact area", which can include both the wind facility and buffer area. Must have data both before and after construction, and must have a control;
- Distance-stratified CI – control-impact study that only includes data collection after impact and compares a control with locations at multiple distances from the centroid of the impact area. Must have a control; and
- Before-After Impact (BAI) - comparison of the impact area pre- vs. post-construction, with no control, no buffer area, and no gradient sampling design.

- Scale of inference – in most cases, this includes the area around the wind facility for which data was collected and inference was made. For surveys, this includes the OSW project footprint(s) and buffer areas; for observational studies, the scale of inference includes the wind facility(s), the location(s) from which observations were made, and size of the area observed; and for tracking studies, it includes information on sample size.
- Response type detected – displacement, attraction, no displacement/attraction, macro-scale avoidance, no macro-scale avoidance, meso-scale avoidance, no meso-scale avoidance. Avoidance is defined as changes in directed movements, while displacement includes changes in habitat use for activities such as foraging and roosting (Appendix B).
- Metric used in reporting the results.
- Response value, if available, and whether it was statistically significant (if tested).
- Offshore wind facility characteristics, if available, including name, distance to shore (measured as closest edge of the project footprint to nearest coastline), footprint area, maximum water depth within the footprint, number of turbines, turbine height, latitude, and region.

If multiple research questions, field study methods, focal species, or wind facilities were included in the same source and results were reported separately, results were summarized separately for the literature review and considered as separate 'studies'. Source documents did not consistently report wind facility characteristics; thus, these metrics were extracted from Cook et al. (2018) and other sources where needed[11]. In a few cases, where distance metrics were not reported in source documents and could not be extracted from other available sources, distances/areas were measured on maps in source documents using the Adobe Acrobat Pro Measure Tool (Adobe Acrobat Pro 2017). In instances where multiple wind facilities were included in a single study without separately reported results, characteristics were summarized across wind facilities, with the summary statistic varying by characteristic: distance to shore (mean), footprint size (sum), number of turbines (sum), maximum water depth (mean), turbine height (mean), and latitude (mean).

[11] Additional sources of wind farm information included thewindpower.net, Wikipedia, and websites of individual wind facilities.

To help inform recommendations on study design and choice of focal species (Sections 5–7), we summarized results across studies to examine whether factors such as taxonomic group, study type, study design, and location influenced the likelihood of detecting effects.

## C.3 Results

Studies included a wide range of field methods (Table C2), analytical approaches, and reporting. Almost all studies were from the North Sea (*n*=42), with a smaller number from the Baltic Sea (*n*=12) and Celtic Sea (*n*=4; Figure C2). Sources included studies that used observational surveys, individual tracking, radar, and visual observations (Table C2). Most sources examining displacement/attraction used observational surveys (boat-based surveys *n*=12, visual aerial surveys *n*=9, digital aerial surveys *n*=4, combined survey methods *n*=4), with various study designs (BAG, BACI, DS-BACI, ACI), though several studies also used visual observations (*n*=2), radar (*n*=3) or GPS/satellite telemetry (n=8). Macro and meso-scale avoidance studies primarily used radar (*n*=11), visual observations (*n*=8), and GPS telemetry (*n*=6), with one study involving a camera tracking system. In many cases, sources examined effects on multiple taxa (Figure C3).

In some cases, source studies also examined multiple taxa and/or multiple offshore wind facilities. The results reported separately were considered separate 'studies' within source documents and summarized as such. Studies focused on a variety of marine bird taxa, with a majority focusing on auks, cormorants, gulls, gannets, terns, loons, and waterfowl, with a few studies of skuas and of petrels (e.g., Manx Shearwater, Northern Fulmar; Table C3). The type of observed response varied by taxon (Table C3) and by individual study. For all groups, variation in the type of response across studies likely related to study conditions and study design. Even for species with common behavioral responses to offshore wind development, there were also findings of null effects from many studies, often related to study design choices such as selection of buffer zone size (Table C4) as well as other factors.

***Table C4.*** *Sample size of study methods represented in the source studies. In some cases, the same study used multiple methods (Table C1), and therefore the number of sources in the table does not add up to the total number of sources included in the literature review.*

| Method Type | Total sources (*n*) |
|---|---|
| Boat-based surveys | 12 |
| Digital aerial surveys | 4 |
| Visual aerial surveys | 9 |
| Multiple survey methods | 4 |
| GPS Telemetry | 11 |
| Satellite Telemetry | 1 |
| Visual observations | 9 |
| Radar | 13 |
| Camera tracking system | 1 |

