Bat and Bird monitoring guidance

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Contents

1. Executive Summary

This guidance provides an up-to-date **catalogue of available monitoring technologies** for flying **birds and bats** at offshore wind farms (OWF) in operation, with a focus on managing the **risk of collision**. Although monitoring requirements across regions seem similar, the focus of regulators varies depending on **national conservation priorities and legislation**.

This guidance aims at **supporting consenting processes** in the early phases of a development project with choosing appropriate technologies for the particular region.
To assist in the planning process for the Wind Farm monitoring campaign, **decision trees** have been included in **section 5.2** depending on the concern or regulatory landscape.

The current approaches and technologies available across the globe have been reviewed and assessed in terms of **performance and compliance** in relation to current monitoring and mitigation requirements, primarily during the **post-construction phase**. The assessment includes the following technologies:

- Radar (2D and 3D)
- Camera
- Accelerometer
- Acoustic equipment
- Large-scale survey platform and large-scale telemetry

These technologies are covering all relevant spatial and temporal scales for **assessment of bird and bat behaviour and collision risk**. As collision mitigation is quickly becoming a central issue globally, the interfacing capacity of **monitoring equipment with SCADA** is included in this review, for the sake of integrating the possibility for smart curtailment where needed.

The assessments undertaken in this guidance consider monitoring technologies as **approaches to monitoring** rather than individual products. This has been judged as necessary to avoid reliance on commercial material in terms of web sites and flyers from technology vendors. The performance of each technology has been rated in relation to the following features:

- Its monitoring performance
- Installation complexity
- Retrofitting potential
- Cost/quality ratio

The results have been summarized in the **assessment matrix, Table 2**. For each method or technology, the performance **strengths and weaknesses** are discussed in relation to various parameters such as

- The species or species groups
- The scale over which it may operate (e.g. micro, meso, macro) and
- The phases of offshore wind farm development during which it is applicable

A key part of the review has aimed to determine the performance of the different technologies as reflected by the **statistical power**[1] of monitoring data achievable **at the species level**.

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[1] The statistical power of monitoring data refers to the probability of detecting an impact of the OWF wind farm on a species of bird or bat. In general terms, the probability increases with the sample size in both impact and reference areas. Thus, the statistical power of monitoring technologies differs due to their different capacity for recording large amounts of data on the species of bird and bat at the OWF

2. Introduction

2.1 Background to the guidance

During the past 10 years, a huge development in innovation and application of automated monitoring technologies focused on the collision risk for birds and bats has taken place globally in response to the build out of offshore wind farms (OWFs). The main driver behind this development has been the rise in requirements which have been put forward by regulators globally. In addition, the development has been motivated by the need to resolve the practical and safety issues related to deployment of human observers on vessels, in aircraft, or on offshore structures. Although evaluation standards for bird monitoring technologies have been developed and applied by for instance the Renewable Energy Wildlife Institute (REWI)[2] in the US, certification of bird and bat monitoring equipment is generally lacking. Consequently, there is a great need for an independent assessment of the quality of available technologies as judged from their technological benefits and drawbacks. This is not the least the case in relation to regulators' requirements and technology readiness levels (TRLs) for OWF.

It is a fact that few monitoring technologies have been developed specifically for detection of flying birds and bats. Most available technologies are merely offshore adaptations of technologies commonly applied onshore without consideration of the particular operational and technical challenges in offshore environments. Accordingly, many innovations have only reached TRL 6 or 7, and only a minority of monitoring technologies are at TRL 8 and 9. Thus, this guidance attempts to fill the gap of a careful assessment of the current status of monitoring technologies in terms of bird and bat detection, installation solution, operational monitoring, retrofit potential and costs. The guidance can therefore be seen as adding information to technology reviews based on published material from vendors[3].

Further, there is a need for assessing the compliance of monitoring technologies in relation to the regional requirements from regulators and other stakeholder groups. Although monitoring requirements across regions seem similar, the focus of regulators varies depending on national conservation priorities and legislation, e.g. strictly protected species covered by EU Birds and Habitat Directives[4] and species covered by the Endangered Species Act in the US[5]. In addition, monitoring requirements may differ due to differences in emphasis on sensitive/protected species or density of flying birds and bats.

2.2 Objectives

The aim of this guidance is to provide an up-to-date review of available monitoring technologies for flying birds and bats at OWFs, specifically in relation to the risk of collision. The guidance should be an easy-to-use catalogue of monitoring technologies focused on progress and challenges for OWF application and - by the use of decision trees - aims at an eased selection of monitoring techniques for post-construction determined by current trends in compliance requirements.

Monitoring technologies for other potential impacts from OWFs like habitat displacement are not covered. As collision mitigation is quickly becoming a central issue globally, the interfacing capacity of monitoring

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[2] www.rewi.org

[3] https://ctprodstorageaccountp.blob.core.windows.net/prod-drupal-files/documents/resource/restricted/ORJIP_SBMon-WP2.pdf

[4] https://ec.europa.eu/environment/news/habitats-directive-new-guidance-protected-species-2021-10-12_en

[5] https://www.epa.gov/laws-regulations/summary-endangered-species-act

equipment with SCADA is included in this review, for the sake of integrating the possibility for smart curtailment where needed.

While the guidance focuses on technologies to be used post-construction, it can serve as a template for planning pre-construction and EIA surveys. This is especially relevant in the context of the growing need for documentation of the impacts on OWFs on wildlife and using the same technology or sampling equipment will make the comparison of the before-after situation a lot more straightforward. Comparing survey results from different survey methodologies, if not interpreted with extreme care, can incur a risk of making the wrong conclusions.

2.3 Document structure

The core of the guidance covers technologies related to post-construction monitoring requirements. The introductory chapter covers the background and scope of this review. Chapter 3 contains an account of authority requirements and provides an overview of the general trends as well as as the regional differences. Chapter 4 provides a description of the different monitoring technologies focusing on recent technical advances and challenges related to application in OWFs. A final assessment and scoring of each monitoring technology in relation to the different authority requirements is provided in chapter 5.

2.4 Regions, habitats, and species

The guidance covers these main regions:

- Asia-Pacific
- UK
- Continental Europe and
- US-Canada

Although OWF development was initiated in Europe, monitoring requirements in relation to birds and bats are now being specified by regulators in all regions and comparable technologies are being applied globally. European progress on monitoring requirements has seen a diversification of the focus of monitoring at OWF. In Europe, we can observe the following landscape of focus areas:

Monitoring of birds in the **United Kingdom and Ireland** has been focused on seabirds and primarily during the breeding season, whereas in the **rest of Europe** wintering waterbirds and migrating birds have drawn most attention. With respect to bird migration, priorities of regulators in the **Netherlands and Germany** have been on nocturnally migrating passerines, which constitute the largest volume of migrating birds. Priorities in **other countries** have been bird species of conservation importance in the country and in the EU. The focus of monitoring requirements for bats seems to have followed the EU legislation, and in particular the Habitats Directive in most European countries. This is illustrated in Figure 2-1.

Both monitoring at OWFs in offshore and coastal habitats is covered. In some situations, coastal wind farms will be required to monitor birds and bats following similar guidelines as OWFs, and requirements in these situations are also included. Two different types of monitoring are needed to cover the different functional uses by birds and bats of offshore and inshore areas. Monitoring of local seabirds and waterbirds will typically be designed to quantify the distribution of seabirds and waterbirds around and inside the OWF. Monitoring of birds and bats on migration will be designed to quantify both the distribution of local seabirds and waterbirds and the migration of landbird and seabird/waterbird species at the site. Inshore habitats may hold a higher diversity of seabirds and waterbirds, while high densities may occur offshore at shallow banks and in areas of oceanographic fronts or upwelling zones or in association with fishing activities. For this reason, intensive monitoring of waterbirds and seabirds may be required at OWF even at locations far from the coast.

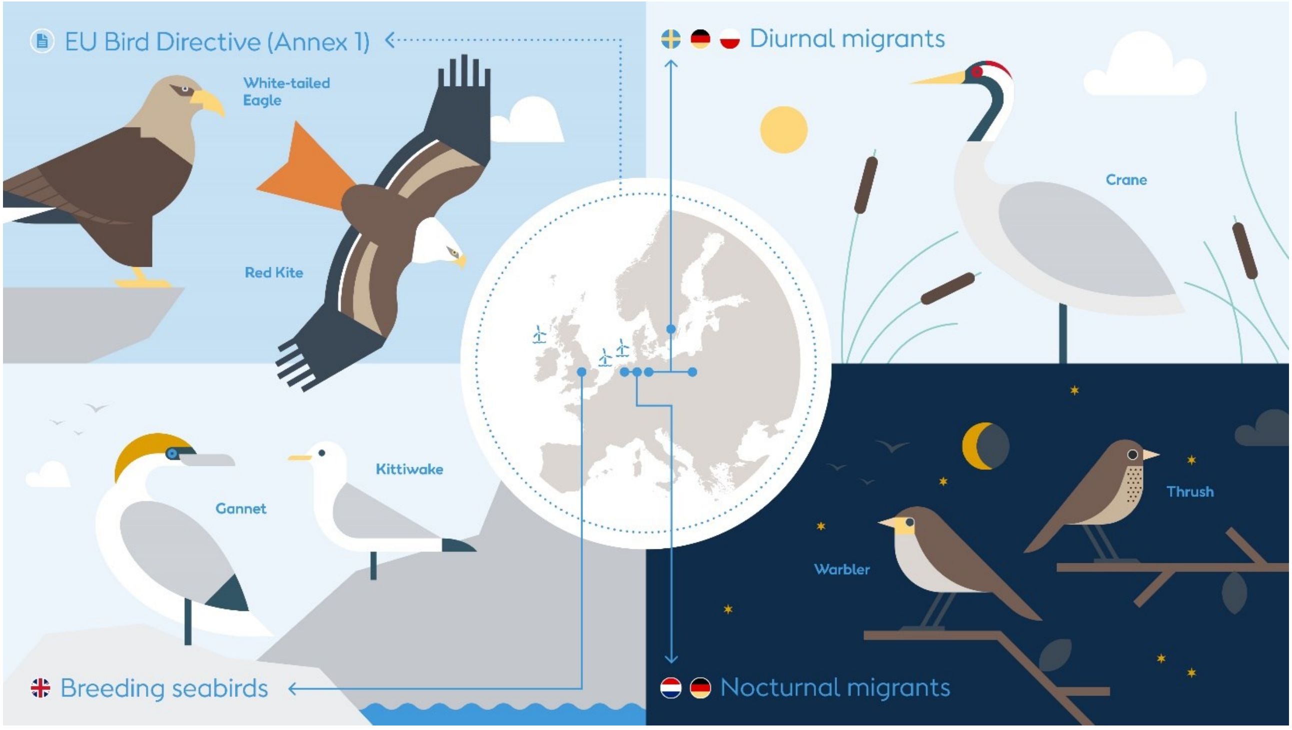

Figure 2-1: Illustration of different focus areas for European birds

Both birds and bats undertake long-distance migration which may cross open sea areas. Intensive bat migration and foraging movements of bats are for instance observed in the Baltic Sea[6]. The same pattern is seen in many species of migrating landbirds which follow land, including many of the species with small population sizes and conservation concern like birds of prey, storks and cranes. Thus, migration of diurnally migrating landbirds is steered by topographical features. These species will follow coastlines in order to either “find and choose” those crossing points or to end up at cumulation points, from which they have to cross. Thus, OWF located at or near such crossing and cumulation points will typically be required to carry out intensive monitoring activities. By contrast, the majority of the numerically dominating nocturnal migration of birds is typically taking place over a broad front and is less dependent on the coastal morphology[7,8]. Their migration routes will cross regions in a broad front, and although substantial numbers may be involved it will only be a fraction of them which will, depending on the overall migration situation, cross in close vicinity to the OWF.

