OWSMRF Scope of Work

Review of systems for monitoring bird collisions at offshore wind farms

(Research Opportunity 1.1a and 1.1b)

This document should be cited as: JNCC. 2022. OWSMRF Research Opportunity 1.1: Review of systems for monitoring bird collision at offshore wind farms. Joint Nature Conservation Committee, Peterborough.

Contents

1 Background

Offshore wind farms (OWF) are seen as a key part of efforts to combat climate change Snyder & Kaiser 2009). However, there are a number of concerns about the potential for these wind farms to have a negative impact on wildlife and biodiversity, particularly in relation to birds (Drewitt & Langston 2006; Gibson *et al*. 2017). To inform the planning process of the potential impacts of the effects associated with wind farms, new proposed developments require detailed Environmental Impact Assessments (EIAs) and Habitats Regulations Appraisal (HRA). EIAs assess impacts to the wider environment, whilst HRAs assess whether a plan or project will have an adverse effect on a site protected under The Conservation of Habitats and Species (Amendment) (EU Exit) Regulations 2019, The Conservation (Natural Habitats, &c.) Amendment (Scotland) Regulations 2019, the Conservation (Natural Habitats, &c.) (Northern Ireland) Regulations 1995 (as amended), and/or The Conservation of Offshore Marine Habitats and Species Regulations 2017 (as amended). As the number of wind energy developments increase globally both onshore and offshore, the potential associated environmental impacts are receiving considerable attention, particularly avian impacts. This is of particular concern at the cumulative scale (i.e. considering impacts of windfarms combined rather than of individual developments in isolation). As the scale of offshore windfarm development expands, the risk of reaching unacceptable levels of cumulative impacts increases. In order to undertake meaningful cumulative impact assessments, there is a need for improved understanding of how birds respond to offshore windfarms and how to quantify the risk to populations of concern. Without such information, decision making is necessarily precautionary, and there is a risk that offshore windfarms may not be deployed at sufficient scale to contribute fully to emission reduction targets and ambitions.

The OWSMRF (Offshore Wind Strategic Monitoring and Research Forum) identified uncertainty around in-combination and cumulative impacts of offshore wind development on black-legged kittiwake (*Rissa tridactyla*) populations currently posed the greatest uncertainty (https://jncc.gov.uk/our-work/owsmrf/). Three knowledge gaps (KG) to inform cumulative/in-combination assessments for black-legged kittiwake were identified:

- KG1: reducing uncertainty around estimates of windfarm collision mortality
- KG2: improving understanding of connectivity between OWF and SPAs
- KG3: improving confidence in modelling population consequences of windfarm effects

As part of the impact assessment process, the likely effects (e.g. collision, barrier effects and/or displacement effects) of a planned offshore windfarm on birds are estimated (KG1). Once the magnitude of these effects has been estimated, it is necessary to understand which SPA colonies (if any) and wider populations these affected birds originate from (KG2). Finally, the potential SPA (for HRA assessments) and/or wider population (for EIA assessments) response to these OWF effects (i.e. reduced productivity or increased mortality) are assessed using population modelling (KG3). Data to inform this process are frequently scant, leading to high uncertainty in magnitude of effects and a lack of confidence in predicted population response to effects.

1.1 Estimating effects of OWF on kittiwakes

The main pathway of effect for kittiwakes and OWF is thought to be mortality from collision with moving rotor-blades. At present, there is little empirical evidence for collision rates at offshore wind farms (although see Skov *et al*. 2018 for an example). Further, given the importance in turbine design and numbers, as well as bird factors such as breeding status, behaviour, and season when estimating collision risk, estimates from one windfarm do not directly translate to a different windfarm. Therefore, proposed windfarm developments use collision risk models such as Band (2012) and its stochastic implementation Masden (2015) and McGregor *et al.* (2018), to estimate the number of collisions expected. The collision estimates are sensitive to input parameters, particularly several related to bird behaviour which are difficult to measure and have a high degree of uncertainty associated with them. This leads to high uncertainty in individual windfarm project estimates of collision mortality which is further exacerbated when assessing cumulative levels of collision across projects.