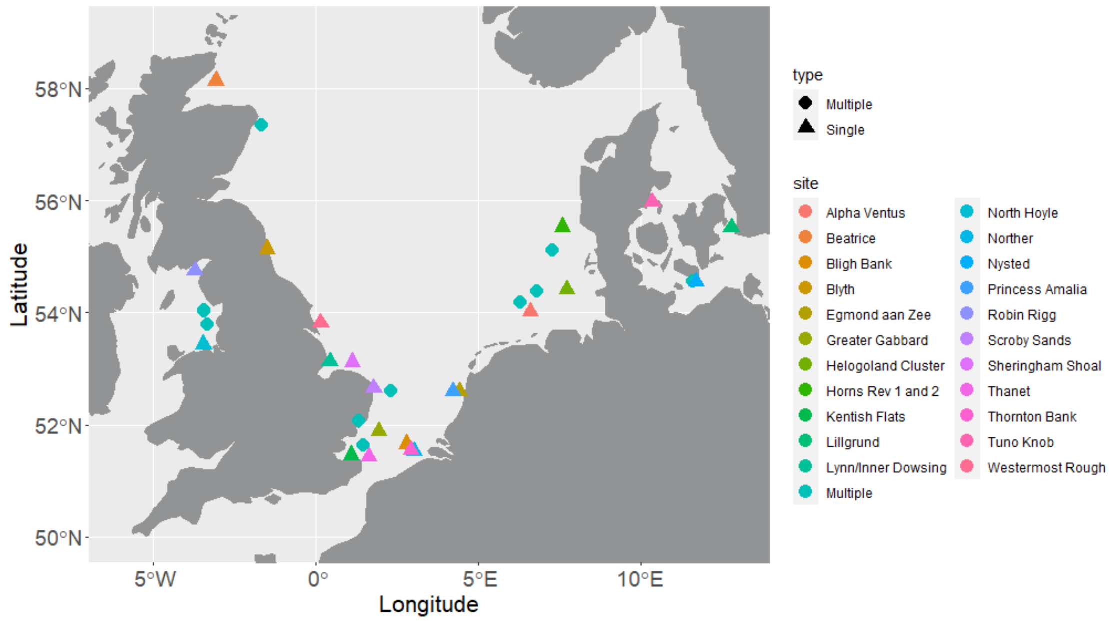


*Figure C2.* *Locations of studies included in the literature review of displacement, attraction, and macro- to meso-scale avoidance of marine birds to offshore wind facilities. Colors indicate studies at different offshore wind development facilities, including individual projects (triangles), or across multiple project sites (circles). For the latter, the latitude and longitude across wind facilities were averaged.*

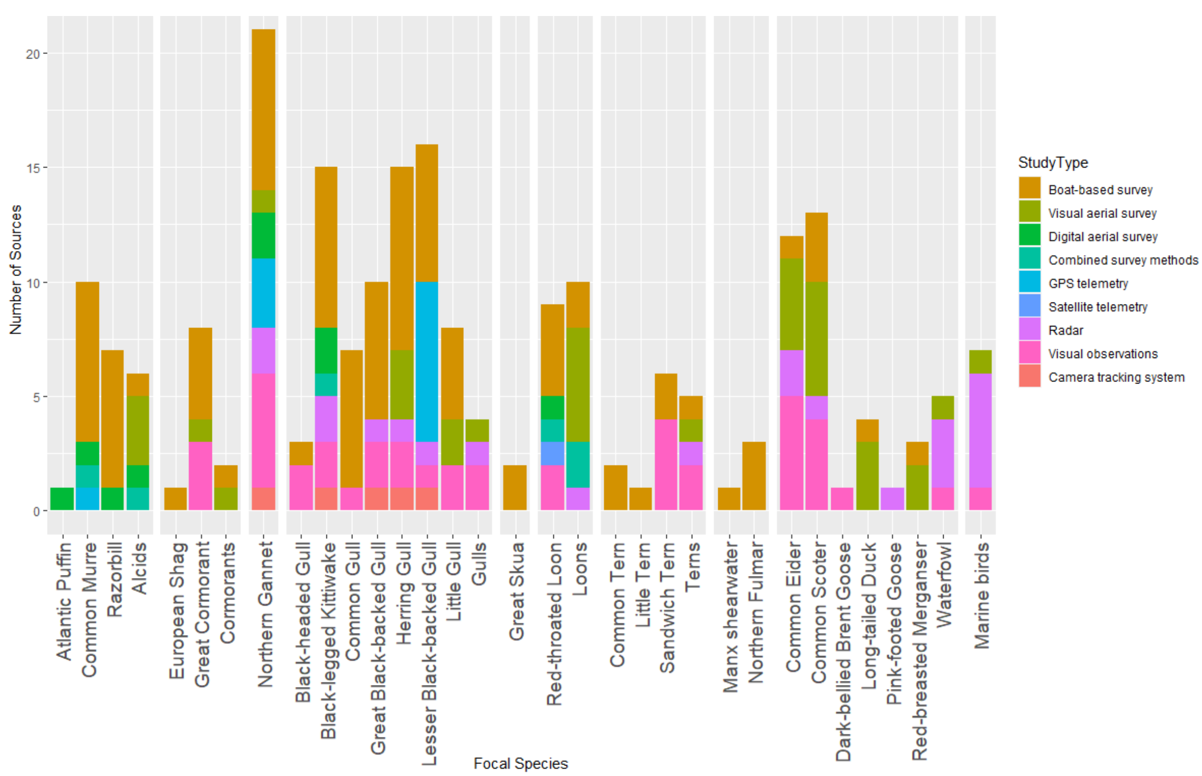


*Figure C3.* *Number of sources by marine bird species and study method. Individual sources may have examined effects on multiple marine bird species or groups or utilized multiple study methods.*

Of the taxonomic groups examined in the literature review, auks and loons exhibited the most consistent evidence of displacement and macro-avoidance; Northern Gannets and waterfowl also tended to exhibit displacement as well as macro- and meso-avoidance. Cormorants generally exhibited attraction, while gulls and terns showed the most variable responses, including both attraction and displacement as well as inconsistent macro-avoidance responses across studies (Table C3). However, in the few studies in which meso-avoidance was examined, this response was identified consistently across species. Finally, the effects on skuas and on petrels were inconclusive, due to their underrepresentation in the reviewed studies.