Many species of waterbirds and seabirds undertake both medium-range and long-distance migration between breeding and wintering areas. In addition, several species make significant movements to marine moulting sites following the breeding season. Waterbirds and seabirds on long-distance migration depend less on water during migration than waterbirds on medium-range migration. The latter group of species

[6] Ahlén et al. 2007
[7] Bruderer and Liechti 1998
[8] Meyer et al. 2000

frequently use coastal areas as guidelines during migration which causes elevated densities of migrating waterbirds in coastal regions in comparison to regions further offshore[9].

2.5 Monitoring technologies and statistical power

High statistical power constitutes an essential quality attribute of a monitoring technology. It reflects the capacity of the technology to detect an impact of the OWF wind farm on a species of bird or bat. In most monitoring situations the probability increases with the sample size obtainable in both impact and reference areas. However, the probability is also controlled by the strength of the hypotheses regarding cause and effect which the monitoring of flight behaviour and collision risk to birds and bats is built on.

For example, effects due to the wind farm may be superimposed on external effects due to changes in oceanographic and local and regional weather conditions[10,6]. Obviously, the variability in the flight activity of birds and bats at OWFs induced by external factors will affect the ability to determine average flight patterns, densities and collision risks which are caused by the OWF, especially from data based on short-term surveys like aerial and ship-based surveys. These constraints will transfer into low statistical power and relatively high levels of uncertainty surrounding the issue of potential bird and bat collisions. A study of collision risk for seabirds at the Horns Rev II OWFs provides a good example of the degree of variability in the flight behaviour (flight height) of seabirds at an offshore wind farm as a function of wind conditions[11], Figure 2-2).

As the largest challenges are related to short-term and species-specific variability in flight behaviour the length and frequency of the monitoring technology and campaigns are key considerations. In other words, the choice of continuous versus short-term measurement campaigns and population (surveys) versus individual-based techniques. These considerations are often steered by the scale of measurements required. For measurements of flight behaviour inside the wind farm deployment of monitoring equipment for 24/7 coverage is generally required to obtain comprehensive and detailed data in a wide range of meteorological and oceanographic conditions. For measurements in a wider area surrounding the OWF short-term surveys as well as high-resolution individual-based telemetry will be required to obtain an extensive coverage at a reasonable cost.

[9] FEBI 2013
[10] Alerstam 1978
[11] Skov & Heinänen 2015

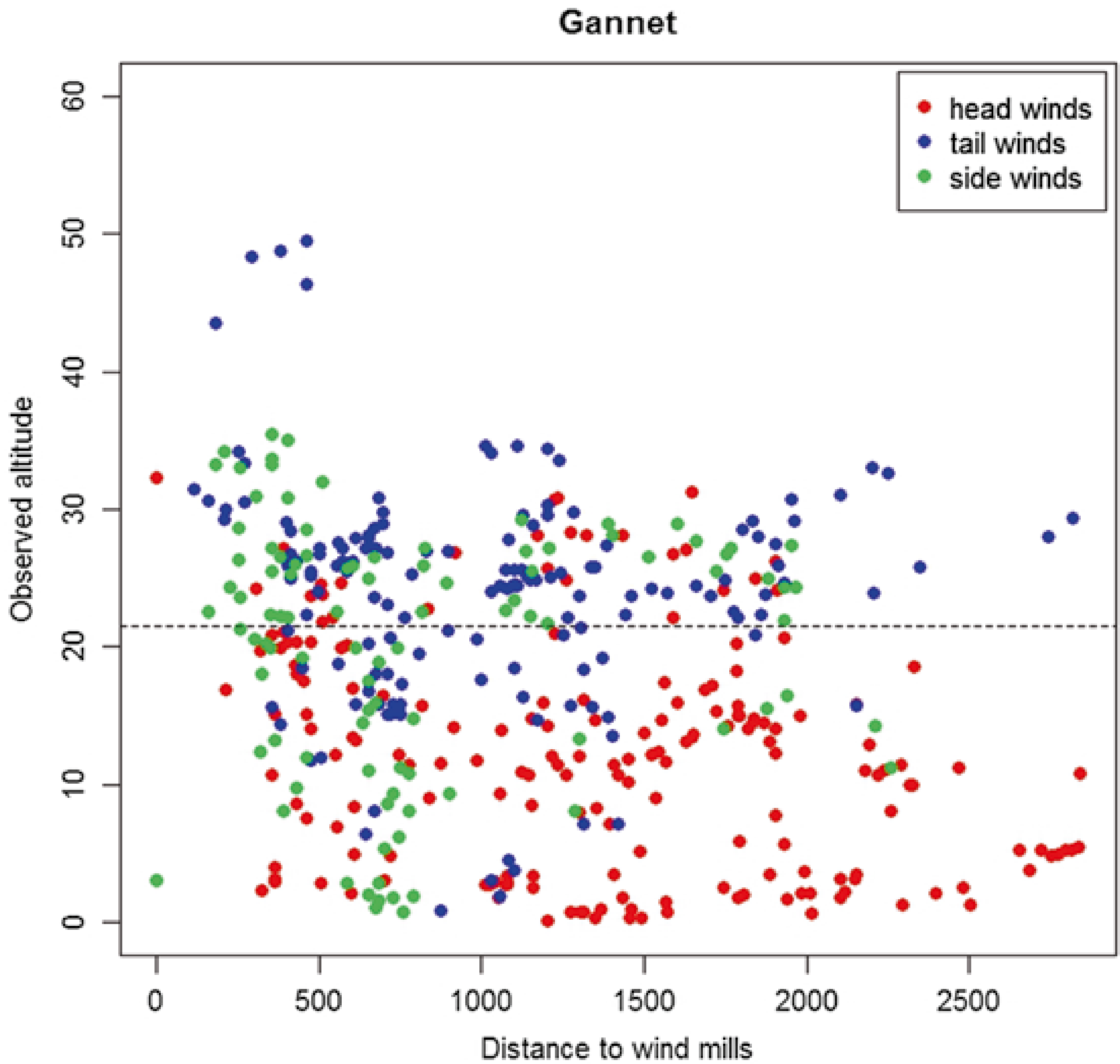

Figure 2-2. ***Observed flight altitude plotted against distance to closest wind turbine for Northern Gannets (Sula bassanus) at the Horns Rev 2 OWF. The different colours indicate head winds (red), tail winds (blue) and side winds (green). The rotor height (lowest tip) of the turbines at Horns Rev 2 is indicated with a dashed black line (from Skov & Heinänen 2015)***

3. Authority Requirements

3.1 Species

3.1.1 Identification

Monitoring requirements for OWFs are generally tailored towards bird and bat species of conservation concern, species sensitive to collision, protected and red-listed species at the national level. Thus, the requirement for collection of species-specific data on the occurrence of birds and bats inside and outside the wind farm during pre- and post-construction periods is evidently strong. In Europe, many birds breed within EU Special Protection Areas (SPAs), and bats breed within designated EU Special Areas of Conservation (SACs) and are protected by European law under the Birds and Habitats Directives[12,13]. OWFs in proximity to SPAs and SACs will be required to determine the interactions between the wind farm and the target species on which these protected areas have been designated. Similarly in other parts of the world, enhanced requirements for monitoring impacts on species of birds and bats targeted by marine and coastal protected areas will be required for OWFs near such areas.

The specific characteristics that determine a species' vulnerability to an OWF have been the focus of many studies, especially in relation to seabirds with the aim to develop better directed monitoring. These include biological characteristics that can influence collision risk, such as body size, flight height, and flight speed[14,15]. They also include behavioural characteristics ranging from complete avoidance that can lead to the loss of habitat, or attraction to sites that can lead to an increased risk of collision with turbines[16,17,18].

A well-established approach has been to use indices of sensitivity, or population vulnerability[19,20]. Sensitivity indices are used by regulators and developers during initial scoping and impact assessments. They are also used in sensitivity maps, combined with data on seabird densities, to identify "hotspot" areas of high risk[21,22,23,24]. Garthe & Hüppop (2004) developed an index of seabird sensitivity to offshore wind farms based on conservation importance scores for different species and perceived behaviour-related risks of collision and displacement. These scores were combined into a single index to give a species vulnerability score.

These seabird sensitivity indices have since been updated by incorporating new data and expanding the species lists[23,25]. The criteria to assess sensitivity have also been adapted by separating species assessments for collision and displacement, resulting in two unique index scores[20]. This is particularly useful, as the species that are most at risk from collision tend to differ from those most at risk from displacement.

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12 EC Birds Directive 1979
13 EU Habitats Directive 1989
14 Masden & Cook 2016
15 Thaxter et al. 2015
16 MacArthur et al. 2012
17 Vanermen et al. 2015
18 Peschko et al. 2020
19 Garthe & Hüppop 2004
20 Furness et al. 2013
21 Leopold & Dijkman 2007
22 Gove et al. 2013
23 Bradbury et al. 2014
24 Searle et al. 2019
25 Humphreys et al. 2015

Recent work has taken this further by separating displacement risk into two scores based on displacement by structures and displacement by ship or helicopter traffic[26].

Figure 3-1: Black legged Kittiwake, a focus species in the North Sea region

3.1.2 Distribution and behaviour

Monitoring of the distribution and behaviour of seabirds and migrating birds and bats at OWFs is generally required for most projects. Requirements in relation to the distribution of birds are typically for bird patterns to be related to some greater area to assess the relative and the actual importance of the OWF area for the species involved. This is obviously a key requirement during pre-construction investigations but may also form the basis for understanding the macro avoidance and displacement pattern of birds post-construction. Inside the wind farm spatial trends in the distribution of flying birds have been recorded in many OWF projects showing tendencies for higher densities in the areas in between turbine rows[27],[28]. Thus, monitoring may be required to enable the resolution of fine-scale distributions of flying birds inside the OWF.