Black *et al.* (2019), described several research opportunities (ROs) which could improve the evidence base for understanding collision effects of offshore windfarms on black-legged kittiwake. The OWSMRF Developer Group (DG), after discussions with the OWSMRF Key Stakeholders, have asked JNCC to produce detailed scopes of work for three research opportunities, including RO1.1a and b, as described in Black & Ruffino (2019). These scopes of work will provide additional detail regarding the project aims and objectives, possible methods that might be anticipated and aspects that would be included/considered. It should provide the information that is required in order to draft an invitation to tender and to judge the quality of applications, should OWSMRF or others wish to proceed with any of these projects.

1.2 Monitoring collisions between kittiwakes and OWF

Complex systems, usually involving either cameras, acoustic equipment or radars either alone or in-combination, are available for detecting collision at offshore windfarms but are very costly and there are ongoing discussions around how well different systems perform in reality. RO1.1 aims to undertake strategic empirical collision monitoring across multiple offshore windfarms (OWFs) in order to both validate collision risk modelling approaches and to provide empirical collision estimates in order to inform understanding of the scale of cumulative collision effects. Collier *et al*. (2011 and 2012) demonstrated that (at the time) only a small number of systems might permit measurement of collisions offshore, and that there were challenges in terms of camera quality, filtering of noise, and offshore testing. Dirksen (2017) provided an updated review of what methods were currently available and/or in development, covering many of the systems initially reviewed in Collier *et a*l. (2012). Dirksen stated: "Field measurements of bird mortality at wind farms are essential for evaluating the adverse risk of wind farm operation on bird populations as well as improving the modelling of potential bird mortality for designing future new wind farms". On land, this can be achieved by collecting carcasses around wind turbines but this is very difficult to implement offshore.

The work described under this research opportunity within Black *et al*. (2019) is broken down into three parts: A review of technologies available for monitoring of bird collisions with OWF, a power analysis and framework for deployment to ensure that sufficient data are collected across an appropriate range of contexts, and finally a strategic deployment of suitable technology at a range of OWF to collect and analyse sufficient data to improve understanding of collision risk for kittiwakes and reduce uncertainty in collision impact assessments for this species. Only the first two parts are addressed in this scope of works, with potential for the final part (strategic deployment) to be addressed separately at a later date.

2 Aims and objectives

The primary aim of collision monitoring could either be to provide: (a) empirical estimates of collision mortality; or (b) improved understanding of how biologically realistic approaches are to predictive collision risk modelling and information to improve model design and/or parameterisation. The former (a) would provide data on actual (as opposed to modelled/predicted) collision rates at monitored turbines across different windfarms, seasons, years. which could then be scaled up to provide empirically based estimates of cumulative kittiwake collisions across existing and planned windfarms. This would provide a clear indication as to whether the existing scale of collision effects is at a level which is unacceptable for any region or within foraging range of any kittiwake SPA, and the degree to which there may be headroom for further windfarm development in areas used by kittiwakes. The latter (b) would provide information which could be used to assess kittiwake behaviour in the vicinity of wind turbines which could lead to more realistic predictive collision models, and/or improved parametrisation for existing models (such as Band 2012, McGregor *et al.* 2018, Kleyheeg-Hartman *et al*. 2018). This would reduce uncertainty in predictions of collision rates for existing, planned and future windfarms, and consequently increase confidence in assessments of scale of effect/adverse impacts across existing, planned and future windfarms.

Ideally, data extracted from a collision monitoring study would address both of these aims: It would provide empirical collision information allowing an assessment of the extent to which current estimates are over, or under, predictions of true collision rates. This would then allow statutory advisors to have a clearer understanding of the extent to which existing and planned windfarms pose a risk to kittiwakes and SPAs, and for developers to understand the extent to which there may (or may not) be headroom for future windfarm development in areas used by kittiwakes. In addition, it would provide information on bird behaviour in the vicinity of wind turbines as a means of validating mechanistic approaches to collision risk modelling at this scale. It would also provide information on key input parameters to models (such as Band 2012, McGregor *et al*. 2018, Kleyheeg-Hartman *et al*. 2018), including how variable these are across seasons, behaviour, environmental conditions, years, site. Sensitivity analyses have consistently shown that bird densities, flight height, flight speed and non-avoidance rates are particularly important predictors of modelled collision risk (e.g. Bowgen & Cook 2018, Masden 2019, Masden 2015) and therefore improved estimates of these parameters, will reduce uncertainty in future predictions of collision rates. Consideration will need to be given to how these parameters are influenced by the presence of a windfarm, and if/how they interact with each other (for example, do slower flight speeds lead to more successful avoidance behaviours). By addressing both of these aims, a strategic monitoring study successfully deployed could both improve understanding of existing levels of effect and available headroom for additional development, and also reduce uncertainty in future project-level impact assessments; in particular when considered in combination with existing windfarms.