***Table C2****. Number of studies (by focal taxon) that found different types of responses. Studies examining displacement and attraction found responses of displacement (-), no effect (0) or attraction (+), while macro- and meso-avoidance studies either found evidence of avoidance (-) or no avoidance (0).*

| | | Displacement and/or Attraction | | | Macro-avoidance | | Meso-avoidance | |
|---|---|---|---|---|---|---|---|---|
| Taxa Group | Focal Species | - | 0 | + | - | 0 | - | 0 |
| Auks | Atlantic Puffin | 1 | | | | | | |
| | Common Murre | 7 | 4 | | | | | |
| | Razorbill | 5 | 3 | | | | | |
| | Auk spp. | 3 | 3 | | | | | |
| Cormorants | European Shag | | | 1 | | | | |
| | Great Cormorant | | 3 | 3 | 1 | 3 | | |
| | Cormorant spp. | | 1 | | | | | |
| Gannets | Northern Gannet | 8 | 2 | 1 | 9 | 1 | 1 | |
| Gulls | Black-headed Gull | | 1 | | | 2 | | |
| | Black-legged Kittiwake | 5 | 6 | 1 | 2 | 2 | 1 | |
| | Common Gull | | 6 | 1 | | 1 | | |
| | Great Black-backed Gull | | 4 | 2 | 1 | 2 | 1 | |
| | Herring Gull | 2 | 6 | 4 | 1 | 2 | 1 | |
| | Lesser Black-backed Gull | 4 | 5 | 4 | 2 | 2 | 3 | |
| | Little Gull | 3 | 3 | 1 | 1 | 1 | | |
| | Gull spp. | | 1 | | 4 | | | |
| Skuas | Great Skua | | 2 | | | | | |
| Loons | Red-throated Loon | 4 | 3 | | 2 | | | |
| | Loon spp. | 8 | 3 | | 1 | | | |
| Terns | Common Tern | 1 | 2 | | | | | |
| | Little Tern | | 1 | | | | | |
| | Sandwich Tern | | 2 | | 1 | 3 | 1 | |
| | Tern spp. | 2 | | | 3 | | | |
| Petrels | Manx Shearwater | | 1 | | | | | |
| | Northern Fulmar | | 3 | | | | | |
| Waterfowl | Common Eider | 5 | 2 | | 5 | 2 | 1 | |
| | Common Scoter | 4 | 4 | 1 | 4 | 2 | | |
| | Dark-bellied Brent Goose | | | | 1 | | | |
| | Long-tailed Duck | 4 | | | | | | |
| | Pink-footed Goose | | | | 1 | | | 1 |
| | Red-breasted Merganser | 2 | | 1 | | | | |
| | Waterfowl spp. | | 1 | | | | | |
| All | Marine birds | 2 | | | 5 | 1 | | |

### *C.3.1 Displacement and Attraction*

Auks, loons, gannets, and waterfowl exhibited strong evidence of displacement effects from offshore wind facilities in Europe, while cormorants showed evidence of attraction. Across and within gull species, there was high variability in observed responses, in some cases with similar numbers of studies showing displacement, no change, and attraction (e.g., Lesser Black-backed Gull). Other groups, including terns, petrels, and skuas, had few studies making it difficult to draw conclusions on potential patterns of responses. Atlantic Puffins and Black-headed Gull were excluded from further assessment of the types of study designs that produced different effects findings (Table C4; Table C5) as there was only one study for each species. For Atlantic Puffins, the one study found evidence of displacement, while for Black-headed Gull there was no evidence of displacement or attraction.

There was variation in observed responses (e.g., whether or not displacement or attraction effects were detected in studies) that related to factors including season, location, and inclusion of construction period data. While most studies examined year-round changes in distributions (primarily utilizing observational surveys or individual tracking), one study compared effects between the non-breeding and breeding season and found a greater change (e.g., stronger displacement effect) during the non-breeding season compared with the breeding season for Common Murres, while there was a significant displacement effect in Black-legged Kittiwakes only during the breeding season but not with all seasons combined (Peschko et al. 2020b).

This review suggests that there may also be environmental and/or location-related factors influencing variation in response at the species level, such as turbine characteristics, distance to shore, level of habitat use prior to construction, or other factors. Multiple sources used the same study design to compare displacement effects across multiple wind facilities with varying results. Leopold et al. (2013) found evidence of displacement at a larger OSW project further offshore for Razorbills and the opposite for Lesser Black-backed Gulls, with displacement effects only detected in the latter species at the smaller, more coastal project. Similarly, Petersen et al. (2006) only found evidence of displacement in Common Eiders at a smaller, nearshore wind facility as compared with a larger facility located farther offshore, where displacement was not detected. Individual-level responses may also vary. For both Northern Gannets and Common Murres, individual tracking studies found evidence that, while most individuals completely avoided project footprints, a small percentage (gannets 11%, Peschko et al. 2021; murres 17% Peschko et al. 2020a) entered the wind facility regularly (gannets) or on a few occasions (murres) with evidence of foraging behavior, suggesting individual variation in responses within species.

The inclusion of data during the construction period may have contributed additional variation in responses for some studies. For Northern Gannets, while most studies found evidence of displacement effects, one study found significant evidence of attraction when comparing pre- and post-construction; however, evidence from the latter study suggested that gannets were attracted to the wind facility during construction and were displaced following construction but to a smaller degree, resulting in an overall net finding of attraction when comparing pre- and post-construction periods (PMSS 2006). The same study found evidence of attraction in Black-legged Kittiwakes during construction, while all other studies of the species found either displacement or no effect, though all but one of those studies (Percival et al. 2013) lacked data during construction. As most studies focused on the pre- and post-construction periods, with little data available during construction, more evidence is needed draw conclusions related to attracted to construction activities. However, gannets have shown attraction to fishing vessels (Votier et al. 2010), and kittiwakes are particularly vulnerable to fisheries associations,