Requirements in relation to behaviour are often driven by the need to describe diurnal and seasonal variability. These requirements as well as the potential variability of bird flight behaviour and documentation in different weather conditions mean that continuous (long-term) monitoring of bird flight behaviour inside the OWF is often required.

[26] Wade et al. 2016
[27] Petersen et al. 2006
[28] Skov et al. 2018

3.1.3 Flight speed

Requirements for quantification of the flight speed of birds through an OWF are typically related to the need to estimate collisions through collision risk modelling (CRM). At present, flight speed data for use in CRM relies on published data based on very small sample sizes, and typically from studies outside offshore wind farms like[29]. Evidence from monitoring activities within OWFs clearly point towards significantly lower flight speed inside the wind farm as compared to areas without wind farms or other infrastructures[28,30]. It should be noted that currently only one flight speed is used in the Band CRM model and is used for calculating both the flux and collision risk when flying through the rotor[31]. With decreasing speed, the flux will decrease, while the collision risk will increase. However, the flux has the largest effect on estimated number of collisions, so the net result is fewer collisions. Other collision risk models may use different speed measurements for flux and collision risk calculations. For the flux calculation, the track speed (speed measured along entire track) is more appropriate and for flight speed through the rotor the flight speed (speed measured instantaneously at segments of the track) is better to use.

3.1.4 Flight height

Requirements for quantification of the flight height of birds in relation to an OWF are both related to collision risk modelling[31] and monitoring of the birds' 3-dimensional use of the air space in the wind farm. In the Band model the flight height refers to the flight height outside the wind farm before any responsive (vertical) behaviour of the bird takes place, while monitoring of the actual flight heights refers to 3-D tracking or point measurements of birds at different locations within the wind farm.

Given that the risk of collision is associated with the flight height (risk is only considered present at flight heights between the lowest and highest points of the rotors), CRMs can be informed by the proportion of birds flying within that risk height. Most of the existing evidence on seabird flight heights comes from observers on boats, assigning birds to height categories, which can be used to generate flight height distributions[32]. However, height estimates from boat surveys are subjective[33] and their accuracy has not been assessed[32]. Other methods for obtaining these include the use of vertical radars (which does not allow species identification), rangefinders, telemetry, and aerial and LiDAR surveys.

Requirements for 3-D tracking of birds at different locations within the wind farm are increasingly requested by regulators as detailed species-specific data on flight height provides insight into the potential collision risks in the OWF. Flight heights of birds in OWFs seem to be related to the distance to the turbines. Accordingly, comprehensive data on flight heights within the wind farm requires that the data are collected at variable distances from turbines and combined with details of avoidance behaviour of the same birds in order to fully describe the risk of collision.

[29] Alerstam et al. 2007
[30] Tjørnløv et al. 2021
[31] Band 2012
[32] Johnston et al. 2014
[33] Camphuysen et al. 2004

3.2 Density

3.2.1 Flux outside OWF (MTR)

The flux of flying birds is a standard measure which is often referred to as a Migration Traffic Rate (MTR, birds/hour*kilometre[34]). Requirements for quantification of the flux of birds through an OWF are typically related to the need for estimating collisions through collision risk modelling (CRM)[31]. The first step in CRM is to establish data on the number of flying birds which in the absence of avoidance behaviour are potentially at risk for collision from the wind farm turbines. These data are required to be collected from the OWF pre-construction or from a comparable area outside the OWF post-construction. The flight activity data is subsequently used in CRM to estimate the potential number of birds flying through the rotor-swept zone throughout a given time unit (typically a year). During the following steps in the CRM the collision risk is estimated by taking the specific avoidance behaviour, bird morphology, flight speed and height into consideration. As CRM is mainly used as a tool during environmental impact assessments data on flux of birds during the baseline situation is generally not required as part of the post-construction monitoring. In addition, comprehensive data on baseline fluxes can only be obtained for local seabirds and waterbirds, whereas baseline data on migrating birds would require long-term studies outside the scope of impact assessments of OWFs.

3.2.2 Flux inside OWF (MTR)

Determination of the flux of birds inside the wind farm and more specifically through the rotor-swept zones (RSZs) is increasingly requested by regulators as the flux provides insight into the potential species-specific collision rate in the OWF. Depending on the level of bird avoidance of the turbines, the measurement of flux in the RSZs may be constrained by the small number of birds crossing through the zones. Consequently, measurements of flux through the RSZs often suffer from low statistical power.

3.3 Avoidance

Avoidance rates constitute an important input parameter to CRM as part of environmental impact assessments and also provide information on actual avoidance behaviour of birds during post-construction. In CRM an avoidance rate factor is applied to the flux rate to take account of the likely degree of successful avoidance. Birds can avoid colliding with wind farm structures through avoidance behaviour, often comprising fleeing responses, activity shifts or changed habitat utilisation. Avoidance responses therefore result in a reduced number of birds entering and possibly avoiding wind turbines, influenced by external factors, such as wind and topography[35]. To facilitate the understanding of bird avoidance-related decisions, the concept of avoidance can be considered at three different spatial scales: birds may avoid the wind farm area (i.e. macro avoidance), turbine arrays or single wind turbines (i.e. meso avoidance) and last-second evasion of rotor blades (i.e. micro avoidance)[36]. Barrier effect is coupled to the process of macro avoidance and can be measured in the same way.

3.3.1 Macro

Macro avoidance can be studied through the identification of underlying mechanisms for the avoidance, yet it is more often analysed and quantified through the distributional patterns assumed to result from the

[34] Bruderer 1997
[35] May 2015
[36] Cook et al. 2014

avoidance behaviour[28]. The quantification is made by comparing the recorded distribution of densities of flying birds in the windfarm with simulated densities in a situation without a wind farm[28,37].

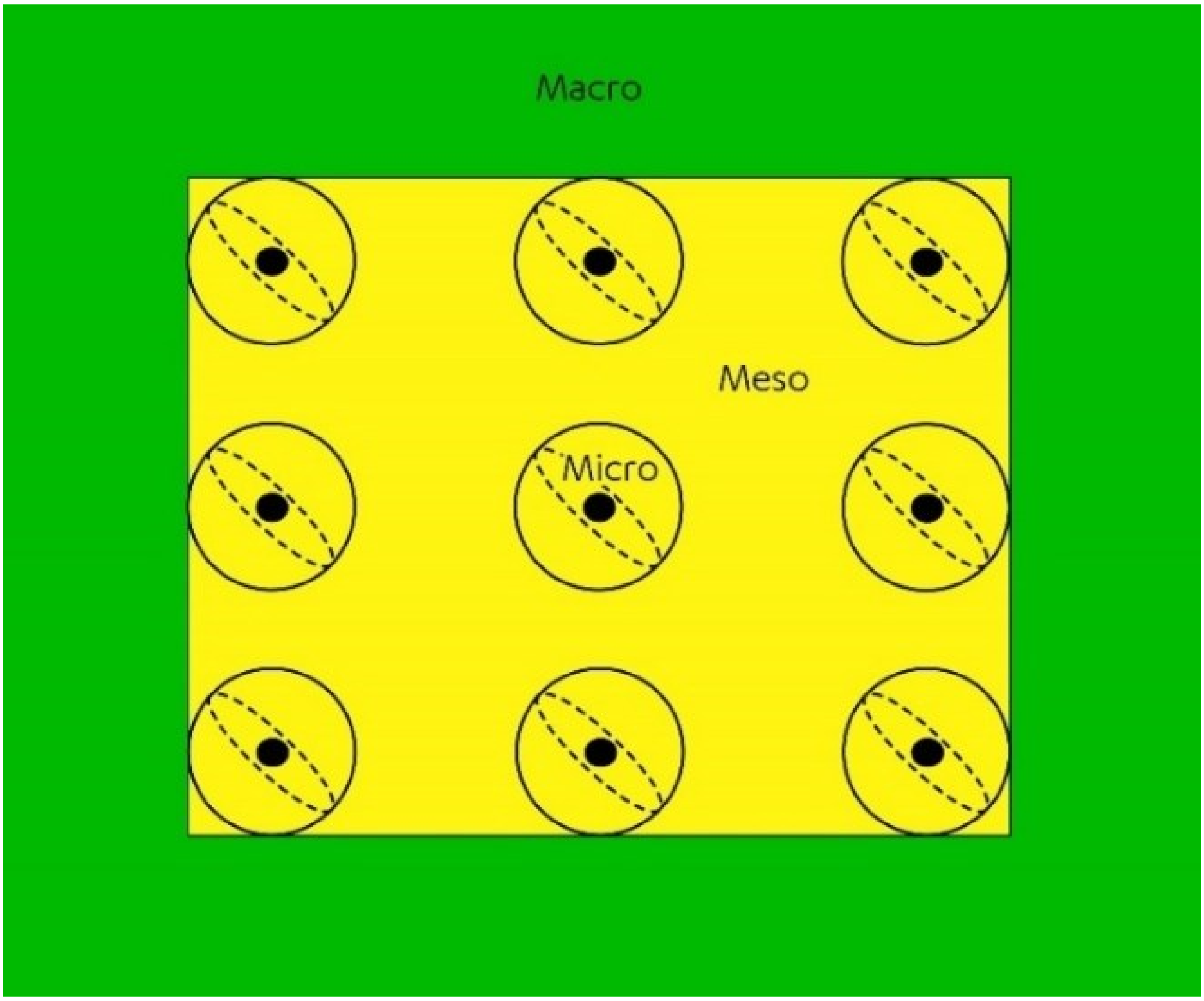

Figure 3-2 Schematic illustrating the spatial scales over which micro-avoidance, meso- and macro-responses operate. Dots refer to turbine tower locations, circles to rotor-swept zones and ellipses (dotted) to a hypothetical rotor position (not to scale, from Cook et al. 2014).

3.3.2 Meso

Meso avoidance can be estimated similarly to macro avoidance by comparing the recorded distribution of densities of flying birds within and between the rotor-swept zones (RSZ) with simulated densities in a situation without a wind farm[30,37].

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[37] Schaub et al. 2020

3.3.3 Micro

Micro avoidance, on the other hand, is typically assessed qualitatively from video data[28].