Throughout this document, ‘collision monitoring system’ is used as a catch-all term but can include systems which monitor bird behaviour within close vicinity of a wind turbine even if not necessarily monitoring collisions in a comprehensive manner. For example, although DT-Bird was developed as a means of real-time collision deterrent or curtailment, it involves detection and monitoring of bird flights in the vicinity of turbines with full coverage of each turbines rotors. WT-Bird is designed to monitor all collisions at a turbine, whilst Visual Automatic Recording System (VARS) and several radar systems are not designed to comprehensively detect collisions but can collect useful information on bird behaviour in the vicinity of turbines including in some cases 3D tracking, which would provide information on bird behaviour including flight heights, speeds and avoidance.

2.1 Aim

The aim of this work is to better understand the collision monitoring systems available that might be suitable for deployment at offshore wind farms; what information they can provide, and to provide information to inform a potential future strategic deployment across the UK.

This can be achieved under the following objectives:

2.2 Objective 1

What methods are available for monitoring collisions and/or bird behaviour at wind turbines, that might be suitable for kittiwakes? Review, describe and evaluate bird collision monitoring systems which could be usefully deployed at offshore wind facilities.

2.3 Objective 2

What information can be collected and how could this be used? Provide clarity on the types of information which can be collected by each system and how this might be used to reduce uncertainty in understanding of cumulative collision.

2.4 Objective 3

Explore scale of deployment required. Power analysis to understand how much data is required (to improve confidence in collision monitoring approaches, and/or to improve empirical evidence-base for collision risk) across seasons, behaviour, environmental conditions and windfarm design for black-legged kittiwake (assuming suitable technology is available and considering limitations to each). What scale of deployment can achieve this power?

2.5 Objective 4

Provide recommendations for further testing and/or deployment. This should provide clear details of any further testing that is required, and guidance to help developers wishing to deploy monitoring equipment.

3 Detailed tasks

3.1 Literature review

Review of published and grey literature to identify technologies/systems which are/have been/is planned to be deployed to monitor collisions at wind farms. This should look beyond UK to Europe, America and elsewhere. The focus is offshore, but systems which have deployed close in-shore and/or onshore should be included if it is felt that they may have potential to be usefully deployed offshore. This should build further on Dirksen (2017) adding further experiences of the systems reviewed in Dirksen (e.g. as described in Skov *et al*. 2018, deployment and testing of WT-Bird at Offshore Wind Farm Egmond aan Zee; reports hopefully available soon), and if appropriate adding additional systems not included in Dirksen (e.g. Matzner & Hull 2020, McClure *et al*. 2018, Aishwarya *et al*. 2016, Suryan *et al*. 2016). As part of this review, offshore windfarm developers should be contacted to seek to consider any relevant work that may have been undertaken as part of preparation for post-consent monitoring (for example reviewing systems that developers are considering deploying).