*Table C3.* *Summary of attraction/displacement findings by taxon and study design. For studies with evidence of displacement ('displacement results'), summary includes percentage of studies that detected displacement, the size of buffer zones examined for these studies (observational surveys only), and study design (BAG=Before-After-Gradient, BACI=Before-After-Control-Impact, ACI=After-Control-Impact, DS-BACI=Distance-stratified Before-After-Control-Gradient; all methods). If studies examined/reported the distance at which displacement was observed, values and number of studies is reported in the "Dist. Observed" column along with the buffer distances used in those studies. The buffer zone size range and study design are also reported for studies that found null effects or evidence of attraction. All distances and ranges are in kilometers.*

| Focal Species | | | Displacement Results | | | | | No Change Results | | | Attraction Results | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group | Species | Total (n) | % of Studies | Buffer Range (km) | Study Design | Dist. Observed (km) | Buffer (km) | % of Studies | Buffer Range (km) | Study Design | % of Studies | Buffer Range (km) | Study Design |
| Auks | Common Murre | 11 | 64% | 4-22 | BAG, DS-BACI, ACI | 9 (n=1) | 22 | 36% | 3-12 | DS-BACI, BAG | - | - | - |
| | Razorbill | 77 | 5757% | 3-10 | DS-BACI, BAG | 0.5 (n=2) | 3 | 43% | 3-10 | BACI, BAG | - | - | - |
| | Auk spp. | 6 | 50% | 3-6 | BAG, ACI | 2.5 (n=1) | 6 | 50% | 0-4 | BACI, DS-CI | - | - | - |
| Loons | Red-throated Loon | 55 | 6060% | 3-20 | BACI, DS-BACI | 3-15 (n=3) | 20 | 40% | 1.5 | BAG | - | - | - |
| | Loons | 11 | 73% | 3-30 | BACI, DS-BACI | 10-16.5 (n=3) | 20 | 27% | 4-10 | BACI, DS-BACI | - | - | - |
| Gannets | Northern Gannet | 100 | 800% | 3-11 | BAG, BACI, DS-BACI, ACI | 2-3.5 (n=2) | 4-11 | 10% | 3 | DS-BACI, BAG | 1010% | 3 | BAG |
| Waterfowl | Common Eider | 66 | 6767% | 2-4 | BACI, BAG | 2.5 (n=1) | 4 | 33% | 0-4 | BACI, BAG | - | | |
| | Common Scoter | 9 | 44% | 2-16 | BAG | 3-5 (n=2) | 4-16 | 45% | 0-4 | BACI, BAG | 11% | 4 | BAG |
| | Long-tailed Duck | 4 | 100% | 2-30 | BAG | 2 (n=1) | 4 | - | - | - | - | | |
| | Red-breasted Merganser | 3 | 66% | 24 | BAG | - | - | - | - | - | 33% | 4 | BAG |
| Cormorants | Great Cormorant | 6 | 0% | - | - | - | - | 50% | 1.5-2 | BAG | 50% | 3-10 | BAG |
| | European Shag | 1 | 0% | - | - | - | - | - | - | - | 100% | 3 | BAG |
| Gulls | Black-legged Kittiwake | 12 | 42% | 0.5-22 | BAG, BACI, DS-BACI, ACI | - | - | 50% | 0.5-22 | BAG, ACI, DS-BACI | 8% | 3 | BAG |
| | Common Gull | 7 | 0% | - | - | - | - | 86% | 0.5-10 | BAG, DS-BACI, BACI | 14% | 3 | DS-BACI |
| | Great Black-backed Gull | 6 | 0% | - | - | - | - | 67% | 0.5-10 | BAG, DS-BACI | 33% | 0.5 | BACI, ACI |
| | Herring Gull | 12 | 17% | 3-4 | BAG | - | - | 50% | 0.5-10 | BAG, BACI, DS-BACI | 33% | 2-24 | BAG, DS-BACI |
| | Lesser Black-backed Gull | 13 | 31% | 3-10 | BACI, BAG, ACI, AG | 2 (n=1) | 3 | 38% | 0.5-10 | BAG, BACI, DS-BACI, ACI | 31% | 3 | AG, ACI, DS-BACI |
| | Little Gull | 7 | 42% | 0.5-10 | BAG, BACI, ACI | 1.5 (n=1) | 3 | 44% | 0.5-10 | BAG, DS-BACI | 14% | 4 | BAG |

*Table C4. Summary of displacement and attraction studies using observational survey methods (boat-based, visual aerial, digital aerial, or combined survey types) including source, focal species (or taxonomic group), stage in the annual cycle (All=year-round, B=breeding season, NB=non-breeding season, offshore wind facility site name, study design (BAG=Before-After-Gradient, BACI=Before-After-Control-Impact, ACI=After-Control-Impact, DS-BACI=Distance-stratified Before-After-Control-Gradient), type of response observed (* indicates statistical significance, lack of * indicates that statistical significance was not tested, such that Displacement*=Significant displacement while Displacement = no statistical test run but evidence of displacement, while No Effect*=If displacement was detected, it was not statistically significant). Buffer indicates the distance around the wind facility surveyed (in kilometers); ~ indicates distance was not reported and was estimated from maps, ranges indicate different sizes of buffers on different sides of the offshore wind facility, and multiple values indicate strata used for DS-BACI approaches. Dist indicates the distance (in kilometers) at which the response was detected (if examined).*