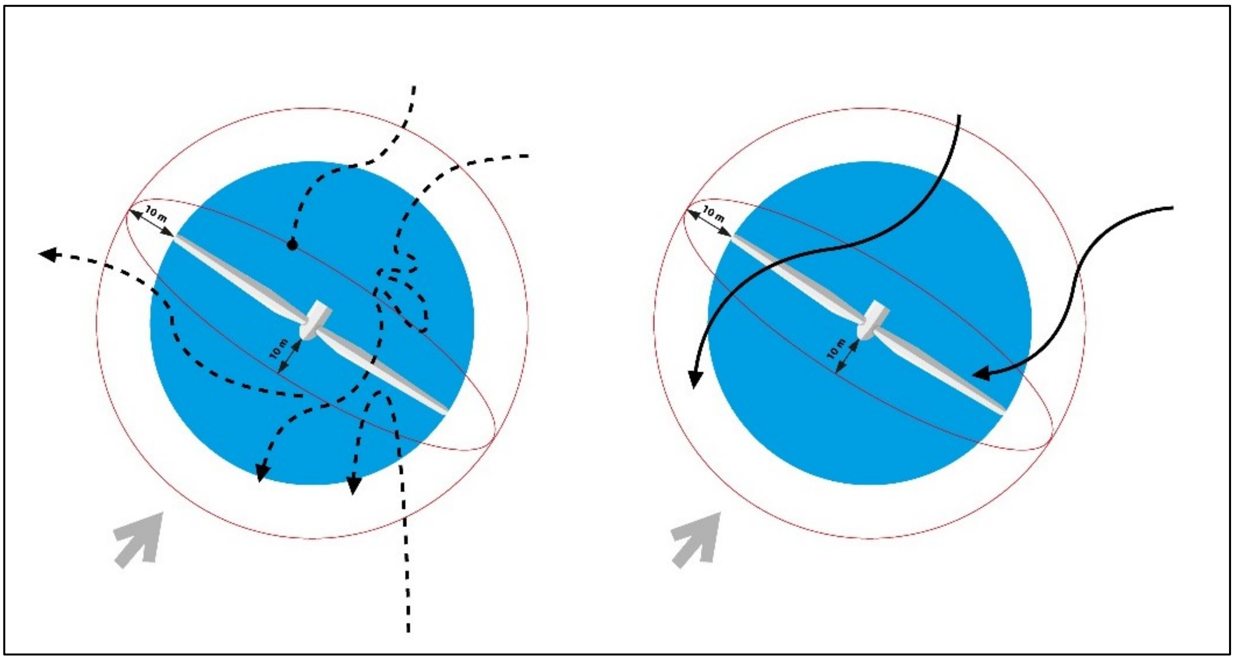

Figure 3-3 Illustration of different types of micro avoidance (from Skov et al. 2018). Within the RSZ (blue circle) + 10 m buffer (red circle), arrows represent bird movement in relation to the rotor (dark blue ellipse + 10 m buffer (red ellipse). The light blue arrow represents wind direction. Birds have been observed to adjust their flight in order to avoid individual blades (dotted arrow), not to adjust but survive when crossing the rotor when operative (solid arrow) or in rare occasions collide (solid arrow). Grey arrows indicate wind direction.

3.4 Collision

3.4.1 Collision rate

As the opposite of avoidance rates collision rates form the primary output from CRM and are used as critical input to environmental impact assessments. At the same time, these rates also provide information on actual collision rates of birds during post-construction. Determination of the collision rates of birds inside the wind farm and more specifically through the RSZs is increasingly requested by regulators for OWF. Depending on the density of birds and level of bird avoidance of the turbines the measurement of collision rates through counts of actual collisions may be constrained by the small number of birds crossing through the zones. As a consequence, measurements of collision rates often suffer from high levels of uncertainty.

3.4.2 Shutdown

Requirements for monitoring technologies to enable interfacing with SCADA are now appearing in many of the world's OWF development regions. The interface is used as a collision mitigation solution to enable controlled/automated shutdown through interfacing with turbines and issuing shut down-on-demand / higher cut-in speed of the turbines. Shutdowns can be applied as automated or controlled shutdown and can either apply to the entire wind farm or single turbines. Controlled shutdown can provide the operator with the opportunity to control the shutdown action depending on the actual bird species at risk, which has the benefit that unnecessary shutdowns can be avoided, and hence more electricity can be generated.

One option for controlled shutdown is a solution in which the wind farm Controller will be given the opportunity to control the shutdown action using an online connection to the monitoring equipment. Another option is through the identification of bird species based on AI-based camera algorithms. Shutdown of single turbines during passage of species of birds of particular sensitivity and concern leads to lower levels of downtime and loss of energy production.

In addition to shutdowns based on an interface between a bird detection system and SCADA, shutdowns may also be required as preventive actions to reduce collisions of birds and bats. The preventive shutdowns are typically operated using a statistical model which predicts the probability for birds/bats based on weather parameters[38].

Deterrents, which constitute another collision mitigation solution, are not included in this guidance, although they are frequently listed as requirements for OWFs during post-construction.

[38] https://rewi.org/resources/wwrf-regional-scale-weather-variables-in-predicting-bat-mortality-and-acoustic-activity/

3.5 Stages of a windfarm

The figure below shows the monitoring activities that are generally most relevant in relation to flying birds and bats during baseline, construction, and post-construction periods (Figure 4), although it is noted that other monitoring activities may be requested by regulators in specific markets

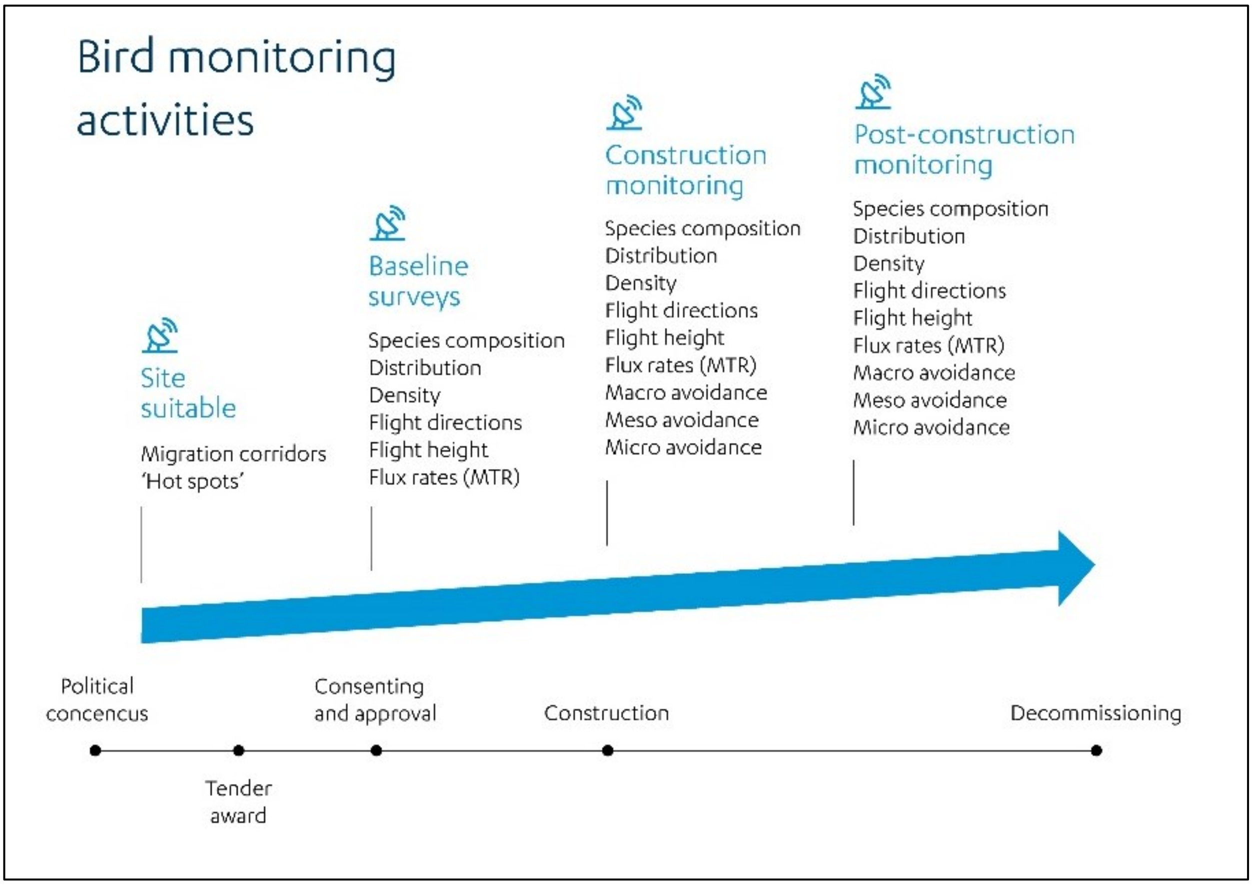

Figure 3-4. Overview of monitoring activities in relation to flying birds during baseline, construction, and post-construction periods.

4. Monitoring Technologies

4.1 Options for deployment of monitoring equipment

Several options exist for deployment of monitoring equipment in OWFs (Figure 4-1). The OSS platform(s) offer the best deployment solution for radars due to the height of the platform(s) which potentially offer an unbroken 360 degrees view over all WTGs in the wind farm. If installed on the OSS platform, the radar should be capable of tracking birds from a vantage point with the sea as a background.

The WTGs offer the best deployment solutions for medium- and short-range equipment like cameras, acoustics, and accelerometers, but may also be used for installation of radars. Cameras can be installed either on the WTG or foundation TP floor or on the WTG or foundation TP railing. Sonic (birds) and ultrasonic (bats) microphones can be installed on the WTG or foundation TP railing, in the nacelle or on the tower. Accelerometers for detection of collisions can be installed in the turbine blades. Radars can be installed either on the WTG or foundation TP floor.

Innovative floating platforms like lidar platforms[39] offer potential solution for medium- and short-range monitoring equipment. These platforms are still at TRL 8, and even with motion compensation may be constrained by waves and swell motion and low height which potentially bias recordings against low-flying birds and bats. They have great potential for pre-construction and EIA surveys, with the advantage of allowing the use of similar equipment and longer monitoring durations to enable comparisons before and after development of the wind farm.