A description of the system and how it works should be provided for each system reviewed, including information on (this list is not comprehensive and should be expanded by bidders in their proposals):

- existing deployment particularly offshore (this may include systems installed on structures other than wind turbines if thought appropriate/useful experience),
- expected suitability for offshore environment, if this has not been tested (e.g. is the equipment waterproof, how would salt spray affect visibility and performance, are there maintenance requirements that would prevent offshore deployment),
- method of monitoring collisions (e.g. visual, acoustic, radar, combination),
- other information collected in addition to (or instead of) collisions (e.g. avoidance behaviour, flight heights/speeds, flux, densities),
- success at collecting data on collision for species similar to and/or smaller than kittiwake,
- ability of system to collect data on other species of UK seabird at risk from collisions, (e.g. gannet) and any issues associated with collecting data on other species besides kittiwake,
- species detection and ID capabilities (e.g. distance, weather conditions, visibility),
- type and format of information recorded/stored and how that information is retrieved from the offshore environment (e.g. person collects hard drive, info downloaded and broadcast to shore-based receiving station),
- indication of how data was analysed and level of resources required to process and analyse data (e.g. degree of automation),
- equipment and turbine requirements for hosting, including whether this can be retro-fitted to operational turbines,
- logistical requirements (power, communications, maintenance, data access), and
- costs per unit (including purchase, fittings, deployment, maintenance, warranties/parts replacement, information storage and support).

The literature review would also consider how data were analysed and used, and the extent to which this differs across different means of collecting the data. For example:

- Was (or could) the data be used to directly estimate empirical collision rates per (surveyed) turbine and if so, what other information was required in order to do this, and how accurate were the estimates thought to be?
- Were (or could) collision risk model parameters extracted from the data (such as flight heights and flight speeds) and how accurate were these thought to be? How might this information most meaningfully be used to improve collision estimates or future predictions?
- Was (or could) the data used to estimate avoidance rates, how was this done, and what do these avoidance rates describe in reality (behavioural avoidance similar to that calculated in Skov *et al*. (2018), model error, or a combination of these?).
- Was (or could) bird behaviour immediately preceding collision/avoidance described or categorised and if so, how was this done and what other information was required in order to do this?
- Was (or could) the data used to estimate flux rates through individual turbines and/or the windfarm as a whole and how was this done?
- Was (or could) the data used to estimate bird densities within, across and outside the windfarm and how was this done?
- is it felt that further useful information could be extracted from the data, or the data analysed further?

3.2 Contacting experts

This will provide additional detail and context that might not be available within literature.

Experts would include:

- Equipment manufacturers/providers to seek clarity on some of the technical questions listed above, if sufficient information is not otherwise available. For example IdentiFlight has been shown to be very accurate at detecting birds of prey at onshore wind facilities (McClure *et al*. 2018), but it is not clear how transferrable this might be to offshore/marine birds.
- Developers hosting, or known to have considered hosting, equipment to understand the implications of technical and maintenance requirements and any difficulties encountered (e.g. in fitting or maintaining equipment across weather conditions and indicate if there were unforeseen difficulties). They might also be able to indicate whether equipment functioned more or less as expected, and if not in what ways it did not meet expectations (e.g. quantity or quality of data collected, information possible to obtain, maintenance requirements). Also, did the developer experience any difficulties with procuring equipment (e.g. delays, availability of systems, replacement parts, expertise for fitting/maintaining). There are likely to be only a small number of offshore wind developments with experience of hosting equipment. This might include for example the ongoing collision avoidance monitoring being undertaken at Vattenfall's EOWDC, DTBird at Kincardine OWF and systems (including DTBird) deployed at the FINO1 research platform as part of the MultiBird project.
- Developers, regulators and SNCBs across Europe and beyond are seeking potentially novel ideas on monitoring collisions at offshore wind farms which may not yet be available in the literature. For example, there seems to be several systems in use across America that we do not believe have been used in the offshore and/or European context (e.g. IdentiFlight, BirdsVision, Merlin) but might be suitable or adaptable. In such cases, as much information as possible should be gleaned, and presented in the same format as the information extracted from the literature review.
- Developers and consultants who have procured systems for deployment of OWFs; are there any issues around procurement (e.g. delays, availability of systems, replacement parts, expertise for fitting/maintaining, hidden costs that are not apparent up-front); were there issues with processing, analysing and interpreting the data; did the systems work more or less as expected; would they have recommendations for future procurement and deployment.

A clear audit of literature sources and experts contacted, with a link to the information provided by each source, will be required so that developers interested in hosting equipment can go to source for further detail if required.