| Source | Focal Species | Study Method | Stage | Site Name | Design | Response | Buffer (km) | Dist (km) |
|---|---|---|---|---|---|---|---|---|
| Rehfisch et al. 2016 | Auk spp. | Combined | NB | Multiple | AG | Displacement* | 15 | |
| Petersen and Fox 2007 | Auk spp. | Visual aerial | All | Horns Rev 1 | BAG | Displacement* | 4 | |
| Welcker and Nehls 2016 | Auk spp. | Boat-based | All | Alpha Ventus | ACI | Displacement* | 3 | 2.5 |
| Goddard et al. 2017 | Auk spp. | Digital aerial | B | Westermost Rough | AG | No Effect* | 9 | |
| Gill et al. 2008 | Auk spp. | Visual aerial | All | Kentish Flats | BACI | No Effect* | 3 | |
| Petersen et al. 2006 | Auk spp. | Visual aerial | All | Horns Rev 1 | BAG | No Effect* | 4 | |
| Leopold et al. 2013 | Common Murre | Boat-based | All | Egmond aan Zee | BAG | Displacement* | ~4-10 | |
| Leopold et al. 2013 | Common Murre | Boat-based | All | Princess Amalia | BAG | Displacement* | ~4-10 | |
| Percival 2013 | Common Murre | Boat-based | All | Thanet | DS-BACI | Displacement* | 0, 0.5, 1, 2, 3 | 1 |
| Peschko et al. 2020b | Common Murre | Combined | NB | Multiple | BAG | Displacement* | ~10-22 | 9 |
| Peschko et al. 2020b | Common Murre | Combined | B | Multiple | BAG | Displacement* | ~10-22 | |
| Vanermen et al. 2015a | Common Murre | Boat-based | All | Bligh Bank | DS-BACI | Displacement* | 0, 0.5, 3 | |
| Vanermen et al. 2016 | Common Murre | Boat-based | All | Thornton Bank | BACI | Displacement* | 0.5 | |
| PMSS 2006 | Common Murre | Boat-based | All | North Hoyle | BAG | No Effect* | 3 | |
| Vallejo et al. 2017 | Common Murre | Boat-based | All | Robin Rigg | BAG | No Effect* | ~5-12 | |
| Percival 2013 | Common Murre | Boat-based | All | Thanet | DS-BACI | No Effect* | 0, 0.5, 1, 2, 3 | 0.5 |
| Trinder et al. 2019 | Common Murre | Digital aerial | B | Beatrice | BACI | No Effect* | 2 | |
| Leopold et al. 2013 | Razorbill | Boat-based | All | Princess Amalia | BAG | Displacement* | ~4-10 | |
| Percival 2013 | Razorbill | Boat-based | All | Thanet | DS-BACI | Displacement* | 0, 0.5, 1, 2, 3 | 0.5 |
| PMSS 2006 | Razorbill | Boat-based | All | North Hoyle | BAG | Displacement | 3 | |
| Vanermen et al. 2015a | Razorbill | Boat-based | All | Bligh Bank | DS-BACI | Displacement* | 0.5, 3 | 0.5 |
| Leopold et al. 2013 | Razorbill | Boat-based | All | Egmond aan Zee | BAG | No Effect* | ~4-10 | |
| Vanermen et al. 2016 | Razorbill | Boat-based | All | Thornton Bank | BACI | No Effect* | 0.5, 3 | |

| Source | Focal Species | Study Method | Stage | Site Name | Design | Response | Buffer (km) | Dist (km) |
|---|---|---|---|---|---|---|---|---|
| Trinder et al. 2019 | Razorbill | Digital aerial | B | Beatrice | BACI | No Effect* | 2 | |
| PMSS 2006 | Northern Gannet | Boat-based | All | North Hoyle | BAG | Attraction* | 3 | |
| Leopold et al. 2013 | Northern Gannet | Boat-based | All | Egmond aan Zee | BAG | Displacement* | ~4-10 | |
| Leopold et al. 2013 | Northern Gannet | Boat-based | All | Princess Amalia | BAG | Displacement* | ~4-10 | |
| Petersen et al. 2006 | Northern Gannet | Visual aerial | All | Horns Rev 1 | BAG | Displacement* | 4 | |
| Rehfisch et al. 2014 | Northern Gannet | Digital aerial | NB | Greater Gabbard | BAG | Displacement* | ~4-11 | 2 |
| Vanermen et al. 2015a | Northern Gannet | Boat-based | All | Bligh Bank | DS-BACI | Displacement* | 0.5, 3 | |
| Vanermen et al. 2016 | Northern Gannet | Boat-based | All | Thornton Bank | BACI | Displacement* | 0.5 | |
| Welcker and Nehls 2016 | Northern Gannet | Boat-based | All | Alpha Ventus | ACI | Displacement | 0.3 | |
| Trinder et al. 2019 | Northern Gannet | Digital aerial | B | Beatrice | BACI | Displacement* | 2 | |
| Percival 2013 | Northern Gannet | Boat-based | All | Thanet | DS-BACI | No Effect* | 0, 0.5, 1, 2, 3 | |
| Leopold et al. 2013 | Loons | Boat-based | All | Egmond aan Zee | BAG | Displacement* | ~4-10 | |
| Mendel 2012 | Loons | Visual aerial | NB | Alpha Ventus | BAG | Displacement* | 0, 2, 5, 10, 20, 30 | 2-20[12] |
| Mendel et al. 2019 | Loons | Combined | NB | Multiple | BAG | Displacement* | 36[13] | 16.5 |
| Petersen and Fox 2007 | Loons | Visual aerial | All | Horns Rev 1 | BAG | Displacement* | 4 | |
| Petersen et al. 2006 | Loons | Visual aerial | All | Horns Rev 1 | BAG | Displacement* | 4 | |
| Petersen et al. 2014 | Loons | Visual aerial | All | Horns Rev 2 | BAG | Displacement* | 10-16 | 13 |
| Vilela et al. 2021 | Loons | Combined | NB | Multiple | ACI | Displacement | 0 | |
| Welcker and Nehls 2016 | Loons | Boat-based | All | Alpha Ventus | ACI/AG | Displacement | 3 | 2 |
| Gill et al. 2008 | Loons | Visual aerial | All | Kentish Flats | BACI | No Effect* | 3 | |
| Leopold et al. 2013 | Loons | Boat-based | All | Princess Amalia | BAG | No Effect* | ~4-10 | |
| Petersen et al. 2006 | Loons | Visual aerial | All | Nysted | BAG | No Effect* | 4 | |
| Heinanen et al. 2020 | Red-throated Loon | Digital aerial | NB | Multiple | BAG | Displacement* | 20 | 10 |
| Percival 2013 | Red-throated Loon | Boat-based | All | Thanet | DS-BACI | Displacement* | 0, 0.5, 1, 2, 3 | 0.5 |
| Percival 2014 | Red-throated Loon | Boat-based | NB | Kentish Flats | DS-BACI | Displacement* | 0, 0.5, 1, 2, 3 | |
| Rehfisch et al. 2016 | Red-throated Loon | Combined | NB | Multiple | AG | No Effect | 15 | |