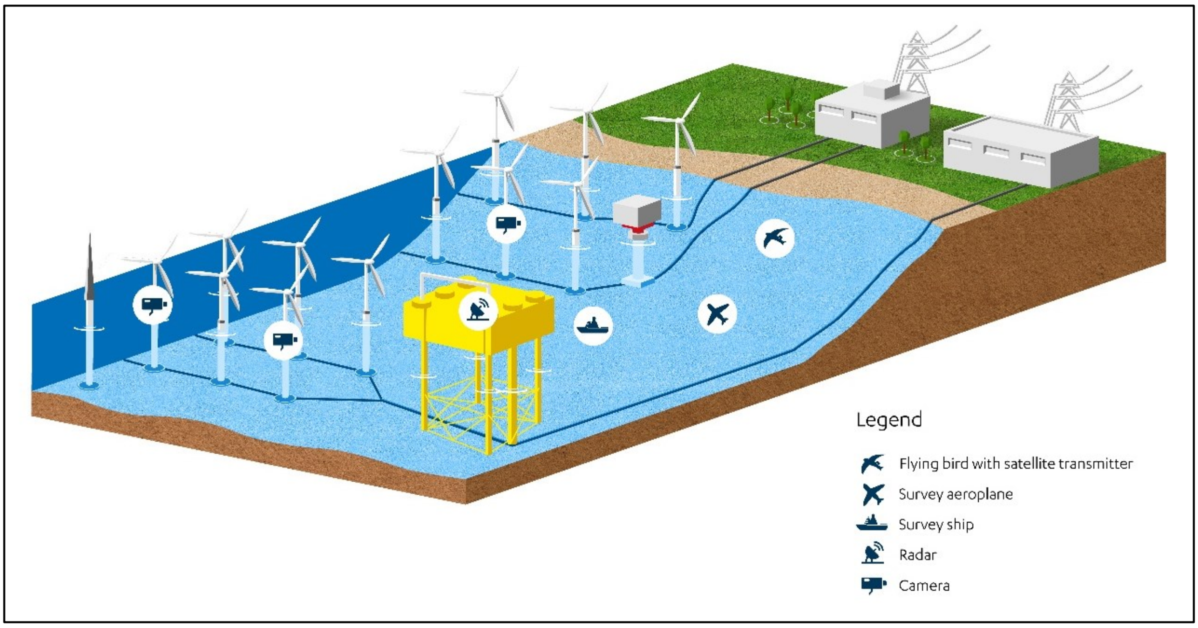

Figure 4-1. Overview of the options for the installation of different monitoring equipment at OWF.

[39] http://www.akrocean.com/

4.2 Radar

Radar is an indispensable technology for monitoring movements of birds and bats, as radar covers wide distances, is independent of daylight and reasonably independent of weather and provides data on migratory intensity and flight paths[34]. An overview of the different radar types that can be used for bird detection is given in Table 1.

Radars can be used to map flying animals in the range from less than 100 m out to about 240 km depending on the hardware at hand, species, flock size and flight view angle[40,41]. For a given type of radar, the performance of bird and bat detection is influenced by the following:

- Wavelength
- Power output
- Scanning mode
- Antenna pattern

Access to relatively cheap marine surveillance radars as well as open access to doppler weather radar data in Europe and the US have enabled wide use of radars for investigating the spatio-temporal patterns of bird flights, including at OWF. It should be stressed however, that for appropriate use of these types of radars, it is of utmost importance that their limitations are acknowledged and taken into account. Due to the advances in radar technology, high-performance radars with optimal capacity for tracking of flying birds offshore have become available, including radars with capability for 3-D tracking and efficient filtering of sea clutter (i.e. waves on the sea surface).

From a horizontal scanning surveillance radar flight trajectories, speed, direction and bird densities can be extracted. The tracks can be analysed with regard to flight behaviour without taking into account the detection capabilities, which are dependent on a range of parameters. However, use of an uncalibrated radar can severely bias data collection and quantification of bird movements in OWF. As with most other bird observation methods, the detection probability by radar decreases with increasing distance to the target. Consequently, when trying to quantify the absolute numbers of flying birds this so-called range bias has to be taken into account. Unfortunately, in many environmental impact studies, radars have been applied in an inappropriate manner by estimating the surveyed volume of air without reference to the detection probabilities of different sizes of birds. By ignoring the different detection probabilities, significant errors can occur in the quantification of bird densities[42].

An overview of the different types of radars applied in bird studies for OWFs is provided in Table 1. For bird studies in OWFs the typical radars applied are X-band and S-band. S-band is less susceptible to precipitation and waves than X-band, which is scattered significantly by waves and precipitation. The waveform of the radar can either be continuous or pulsed. The continuously transmitted wave is received simultaneously, and ranging is accomplished by frequency-sweeping the transmitted radiation at multiple frequencies in different directions as seen in phased array radars like the 3D MAX radar from Robin Radar Systems[43]. However, most radars used in OWF studies emit pulsed radio energy[34].

The average power (measured in kW) of a radar, and the antenna size together with the receiver sensitivity, determine the ability to detect a bird or bat target at a given distance. This means that the higher the signal

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40 Gauthreaux & Belser 2003

41 Desholm et al. 2006

42 Schmaljohan et al. 2008

43 https://www.robinradar.com/max-avian-radar-system

to noise level in the receiver, the further away and the smaller a target the radar can detect. The spatial resolution of the radar will define how precise birds can be mapped. An example could be a long-range Doppler weather radar which cannot detect or follow single individuals or flocks of birds but operates in large spatial resolution cells. A spatial resolution cell of a Doppler weather radar is normally 250-1000m and will illuminate on the radar monitor as a single target if enough targets are present in that specific three-dimensional air space[40,44]. Consequently, the spatial resolution cell increases in size with distance from the radar[44].

Beam width varies between the different types of radar antennas but can be categorized in two distinctive types. First, the fan-beam type, which is emitted from a surveillance radar with a T-bar antenna that usually rotates around a vertical axis as the beam has a wide vertical (10°-30°) and a narrow (≤2°) horizontal beam width[34]. Thus, it offers a high resolution in a horizontal plane but little or no altitude information is obtained. Doppler weather radars and tracking radars have narrow and conical shaped so-called pencil beam antennas. These pencil beams can either be used as a fixed beam (vertical or at different elevation angles) or for conical scanning at different vertical angles thus gathering information on the spatial distribution of birds in a half-sphere above the radar[34].

The advantage of the pencil beam and the phased-array over the fan-beam radars is that they allow for estimation of flight height and coverage for a particular type of target to be investigated in case quantification of absolute bird numbers aloft are desired[45]. The advantage of the fan-beam and phased array radars over the pencil beam radars is that full tempo-spatial coverage is ensured enabling the detection of bird movements which are clustered in time and space as typically seen in birds during diurnal migration. Weather doppler radars are most useful for long-range applications where focus is on mapping the coarse but general movement patterns of flying birds[46]. These radars can be used to estimate the relative density or absolute densities of flying birds to a distance of 40-50 km, yet the lack of coverage of lower altitudes (< 200 m) is a major limitation in relation to studies associated with OWF.

The ornithological use of radar in OWF studies is typically characterized by standard marine surveillance radar. One advantage of operating this type of radar is the relatively high resolution, which enables the researcher to collect detailed information about aerial movement patterns of birds and bats at the spatial level of single individuals[47]. Marine X- and S-band radars represent relatively cheap off-the-shelf equipment and constitute the most widespread radars used in bird studies for OWF. The radar can be operated in horizontal (two-dimensional spatial pattern) or vertical (altitude information) modes.

Several companies have developed modified standard marine radar including novel software to discriminate between clutter and birds and offer them as bird radars. However, efficient filtering of wave clutter remains a key challenge for standard marine radars and most technologies offered will be limited to application in calm weather conditions. During conditions with higher sea states and sea clutter, bird detection will be either biased due to high number of false positives or if applying dynamic clutter filters high levels of false negatives. More expensive high-performance marine radars with doppler functionality like the SCANTER-5000 from Terma[50] offer tracking capability of flying birds in cluttered sea conditions and thus provide a better solution in environments dominated by relatively high wind speeds and waves.

[44] Diehl & Larkin 2005
[45] Eastwood 1967
[46] Buurma 1995
[47] Desholm & Kahlert 2005

Although standard marine radars have limitations for tracking bird and bat movements in cluttered sea conditions, they can be used for quantitative measurement of flight height by vertical orientation of the antenna. During these applications, a blind sector is operated towards the sea surface.

The limitations for controlling the bias caused by noise from waves mean that standard marine radars in horizontal mode should mainly be used in applications which do not require high signal-to-noise ratio and quantification. These types of applications are:

- Comparison of the flux or density of birds and bats in different parts of the wind farm
- Measurements of flight speed
- Assessment of flight behaviour in different parts of the wind farm
- Estimation of macro avoidance
- Estimation of meso avoidance

The high-resolution marine radars are especially required for applications which demand high signal-noise ratio and quantification. Such applications are quantification of flux of birds and bats for CRM estimation and mitigation of collision risk through controlled shutdowns. If standard marine radars are used as a basis for controlled shutdowns the potentially high level of false positives will introduce risks for unnecessary shutdowns. Conversely, in case of high level of false negatives the detection system may not offer the required protection of flying birds and bats.

Table 1 Different types of radars applied in bird studies for OWF with examples of brands.

Type	Wavelength	Waveform	Beam width	Spatial resolution	Range	Vertical coverage	Example
Weather radar	X- and S-band	Pulsed	Narrow	250-1000m	150-200 km	>0.5°	NEXRAD[48]
Standard marine radar (X-band)	X-band	Pulsed	Wide vertical narrow horizontal	5-10m	6 km	>-10°	FAR-3000[49]
Standard marine radar (S-band)	S-band	Pulsed	Wide vertical narrow horizontal	8-15m	8 km	>-10°	FAR-3000[49]
High-resolution marine radar	X-band	Pulsed	Narrow	2-3.5m	12km	>-10°	SCANTER 5000[50]
Phased array radar	X-band	Continuous	Narrow	3-5m	10km	>-1°	3D MAX[51]
Fixed beam radar	X-band	Pulsed	Narrow	5-10m	1km	>-10°	Birdscan MW[52]

48 https://www.ncei.noaa.gov/products/radar/next-generation-weather-radar
49 https://www.furuno.com/files/Brochure/105/upload/FAR-3000%20series%20Brochure.pdf
50 https://www.terma.com/media/ez1j2fn0/termascanter5000_cs_vts_a4_dec2021.pdf
51 https://www.robinradar.com/max-avian-radar-system
52 https://swiss-birdradar.com/systems/radar-birdscan-mv1/