3.3 Produce recommendations for further testing and/or development requirements

Depending on the outcomes of the above two tasks, it may be that a system is unlikely to have sufficient technical ability to collect the information that is required, at the necessary scales (see power analysis below). If that is the case, then recommendations for what further testing or development is required in order to progress systems with a high degree of potential should be made, as well as how this might best be undertaken given the existing and upcoming projects across the UK in which testing might occur. This would need to consider:

- Has the system been proven onshore, and if so what aspects in particular might need to be assessed in order to understand suitability for monitoring of kittiwakes in offshore environment?

- How much of the testing can be done onshore and which aspects need to be undertaken offshore, and does the testing necessarily need to take place on a wind turbine (for example, ability to identify kittiwakes might be tested onshore, whilst susceptibility to damage or reduced visibility as a result of sea spray may need to be tested offshore but not necessarily on a wind turbine).
- What scale of testing is required and over what time period?
- Which areas might be suitable for testing (e.g. sufficient kittiwake densities, suitable environmental conditions)
- What windfarm characteristics are required in order to undertake testing
- How is testing best facilitated; is this something that developers should lead or are partnerships with manufacturers likely to be more successful, and how might this be facilitated and managed?
- To what extent are equipment manufacturers willing to engage in testing, and act on outcomes? For example, if salt-spray is a potential issue, are equipment manufacturers willing to engage in testing of this and are they likely to be willing to develop a solution to this?
- How will the outcomes of testing be assessed; in other words, how would decisions be made around whether the equipment is indeed suitable for deployment offshore in order to monitor kittiwake collisions/behaviour, either in current state or with further (clearly specified) development?

3.4 Power analysis

There are several aspects to this analysis which would need to be considered. This should be undertaken for two slightly different questions; as described above, depending on what systems are available and precisely what information they capture, there are alternative questions which can be addressed. Each power analysis would need to consider different turbine designs and kittiwake densities across space and time, to understand how the specific deployment pattern might affect power.

Monitoring of empirical collision rates:

- What is a realistic assumption around kittiwake encounter rates given densities in space and across seasons?
- How many deployments/over what time period are required to observe a sufficient number of collisions to reduce uncertainty in cumulative collision rates? The baseline assumption is that a whole turbine is continuously monitored by each deployment; where this is not the case, this will need to be considered within the power analysis.
- What range of conditions needs to be monitored to fully understand cumulative (across windfarms) collision rates, and to understand collision rates for different windfarms. This would need to include conditions for which it may be desirable to obtain data but which in reality may be very difficult to do so (e.g. poor visibility), and an assessment of the implications of not collecting data in these conditions. Other conditions to consider include season, primary use of area (e.g. passage, foraging, resting) and typical weather conditions.
- How might the required scale of deployment be achieved given existing and planned windfarms in offshore UK waters? What are the key assumptions and dependencies for the suggested scale of deployment to achieve sufficient data across a sufficient range of conditions?

Monitoring to improve confidence on estimates of collision risk:

- What are the key data requirements in order to provide improved confidence in collision-risk estimation, and how would they be used?
- How many deployments/over what time period are required to validate approaches and improve confidence in parameters for predicting collisions?
- What range of conditions needs to be monitored in order to provide robust parameterisation for collision risk estimation methodologies? This would include season, primary use of area (passage, foraging, resting) and typical weather conditions, amongst other considerations.
- How might the required scale of deployment be achieved given existing and planned windfarms in offshore UK waters? What are the key assumptions and dependencies for the suggested scale of deployment to achieve sufficient data across a sufficient range of conditions?

The outputs from these power analyses would then inform a broad framework for a strategic collision-monitoring study design. For example, it might help to reach agreed understanding of which of the primary monitoring questions (empirical collision monitoring or bird behaviour and model parameterisation) is most achievable. It could then support developers or other stakeholders to consider upcoming projects across the UK and understand how sufficient coverage and power might be achieved. It would support planning to cover the range of contexts required, turbine requirements to host equipment. Ideally it would provide an indication of which systems might be most suitable to achieve these requirements or indicate what further testing and development may be required before such a strategic deployment is feasible. Depending on the outcomes of the previous tasks, it may be that a single system is not alone able to answer the aims of a strategic deployment and that a combination of systems is more suitable; this should be considered and an indication of appropriate combination(s) of systems to answer the monitoring questions should be provided.