[12] 100% displacement at 2 km from wind farm, significant decrease up to 20 km strata, with significant increase in 30 km strata.
[13] Average buffer distance, variable around different wind farms, with minimum of 19 km and a maximum of 79 km.

| Source | Focal Species | Study Method | Stage | Site Name | Design | Response | Buffer (km) | Dist (km) |
|---|---|---|---|---|---|---|---|---|
| Rexstad and Buckland 2012 | Red-throated Loon | Boat-based | All | Kentish Flats | BAG | No Effect | 1.5 | |
| Nilsson and Green 2011 | Common Eider | Boat-based | NB | Lillgrund | BAG | Displacement | 2 | |
| Nilsson and Green 2011 | Common Eider | Visual aerial | NB | Lillgrund | BAG | Displacement | 2 | |
| Petersen and Fox 2007 | Common Eider | Visual aerial | NB | Horns Rev 1 | BAG | Displacement* | 4 | |
| Petersen et al. 2006 | Common Eider | Visual aerial | All | Nysted | BAG | Displacement* | 4 | |
| Guillemette et al. 1998 | Common Eider | Visual aerial | NB | Tunø Knob | BACI | No Effect* | 0 | |
| Petersen et al. 2006 | Common Eider | Visual aerial | All | Horns Rev 1 | BAG | No Effect* | 4 | |
| Petersen and Fox 2007 | Common Scoter | Visual aerial | NB | Horns Rev 1 | BAG | Attraction* | 4 | |
| Leopold et al. 2013 | Common Scoter | Boat-based | All | Egmond aan Zee | BAG | Displacement* | ~4-10 | |
| Petersen et al. 2006 | Common Scoter | Visual aerial | All | Horns Rev 1 | BAG | Displacement* | 4 | |
| Petersen et al. 2006 | Common Scoter | Visual aerial | All | Nysted | BAG | Displacement* | 4 | |
| Petersen et al. 2014 | Common Scoter | Visual aerial | NB | Horns Rev 2 | BAG | Displacement* | 10-16 | 5 |
| PMSS 2006 | Common Scoter | Boat-based | All | North Hoyle | BAG | Displacement* | 3 | |
| Guillemette et al. 1998 | Common Scoter | Visual aerial | NB | Tunø Knob | BACI | No Effect* | 0 | |
| Leopold et al. 2013 | Common Scoter | Boat-based | All | Princess Amalia | BAG | No Effect* | ~4-10 | |
| PMSS 2006 | Common Scoter | Visual aerial | NB | North Hoyle | BAG | No Effect* | 3 | |
| Nilsson and Green 2011 | Long-tailed Duck | Boat-based | NB | Lillgrund | BAG | Displacement | 2 | |
| Nilsson and Green 2011 | Long-tailed Duck | Visual aerial | NB | Lillgrund | BAG | Displacement | 2 | |
| Petersen et al. 2006 | Long-tailed Duck | Visual aerial | All | Nysted | BAG | Displacement* | 4 | |
| Petersen et al. 2011 | Long-tailed Duck | Visual aerial | NB | Nysted | BAG | Displacement* | ~10-30 | |
| Petersen et al. 2006 | Red-breasted Merganser | Visual aerial | All | Nysted | BAG | Attraction* | 4 | |
| Nilsson and Green 2011 | Red-breasted Merganser | Boat-based | NB | Lillgrund | BAG | Displacement | 2 | |
| Nilsson and Green 2011 | Red-breasted Merganser | Visual aerial | NB | Lillgrund | BAG | Displacement | 2 | |

including incidental take (Wong et al. 2018). It seems possible that bird responses to vessel activity, which is heaviest during the construction period, may be driving these patterns.

The only species exhibiting relatively consistent attraction across studies were the Great Cormorant and European Shag (Table C5). Great Cormorants tended to show stronger attraction to offshore wind facilities located farther from shore. They were attracted to facilities farther from shore (6–23 km, *n*=3 studies), compared to studies that found no effect (7–9 km; *n*=3 studies), though the buffer area surveyed was often small, particularly for those studies that found no effect. Given that cormorants may use offshore wind turbines as perching and roosting opportunities (Dierschke et al. 2016), perching opportunities may become more attractive at offshore wind projects located farther from shore where fewer natural structures exist.

Null effect studies (e.g., no displacement/attraction detected) included those that found non-significant displacement/attraction effects. In general, null effect studies had lower densities of the focal taxon pre-construction (e.g., low exposure), examined smaller buffer areas (for observational survey studies), and used a before-after-control-impact study design rather than a gradient design. Many of these were telemetry studies that only used data after construction to examine the behavior and habitat use of individuals, with variation in responses at different distances from facilities (Johnston et al. 2022). This suggests that buffer size, study design, and scale of the analysis play an important role in the ability to detect effects of offshore wind energy development on birds. In addition, while most studies used a single study method, Nilsson and Green (2011) compared data from boat-based and visual aerial surveys and found differences in responses of Herring Gulls by survey type. This further exemplifies the importance of careful consideration of study methods, ensuring that all methodological biases are controlled to the extent possible. No clear patterns were found regarding the effectiveness of different study methods for detecting displacement or attraction, likely due to the wide variation in implementation protocols within each study method. For additional recommendations on study design and choice of study method, see Sections 6-7 and (specifically for observational surveys) Section 10.