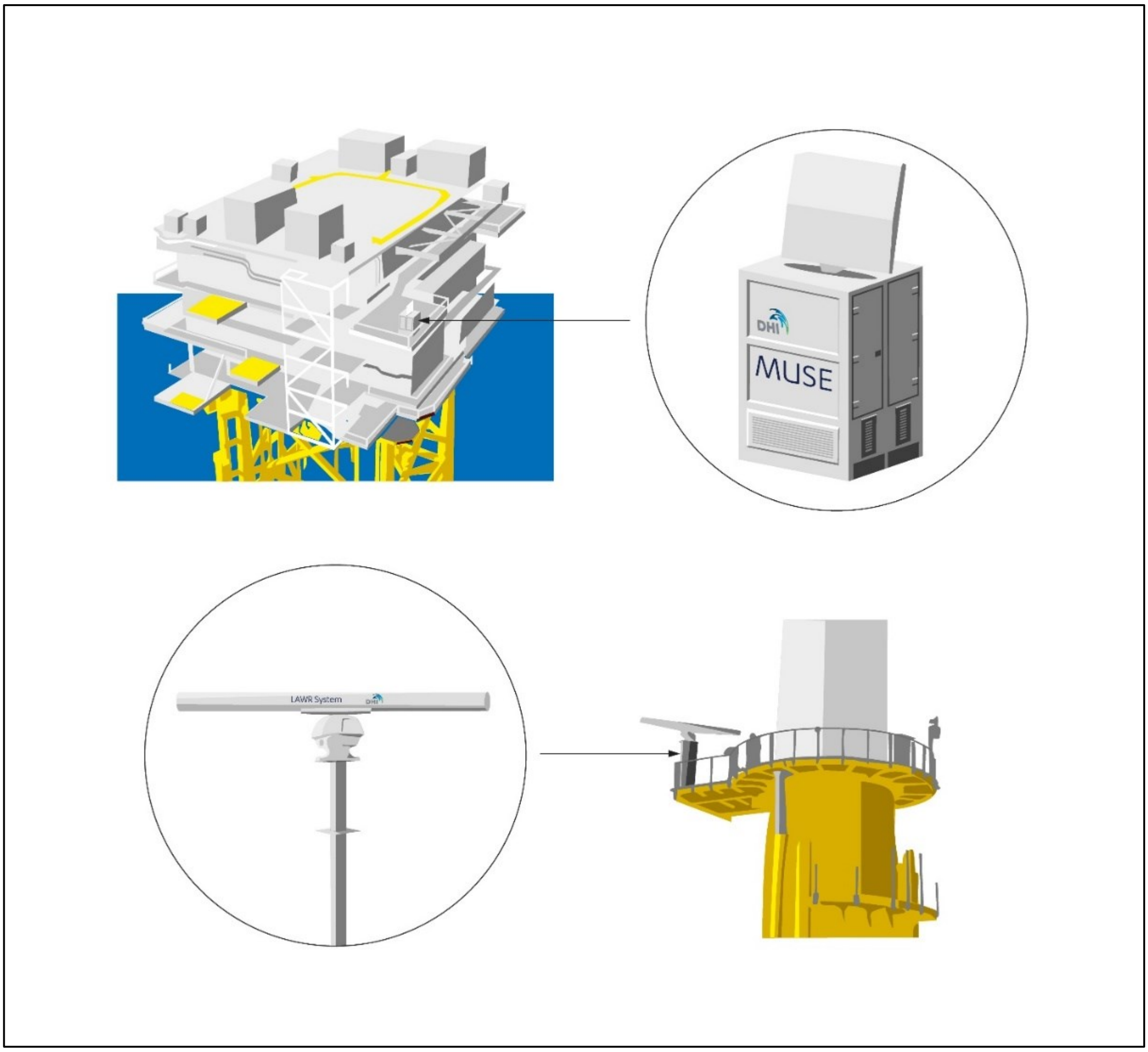

Figure 4-2. Sketch showing options for the installation of radar at OWF. Upper graphic shows installation of 3-D radar with microshelter on OSS, while lower graphic shows installation of 2-D radar on WTG platform.

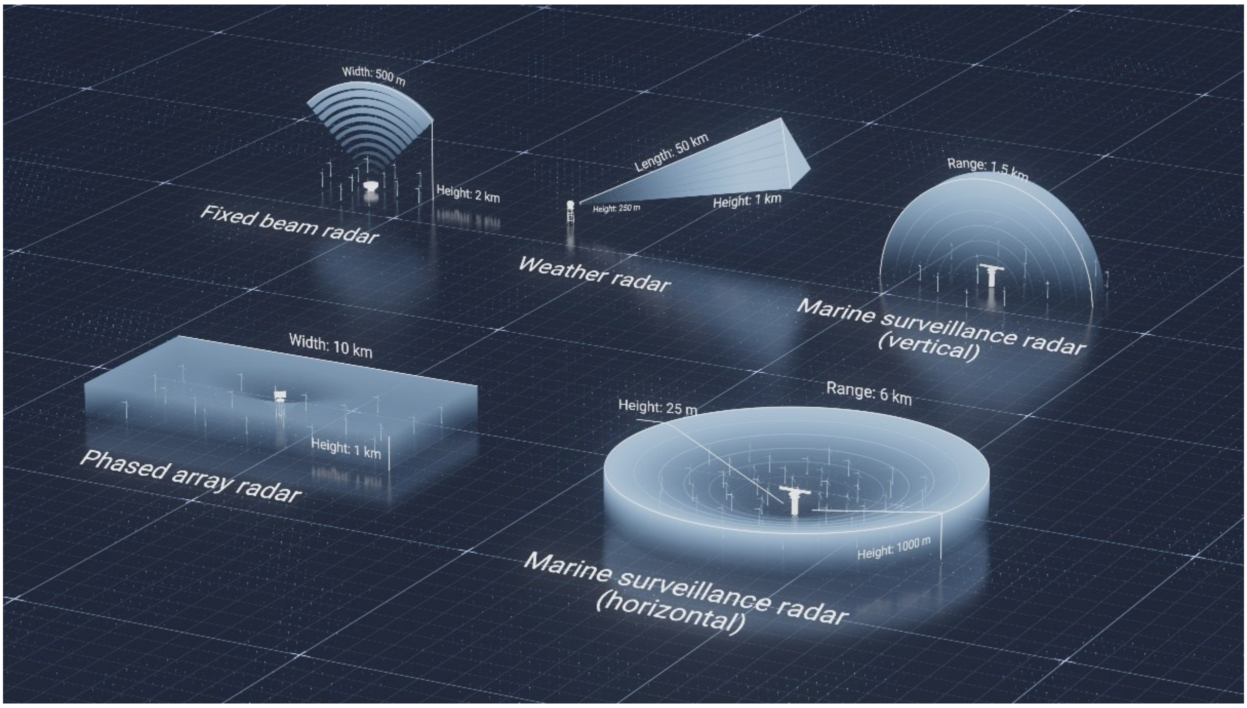

Figure 4-3. Examples of coverage patterns for different radar types used for bird detection in OWFs.

4.3 Camera

Digital cameras are increasingly used for post-construction monitoring of birds and bats in offshore wind farms. A wide range of applications of cameras in post-construction monitoring has been tested and implemented using mainly technologies developed for application within other fields like defence and security. However, the main advantages of digital cameras are:

- Ability to distinguish flying bats from birds
- Ability to identify individual species of birds
- Ability to detect bats and birds in the rotor-swept zone (not possible with radar systems)

The main disadvantage of digital cameras is their limited range in bad weather, with more water droplets in the air causing reduced visibility and deterioration of the image quality. The digital camera(s) can be installed either by mounting on the side of the turbine tower, on the turbine platform, on a survey platform, or on the nacelle (Figure 4-5). The cameras may be automatically controlled by system software or can be remote-controlled from onshore via the internet.

The following five parameters are key for determining the potential use of a camera for monitoring birds and bats:

- Stereoscopic view or triangulation with radar data
- Fixed or moving angle of view
- Zoom capacity
- Visual/thermal lenses
- AI-based species recognition

If cameras are used without interfacing with radar accurate distance and height measurements and reliable estimation of the size of the tracked bird or bat can only be made by application of stereoscopy in which the bird/bat target is followed by at least two cameras with fixed but different angles of view. This is used in several systems onshore like IdentiFlight[53], and tested offshore in systems like Spoor[54]. Applications of stereoscopic cameras for monitoring flight paths of birds and bats in the rotor-swept zone (RSZ) have not yet been developed at a high TRL level to allow for automated estimation of micro avoidance and detection of collisions. The potential use of stereoscopic cameras for this purpose includes monitoring of the rotor-swept zone (RSZ) of the installation turbine as well as monitoring of the RSZ of a neighbouring turbine.

The choice between cameras with fixed or moving angle of view is related to the required magnification as determined by the focal length of the camera. Cameras with fixed angle of view typically employ a short focal length in order to cover as large an area of the RSZ or the areas between the turbine rows as possible. If the focal length of the lens is in the range of a short telephotographic lens, the field of view is relatively large, but only large birds will be recorded at distance and automated species recognition will be challenging[55]. Accordingly, cameras with fixed angle of view are most commonly used for monitoring birds and bats at short distances within the RSZ of the installation turbine. Pan-Tilt-Zoom (PTZ) cameras are typically operated with a large focal length and a zoom capacity between 20 and 100 times the capacity of cameras with a fixed angle of view. This comes with a compromise, resulting in a smaller field of view. The detection distance of PTZ cameras varies with the size of the bat or bird and the zoom capacity of the camera but will always be significantly less than with radar.

53 www.identiflight.com
54 www.spoor.ai
55 Hüppop & Hill 2007

Both daylight and thermal cameras can be applied for monitoring birds and bats and therefore offer continuous 24/7 coverage. Some PTZ cameras support two payloads which allow for combined recordings of the same birds/bats by visual and thermal channels. In general, the resolution of thermal lenses is less than the corresponding visual lenses, yet the thermal lenses provide detection of birds and bats during foggy conditions. However, the resolution of the thermal lens also depends on whether the lens is cooled or uncooled. Cooled thermal cameras are more expensive and use an integrated cryogenic cooler, which chills the thermal image core to increase the sensitivity and accuracy of the thermal image[56].

Through the development of artificial intelligence (AI), automated species recognition software is increasingly being developed which allows for distinguishing birds from bats and identification of bird species. The software may be used with both daylight and thermal cameras. For the species-recognition to be useful in any OWF applications the camera software has to be trained to recognize both target species of birds and all common types of birds occurring at the OWF. In general, training the camera software to identify a particular bird species with high probability (>90%) requires a very large sample (10,000 images+) of training images/videos[57]. The AI-based software may be used to screen recorded images/videos or to identify birds in real-time as required for species-specific shutdowns. The former application reduces the amount of effort required from ornithologists as thousands of videos clips taken do not need to be reviewed to confirm if a bird has been recorded.