4 Outputs

It is envisaged that the main outputs would be:

Report detailing the methods, sources, and outcomes of the review of available technology, and of the power analysis. This would include a comparison across a range of potentially appropriate systems/technologies, listing various technical information, logistical requirements, proven record offshore, ability to detect and ID kittiwake collisions, costs (information as listed in section 3; detailed tasks). It would indicate which systems have a) the most certainty in recording useful information, b) the greatest potential to provide efficient monitoring at large scale, c) whether offshore field-trials would be required in order to further test/assess before widescale deployment.

The format for this report will be agreed with the contractor at the start of the contract, but fact sheets similar to those presented in Dirksen 2017 (but including additional information as listed in section 3) for each system might be useful.

The report would also then describe the power analysis that has been undertaken including methods and results/outputs, covering both of the monitoring questions separately. For each monitoring question (empirical collision monitoring or bird behaviour and model parameterisation) it would indicate which systems offer the most potential to provide sufficient information on collision and avoidance to fulfil the requirements found by the power analysis (even if further development and/or testing is required). It would also provide a summary of what might be expected based on the currently available systems (i.e. if no further testing or development were to be undertaken, what is the most viable approach to take).

If not included as part of the report, then an appendix or other means of providing the audit of experts contacted and linking to the information provided will be required (e.g. a spreadsheet or supplementary table).

Comparison spreadsheet which would provide readily accessible information for each system. This would capture a lot of the same information as the report but potentially additional technical details and in a format allowing easy comparison and cross-referencing across systems.

Series of recommendations for further testing. For each system identified as having good potential but requiring further testing or development, a check-sheet should be provided which details the recommendations for testing and further development that is required, and the how this might best be facilitated, using the outcomes from the 'Produce recommendations for further testing and/or development requirements' task.

Framework for deployment. This would provide a series of principles to aid in planning of strategic collision monitoring and would include a series of scenarios to demonstrate the range of options available. For example, these scenarios may consider one or two of the 'most appropriate' systems identified in the review (or a combination of systems) and describe the turbine requirements and scale of deployment required to meet the data quantity across the full range of contexts identified as required in the power analysis. A description of how each scenario might be achieved given available infrastructure and kittiwake distributions across the UK should also be provided. A checklist of requirements (turbine, maintenance, access, data/communications, suitability for retrofitting) and costs for each of the shortlisted systems that developers could use to quickly assess which systems might be suitable for their particular windfarm projects should also be provided.

5 Timescale

It is expected that this work will take approximately five months to complete. An indicative timeline is provided below, but this is to be confirmed, and we welcome suggested timelines from bidders. Sufficient time for meaningful engagement with a steering group and to act upon recommendations from the steering group should be included in any proposed timeline.

- Week 1: start-up meeting
- Weeks 2–6: literature review and contact experts, progress meeting
- Weeks 7–13: power analysis, testing recommendations and production of draft outputs
- Weeks 14–16: expert review of draft outputs, progress meeting
- Weeks 17–18: funder review of outputs
- Weeks 19–21: final outputs and project close

6 Contractor requirements

Successful contractors would need to demonstrate a thorough comprehensive understanding of collision risk modelling and the issues around it. For example, the contractor would need to demonstrate a good understanding of the difference between empirical avoidance rates and those used in the Band model, and the issues around collecting direct measures of collision versus better parameterisation of collision risk models. The contractor needs a sound background in quantitative ecological modelling. Also, the contractor should have the ability to identify and approach appropriate developers, regulators, ecological consultants and other experts (e.g. within SNCBs and NGOs) across Europe and beyond in order to gather the required information and experiences. Expertise in ecological power analysis is required, and although they do not need an engineering background, enough technical understanding to be able to assess, describe and critique various different technological systems is required. Familiarity with marine birds and understanding of their 3-dimensional flight behaviour in and around offshore windfarms is also required in order to identify whether systems have potential to adequately capture such behaviours.

7 References

Aishwarya, K., Kathryn, J. C. & Lakshmi, R. B. 2016. A survey on bird activity monitoring and collision avoidance techniques in windmill turbines. IEEE Technological Innovations in ICT for Agriculture and Rural Development (TIAR), Chennai, pp. 188-193.