For observational surveys, we further summarized results by species, survey method, study design, response (including statistical significance), buffer size surveyed, and the distance at which an effect was detected (Table C5). These results exemplify the variation in study designs among studies, and in particular the variation in buffer areas surveyed outside of project footprints. Percent spatial coverage and the ratio of affected area to overall survey area were very infrequently reported, making additional inference around spatial coverage difficult. Despite the high number of observational surveys utilizing variations on the Before-After-Gradient study design, few reported effect distances in addition to effect detection.

Inconsistency in analysis and reporting complicated the summarization of data (see recommendations below), particularly as the choice of effect size metric was highly variable among studies and often lacked reporting of associated uncertainty, and buffers were implemented in different ways depending on the study design (e.g., some Before-After-Control-Impact studies included a buffer in the affected area in comparison with a control, while others did not). Thus, caution should be taken in using summary data from any individual study in the above tables to inform the design of future studies.

### *C.3.2 Macro- and Meso-Avoidance*

Macro- and meso-scale avoidance studies primarily used radar and visual observations or GPS telemetry, with many studies conducted during migration periods, particularly for waterfowl. The majority of findings focused on macro-avoidance and a few studies examined both macro- and meso-avoidance. Macro-avoidance detection varied by species, study design, and method (Table C6). Sources of variation were similar to those discussed above in relation to displacement/attraction studies. For example, macro-avoidance varied by life history stage for some species, including Great Cormorant, but not gulls or Common Scoter (Rothery et al. 2009).

***Table C5.*** *Evidence of macro-avoidance of offshore wind facilities by taxon and species, including the percent of studies that found evidence of macro-avoidance, the study design (BAI=Before-After-Impact, ACI=After Control-Impact, BAG=Before-After-Gradient, BACI=Before-After-Control-Impact), and the study method (radar, GPS tracking, visual observations) for studies that found macro-avoidance and those that found no response.*

| Taxa Group | Focal Species | Total Studies (n) | Studies Finding Macro-Avoidance | | | Studies Finding No Effect | | |
|---|---|---|---|---|---|---|---|---|
| | | | % of Studies | Study Design | Method | % of Studies | Study Design | Method |
| Cormorants | Great Cormorant | 4 | 25% | BAI | Visual Obs. | 75% | BAI, ACI | Visual Obs. |
| Gannets | Northern Gannet | 10 | 90% | ACI | GPS, Visual Obs., Radar | 10% | BAI | Visual Obs. |
| Gulls | Black-legged Kittiwake | 4 | 50% | ACI | Radar | 50% | BAI, ACI | Visual Obs. |
| | Great Black-backed Gull | 3 | 33% | ACI | Radar | 67% | BAI, ACI | Visual Obs. |
| | Herring Gull | 3 | 33% | ACI | Radar | 67% | BAI, ACI | Visual Obs. |
| | Lesser Black-backed Gull | 4 | 50% | ACI | GPS, Radar | 50% | ACI | Visual Obs., GPS |
| | Little Gull | 2 | 50% | ACI | Visual Obs. | 50% | ACI | Visual Obs. |
| | Gull spp. | 4 | 100% | ACI | Visual Obs., Radar | - | - | - |
| Terns | Sandwich Tern | 4 | 20% | BACI | Visual Obs. | 80% | ACI, BAI | Visual Obs. |
| | Tern spp. | 3 | 100% | ACI | Visual Obs., Radar | - | - | - |
| Waterfowl | Common Eider | 7 | 71% | ACI, AG, BAG, BACI | Visual Obs., Radar | 29% | BAI | Visual Obs. |
| | Common Scoter | 6 | 67% | ACI | Visual Obs., Radar | 33% | BAI | Visual Obs. |
| | Dark-bellied Brent Goose | 1 | 100% | ACI | Visual Obs. | - | - | - |
| | Pink-footed Goose | 1 | 100% | ACI | Radar | - | - | - |
| All | Marine birds | 6 | 83% | ACI, BACI | Radar | 17% | ACI | Radar |

Site characteristics may also play a role. For example, two studies of Little Gull with similar methods and study designs showed variable results, with one study finding evidence of macro-avoidance (Blew et al. 2008) while the other found no evidence (Krijgsveld et al. 2011). While distance to shore and footprint size were similar across wind facilities examined, the number of turbines (and thus density of turbine placement) varied, with macro-avoidance at an 80-turbine project contrasting with no evidence of avoidance at a 36-turbine project. However, the sample sizes available to make this type of inference are currently quite limited.

The choice of study method may also influence a study's ability to detect avian avoidance; many of the null effect results came from visual observation studies ($n$=9), while radar studies ($n$=13) tended to detect effects. For example, in the case of Black-legged Kittiwakes, studies using radar found evidence of macro-avoidance (Skov et al. 2012a, Skov et al. 2018) while those that found no response used visual observations (Rothery et al. 2009). Variation in the scale of inference of these methods (e.g., radar has a farther range) may help explain the discrepancy in these results. In addition, many of the avoidance studies collected data only after construction using a control-impact approach. Pre-construction data likely play a key role in understanding species avoidance of facilities.