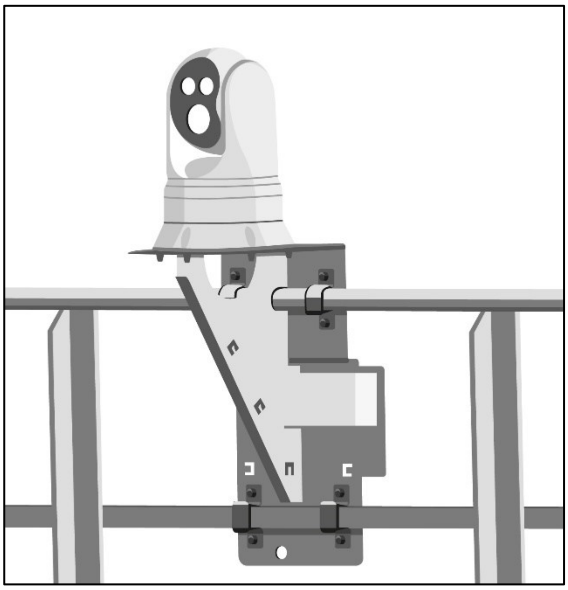

Figure 4-4. Installation of PTZ camera with combined daylight and thermal lenses on WTG.

4.4 Radar coupled with cameras

Increasingly, camera systems are paired with radar to obtain species-specific and geo-referenced data on bird movements over large areas. If radar and camera tracking are fully integrated, the geo-referencing of video and image data will be accurate and the temporal resolution will match the time-steps of the radar track data. One of the main advantages of fully integrated radar and camera tracking is the possibility to undertake species-specific single-turbine shutdowns by the combined use of high-performance radar and

[56] Chilton 2013
[57] Wäldchen & Mäder 2018

long-range cameras. This combination allows species identification through AI technology at a distance from the RSZ and sufficient response time by the WTG in question.

By triangulation between the radar and data from a PTZ camera it is further possible to obtain 3D tracking data of the monitored bird/bat. This provides a solution for collection of information on meso-avoidance behaviour. If the camera is installed on a separate platform outside the wind farm, it may also be possible that macro-avoidance behaviour could be recorded, although detecting and identifying birds over such scales would be challenging.

4.5 Survey platform

Aerial and ship-based surveys provide the optimal means for collection of the following data:

- Baseline data on bird and bat migration (use of radar, observers, and acoustics from boat)
- Macro avoidance behaviour post-construction
- Barrier effects post-construction
- Displacement post-construction

This is the case, even if the poor temporal coverage of these surveys is typically skewed towards calm weather conditions which may not be representative. All the alternative means for collection of post-construction data at the macro scale are associated with much larger issues and uncertainties. Aerial and ship-based surveys may collect useful data on meso avoidance of birds. However, the short-term and biased coverage of the OWF area means that these surveys are less likely to provide representative data with reasonable statistical power on birds' use of the OWF area.

Visual aerial survey methods suffer from reliability[58] and safety[59] drawbacks which are overcome by new digital methods[60]. Digital surveys collect a series of high resolution digital still images or videos which are captured using aircraft-mounted camera equipment, typically forming a grid of images across the survey area. The first trials of digital data collection methods were made in 2007, with comparison and calibration surveys taking place from 2009 onwards[60]. This technique has been applied successfully to generate statistically robust population estimates and describe distribution of seabirds for offshore wind farm sites and is now considered a standard[61].

The difference in raw bird counts recorded between aerial and boat-based methods may, in part, be due to boat association, namely an attraction of aerial foragers to boats which may represent a source of food[62,63]. In comparison, digital aerial surveys are flown at an altitude that avoids disturbance to birds[59]. For other species of seabirds, the presence of boats can have a displacement or avoidance effect. In the former case, birds flee the oncoming survey vessel. They are thus either not detected (underestimated) or are detected away from the vessel.

In spite of these drawbacks, ship-based surveys offer the only reliable means for identification of auks to species level[33]. Hence, although less area can be covered during the same time using boat-based surveys, these types of surveys may be required as an alternative or supplement to aerial surveys in situations where

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58 Van Der Meer & Camphuysen 1996
59 Thaxter & Burton 2009
60 Clough et al. 2012
61 Normandeau 2019
62 Skov & Durinck 2001
63 Gremillet et al. 2008

auks comprise an important component of the bird community. While visual aerial surveys are useful for surveying large, remote areas in a short period of time, the low altitude generates large-scale disturbance amongst birds and health and safety concerns prevent post- (and sometimes pre-) construction monitoring.

At present, there are two main digital aerial survey techniques: digital still and video surveys. UAV and drone surveys have not yet matured to a level which makes them available for commercial use. Digital still imagery is based on a grid design, whereby a series of independent images with a randomised starting point are collected throughout the study area. Video methods, in contrast, typically collect a continuous stream of data along line transects which run in parallel across the survey region.

4.6 Telemetry

A wide range of individual-based telemetry technologies have been applied on birds as well as bats in an attempt to gain more detailed insight into movement patterns and home ranges. However, GPS loggers and transmitters are most commonly used in relation to OWFs[15,64,65,66,18]. These devices provide precise coordinates of instrumented individuals and may also provide information on flight height if the sampling interval is frequent enough[67]. Loggers are archival and therefore must be recovered whereas transmitters have the advantage of uploading fixes via satellite uplink.

GPS devices can only be deployed on medium-sized and large species of birds (> 100g) due to the weight. Radio-tagging offers an alternative solution for small-bodied species[68,69]. In radio tagging the emitted signals from radio tags can be detected either by hand-held devices or a base-station[70]. This allows information on, for instance, colony attendance[71] and also at-sea movements (Votier et al. 2006), although at relatively low precision. A more general study by Paton et al. (2021) provides detailed information on the different types of antennas that can be used and their benefits. If using hand-held devices to collect data from the radio tags, the tagged bird must be within range. Perrow et al., (2006) reported that the range of the tags used had to be within 1km of the recording device. The detection range of the antenna depends on its height and type, with antennas capable of having a detection range of 2-20km[72].

Location fixes can be recorded every two minutes when tracking with hand-held receivers, with automated radio telemetry stations allowing for birds to be monitored continuously as long as the individual is within range (ten to hundreds of signals per minute can be received[73]. The drawback of using radio-tagged birds in relation to OWFs is the risk of low sample sizes obtainable within the wind farm array. As a result, data collected can be used within CRM, however empirical collision rates cannot be estimated using this technology. Yet, information obtained from radio-tagged individuals can provide insight into macro avoidance behaviour[68,70].

GPS tags provide high precision location information on instrumented birds enabling a detailed understanding of behaviour and movement. Tags either transmit data (via satellite or GSM) or archive information which is recovered from a base-station at a focal point or by re-catching the bird. A large number

64 Wade et al. 2014
65 Garthe et al. 2017
66 Thaxter et al. 2018
67 Ross-Smith et al., 2016
68 Perrow et al. 2006
69 Ponchon et al. 2012
70 Loring 2016
71 Votier et al. 2011
72 Paton et al. 2021
73 Bridge et al. 2011

of seabirds have been tracked using GPS tags, including studies in relation to offshore wind farms such as Guillemots[74], Lesser Black-backed Gulls[15,75] and Northern Gannets[65]. Devices can be set to record fixes at a wider range of intervals from multiple times per second upwards and have variable duty cycles to optimise coverage of important periods of time. This can generate very large datasets depending on the attachment method (i.e., long-term or short-term deployment) and power source (i.e., steady state batteries or solar panels). Factors such as tags detaching and battery depletion can cause GPS tags to fail.

GPS devices record the date, time, and position (latitude, longitude) within the scheduled sampling interval. The device can obtain data on flight height and speed, allowing for behaviour to be reported (e.g. if the bird was foraging, resting or travelling). Information on macro-avoidance behaviour can also be obtained and seasonal patterns in habitat use can be estimated[18,65]. Repeated tracking of the same individuals may help identify changes in birds' responses over time to existing wind farms and therefore provide information on species specific macro-scale avoidance. Tracking can provide data to describe bird behaviour more accurately over large area, while as for radio tagging limited data may be obtainable with GPS within operational wind farms. This technology may also provide further information on the impacts of barrier to movement and identify areas where species disperse to if disturbed by the wind farm.

4.7 Other

In addition to the above-mentioned monitoring techniques acoustic recorders can provide useful information on species composition and temporal patterns of bat and bird migration[76]. This is not the least the case with bats for which acoustic monitoring constitutes the only means to identify species. Although all species of bats are emitting high-frequency sounds they vary a great deal in strength from 50 to 120 dB[77], and so interpretation of acoustic recordings in terms of species composition of bats should be undertaken with care. For birds acoustic monitoring albeit still being useful is highly skewed towards species which are calling during migration, and species composition is therefore typically biased[78, 79,80].

Microphones can be deployed on the WTG platform fence, on the tower or/and at the nacelle. Depending on where the microphone is positioned, background noise can become more pronounced, resulting in the application not functioning well. The microphone should be placed away from the sea and at such a distance that it would not cause interference[80]. Unfortunately, all currently available acoustic recording devices for bats and birds are self-contained units with limited or no remote control possibilities. As a consequence, acoustic systems designed and optimized for the needs of offshore wind farm operators for real-time monitoring and shutdown are still pending.

Although software for automated detection and species identification of bat sounds and bird calls has been developed most users limit the application of acoustic software to screening the collected sound files, while manually classifying the recorded birds and bats to species[79,76]. The disadvantages of using detection software, however, is that the false positive rates can increase due to wrongly identified detections (these rates are generally higher than in manual analysis[81].

[74] Peschko et al. 2020
[75] Vanermen et al. 2020
[76] Hill et al. 2014
[77] Jakobsen et al. 2013
[78] Alerstam 1993
[79] Hill & Hüppop 2009
[80] Krijgsveld et al. 2011
[81] Molis et al. 2019

Additionally, accelerometers installed in the rotor blades can pick up vibration signals and can register when a collision event has occurred[82] (Figure 4-5). Accelerometers have not yet been used widely within OWF but have been tested both onshore and offshore. The most advanced system (WT Bird) has reached a TRL of 7 through tests in land-based wind turbines, and TRL 8 following trials on offshore turbines during 2011 in the Dutch Offshore Wind farm Egmond aan Zee. The WT Bird system uses a combination of accelerometers to detect collision incidents, and infrared (active infrared) video cameras to record video footage of the event. The updated version of the system is designed to detect collision impacts during day and night, including objects as small as 8 grams[83].