Band, B. 2012. Using a Collision Risk Model to Assess Bird Collision Risks for Offshore Wind Farms. Report by British Trust for Ornithology (BTO), Bureau Waardenburg bv and University of St Andrews. Report for The Crown Estate.

Black, J., Cook, A.S.P.C. & Anderson, O.R. 2019. Better estimates of collision mortality to black-legged kittiwakes at offshore windfarms. *JNCC Report No. 644*. JNCC, Peterborough, ISSN 0963-8091.

Bowgen, K. & Cook, A.S.P.C. 2018. Bird Collision Avoidance: Empirical evidence and impact assessments. *JNCC Report No. 614*. JNCC, Peterborough, ISSN 0963-8091.

Collier, M.P., Dirksen, S. & Krijgsveld, K.L. 2011. A review of methods to monitor collisions or micro-avoidance of birds with offshore wind turbines. Part 1: Review. Report 11-078, Bureau Waardenburg, Culemborg, Netherlands.

Collier, M.P., Dirksen, S. & Krijgsveld, K.L. 2012. A review of methods to monitor collisions or micro-avoidance of birds with offshore wind turbines. Part 2: Feasibility study of systems to monitor collisions. Report 11-215, Bureau Waardenburg, Culemborg, Netherlands.

Cook, A.S.C.P., Humphreys, E.M., Bennet, F., Masden, E.A. & Burton, N.H.K. 2018. Quantifying avian avoidance of offshore wind turbines: Current evidence and key knowledge gaps. *Marine Environmental Research*, **140**, 278–288.

Dirksen, S. 2017. Review of Methods and Techniques for Field Validation of Collision Rates and Avoidance Amongst Birds and Bats at Offshore Wind Turbines. Report SjDE 17-01, Wind op Zee Ecologisch Programma.

Drewitt, A.L. & Langston, R.H.W., 2006. Assessing the impacts of wind farms on birds. *Ibis*, **148**, 29–42.

Gibson, L., Wilman, E.N. & Laurance, W.F., 2017. How Green is "Green" Energy? *Trends in ecology & evolution*, **32**, 922–935.

Kleyheeg-Hartman, J.C., Krijgsveld, K.L., Collier, M.P., Poot, M.J.M., Boon, A.R., Troost, T.A. & Dirksen, S. 2018. Predicting bird collisions with wind turbines: Comparison of the new empirical Flux Collision Model with the SOSS Band model. *Ecological Modelling*, **387**, 144–153.

Masden, E. 2015. Developing an avian collision risk model to incorporate variability and uncertainty. Scottish Marine and Freshwater Science Report, Vol 6 No 14.

Masden, E. 2019. The importance of flight speed in collision risk models. Presented at the Conference on Wind energy and Wildlife impacts, Stirling.

Matzner, S., Warfel, T. & Hull, R. 2020. ThermalTracker-3D: A thermal stereo vision system for quantifying bird and bat activity at offshore wind energy sites. *Ecological Informatics*, **57,** 101069.

McClure, C.J.W., Martinson, L. & Allison, T.B. 2018. Automated monitoring for birds in flight: Proof of concept with eagles at a wind power facility. *Biological Conservation*, **224**, 26-33.

McGregor, R.M., King, S., Donovan, C.R., Caneco, B. & Webb, A. 2018. A Stochastic Collision Risk Model for Seabirds in Flight. Report for Marine Scotland.

Skov, H., Heinänen, S., Norman, T., Ward, R.M., Méndez-Roldán, S. & Ellis, I. 2018. ORJIP Bird Collision and Avoidance Study. Final report, The Carbon Trust.

Snyder, B. & Kaiser, M.J., 2009. A comparison of offshore wind power development in europe and the U.S.: Patterns and drivers of development. *Applied Energy*, **86**, 1845–1856.

Suryan, Robert & Albertani, Roberto & Polagye, Brian. 2016. A Synchronized Sensor Array for Remote Monitoring of Avian and Bat Interactions with Offshore Renewable Energy Facilities. Technical Report.