Of the few studies that examined meso-avoidance, all found some evidence of this response. Skov et al. (2018) documented meso-avoidance in Northern Gannet, Black-Legged Kittiwake, Great-Black-backed Gull, Herring Gull, and Lesser Black-backed Gull, and additional studies showed similar findings for Lesser Black-backed Gull (Thaxter et al. 2018, Vanermen et al. 2020a) Sandwich Tern (Perrow et al. 2015), and Common Eider (Tulp et al. 1999). The only species that displayed no evidence of meso-avoidance was Pink-footed Goose (Plonczkier and Simms 2012). Studies used various methods including radar, GPS, visual observations, and camera tracking systems. Because of the scale of meso-avoidance (i.e., avoidance of wind turbines within the project footprint), studies of this response are contingent upon the birds entering the wind facility. As such, species that show high levels of displacement and macro-avoidance are unlikely to be studied in this context.

## C.4 Discussion

The available literature was highly variable in quality, which made synthesis challenging. In particular, gray literature reports of monitoring activities at individual wind facilities were in some cases opaque and lacking in essential details, indications of a need for greater scientific rigor and peer review. Common challenges encountered during the literature review included:

- Long and convoluted reports with extraneous detail and poor descriptions of methods and results.
- Lack of key details on study methods, study area, and wind project site characteristics. In many cases the level of detail did not provide enough information for the study to be replicable, and in some cases, it was difficult to tell how and where the study was even conducted.
- High levels of variation in study design and analysis within the general categories of before-after and control-impact vs. gradient designs, making it difficult to adequately characterize studies. For example, in the case of control-impact study designs, the inclusion of buffers combined with the effect area in comparison with control areas was highly variable, as were the number of controls used and the distance between controls and project footprints. In the case of gradient study designs, the use of distances bands in analysis was inconsistent, among other sources of variation.

- Substantial variation in how buffer zones were implemented, particularly for studies using observational surveys. Many Before-After Gradient studies used variable buffer zones, whereby the distance included in the zone differed on each side of the wind facility. In the case of Before-After-Control-Impact studies, the definition of the "impact" site also varied substantially, with inclusion of different size buffer zones (or no buffer zones) alongside the project footprint.
- Inconsistent use and reporting of quantitative analytical methods and statistical tests.
- Other inconsistent and sometimes poor-quality reporting of results; for example, a quantitative measure of change (such as degree/magnitude of change or distance at which effects were observed) was not always included in reports and it could be very difficult to extract key findings. In addition, associated effect size uncertainty was often not reported.

Given these challenges, we recommend the following for study design that studies of displacement, attraction, and macro- to meso-scale avoidance of offshore wind facilities by marine birds:

- Collect data following best practices, existing guidelines, and established protocols for effectiveness and efficiency.
- Collect data before and after wind facility construction, as well as during construction for species that may be affected by construction activities (e.g., vessels).
- Utilize gradient study designs without separate control areas. It can be quite difficult to select a representative control area in the marine environment (Methratta 2021). Additionally, some studies in our dataset (particularly earlier studies) selected inappropriate control locations in proximity to the wind facility, such that bird behavior in these areas could have still been affected by the offshore wind development.
- Use consistent data collection methods over space and time (to the degree possible) to avoid introducing methodological biases into study design.
- Incorporate data collection on behaviors (such as perching, foraging, etc.) to help understand potential habitat-related drivers of changes in habitat use.
- Carefully consider the spatial and temporal scale of the proposed study, including consideration of 1) the research question, 2) existing knowledge of focal taxa's scale of response, 3) statistical power, and 4) sources of variation (see below).
- Consider sources of spatial and temporal variation in responses, including life history stage, site characteristics, and other anthropogenic factors that may influence movement and habitat use. Incorporate these variables into study design and analysis when possible, and at minimum, clearly report these data such that future synthetic reviews and meta-analyses can explore their effect on bird behavior.
- Include quality assurance and quality control to minimize inaccuracies in the data and subsequent results.

Additional recommendations for study design can be found in Section 7 of the main document as well as Section 10 (specific to observational surveys).

We recommend that studies of displacement, attraction, and macro- to meso-scale avoidance of offshore wind facilities by marine birds consistently report the following:

- Methodological details of study design, such that the study could be easily replicated. This should include, but is not limited to, 1) study design (e.g., BAG, BACI etc.), 2) field study method (e.g., survey platform and make/model, data collection methods, etc.) 3) data type or metric being assessed, 4) spatial and temporal scale of the study, including buffer sizes, number and timing of surveys, survey effort, percent spatial coverage, etc., and 5) sample sizes.

- Analysis approach, including effect size metric, type of uncertainty, statistical tests, modeling frameworks, and other details such that the analysis is replicable.
- Statistical test results and effect size and associated uncertainty.
- Potential sources of variation, including site characteristics (e.g., distance from shore, footprint size, number of turbines, turbine height, turbine spacing, and water depth).

Additional reporting recommendations can be found in Section 8 (all methods) and Section 10 (observational surveys). In addition to reporting key information, making data publicly available in a timely manner with comprehensive metadata, contributing analytical products to data portals, and publishing results in the primary literature (and at minimum making grey literature publicly available at a stable web link), all are necessary to ensure that site-specific study data can be used to improve our understanding of effects to marine birds from offshore wind development at the regional scale and help us to further refine recommendations for the design of future studies.

### *C.4.1 Next Steps*

In addition to the summary presented here, members of the Specialist Committee and support staff have used the database of studies developed during this effort to conduct a quantitative meta-analysis of studies that used observational survey methods (Lamb et al. 2024). This meta-analysis further informs understanding of displacement/attraction responses by taxon, as well as informing recommendations for survey methodology and reporting standards. Other next steps are outlined in Part V of the main document.