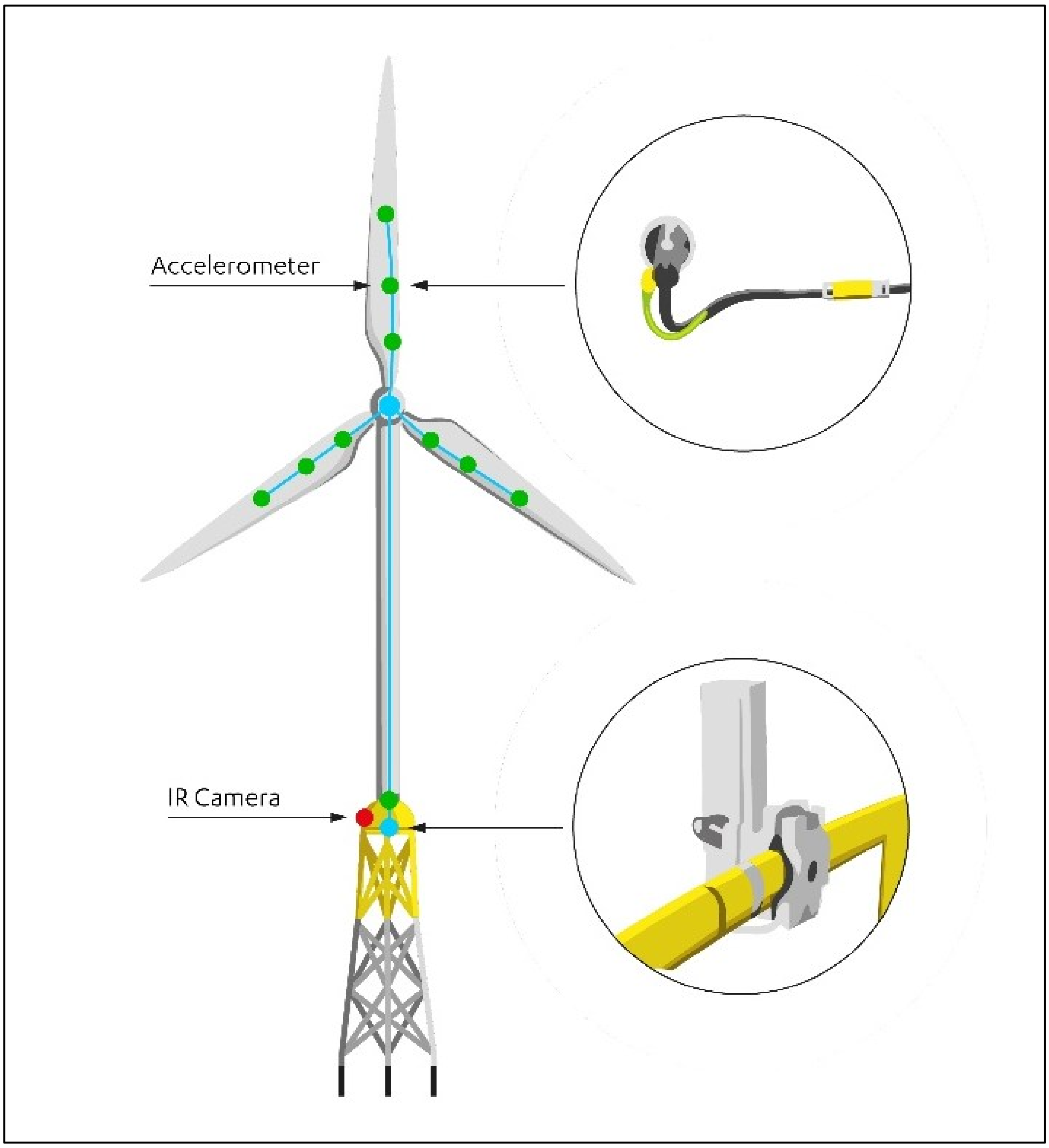

Figure 4-5. Sketch showing installation of accelerometers coupled to cameras on WTGs

[82] Collier et al. 2012
[83] Stucker et al. 2022

5. Assessment and Scoring

5.1 Assessment and scoring system applied

The monitoring technologies being assessed and the scoring system applied are indicated in Table 2. The technologies have been grouped into radar, camera, other, survey platform and telemetry, and each technology is rated as either very good, good, average, bad or not available in relation to each of the key monitoring requirements. The factors controlling the rating are the following:

- How well do they fulfil the requirements
- How difficult is it to install the system
- Component price
- Retrofit ability

In many instances a monitoring technology may be applied to address several required pieces of information about bird and bat flight behaviour associated with OWF. However, the majority of technologies possess weaknesses when applied outside their target area of application. For example, radar may provide some information on flying birds and bats like the size of the target which may be of use for identification of the species or type of species concerned. Yet, the radar measurements of size of a tracked target is variable and depends among other things on the angle between the target and the radar beam. Accordingly, radar data on their own do not fulfil the requirement for species identification.

Rating of the difficulty of installing the system has been scored with the more complex installations given the lowest score. The price of the system has been rated by giving the systems with the highest quality/price ration the highest score. Rating of the retrofit ability has been scored by giving systems with a good potential for retrofitting the highest score.

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Table 2. Scoring system applied in the assessment of monitoring technologies (next page).

		Implementation			Density		Species				Avoidance			Collision	
Type	Equipment	Retrofit	Installation Complexity	Cost of equipment	Flux outside OWF[1]	Flux inside OWF[1]	Distribution and behaviour	Species id	Flight speed	Flight height	Macro avoidance	Meso avoidance	Micro avoidance	Collision rate	Shutdown
Radar	3D Radar[2]	●	▼	▼	▲▲	▲▲	▲	▼	▲▲	▲▲	▲▲	▲▲	▼	▼	▲
	2D Radar[2]	●	▼	●	▲▲	▲▲	▲	▼	▲▲	-	▲▲	▲▲	▼	▼	▲
	Radar coupled to camera[2]	●	▼	▼	▲▲	▲▲	▲▲	▲▲	▲▲	▲▲	▲▲	▲▲	▲▲	▲▲	▲▲
	Radar with fixed antenna[2]	●	●	●	●	●	▼	▲	●	-	▲	▲	▼	▼	●
Camera	Fixed camera[2]	▲	▲	▲	-	-	▼	▲	▼	-	▼	▼	▲▲	▲▲	●
	Dome with multiple fixed cameras	●	●	▼	-	-	▲▲	▲▲	▼	-	▼	▼	▲▲	▲▲	●
	Moving camera	▲	▲	●	-	-	▲▲	▲▲	▼	-	▼	▼	▲▲	▲▲	●
Other	Accelerometer as single sensor	▼	▼	▼	-	-	-	-	-	-	-	-	-	●	-
	Accelerometer coupled to camera	▼	▼	▼	-	-	-	-	-	-	-	-	-	▲	-
	Microphone[2]	▲	▲	▲▲	-	-	-	▲▲	-	-	-	-	-	-	●
Survey Platform	Ship-based surveys	-	-	▼	●	●	▲	▲▲	-	▲▲	▲▲	●	▼	▼	▼
	Aerial visual surveys	-	-	▼	▼	▼	●	▲▲	-	▲▲	▲▲	●	▼	▼	▼
	Aerial digital surveys	-	-	▼	▼	▼	●	▲▲	-	▲▲	▲▲	●	▼	▼	▼
	UAV/drone surveys	-	-	▼	▼	▼	●	▲▲	-	▲▲	▲▲	●	▼	▼	▼
Telemetry	Radio transmitters	▼	▼	●	▼	▼	▲▲	▲▲	▲▲	▲▲	▲▲	●	▼	▼	▼
	Satellite transmitters	▼	▼	●	▼	▼	▲▲	▲▲	▲▲	▲▲	▲▲	●	▼	▼	▼
	Archival tags	▼	▼	●	▼	▼	▲▲	▲▲	▲▲	▲▲	▲▲	▼	▼	▼	▼
	Acoustic telemetry	▼	▼	●	▼	▼	▲▲	▲▲	▲▲	-	●	▼	▼	▼	▼

Very good	▲▲
Good	▲
Average	●
Bad	▼
Not Available	-

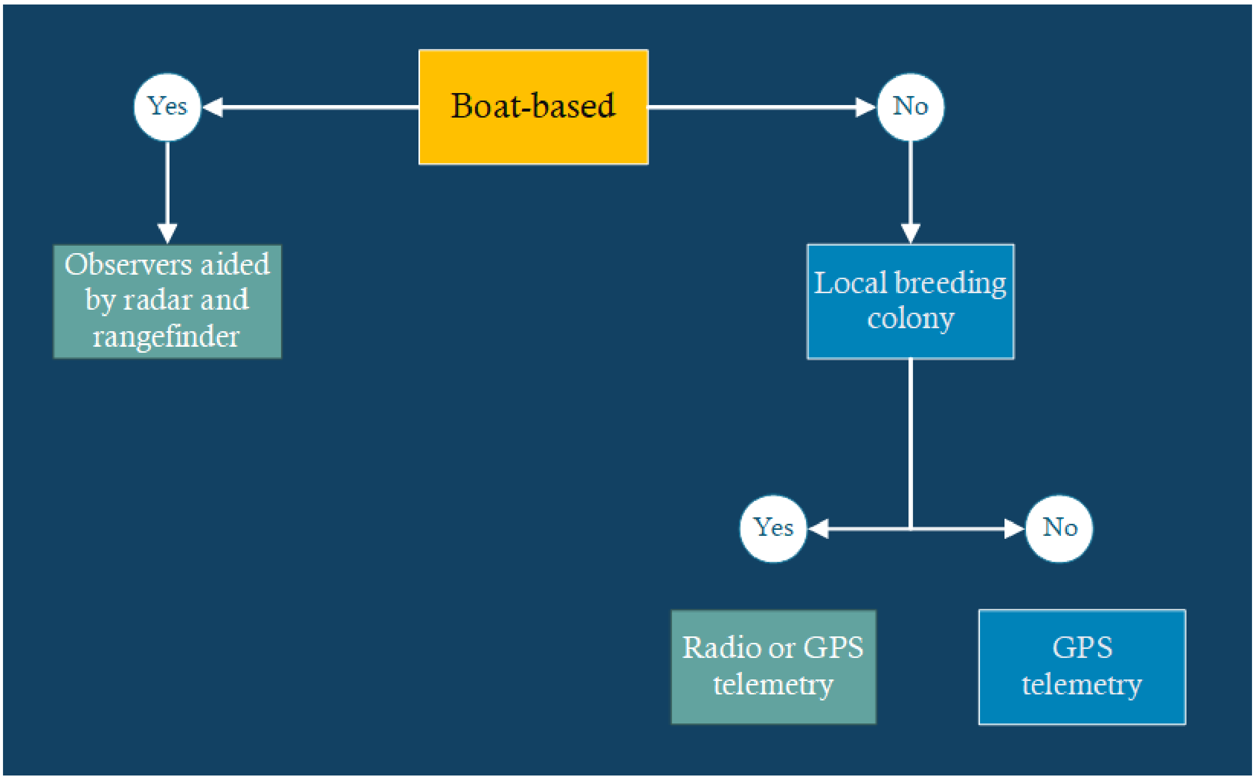
[1] Birds/hour*kilometre (MTR)

[2] Useful for bats

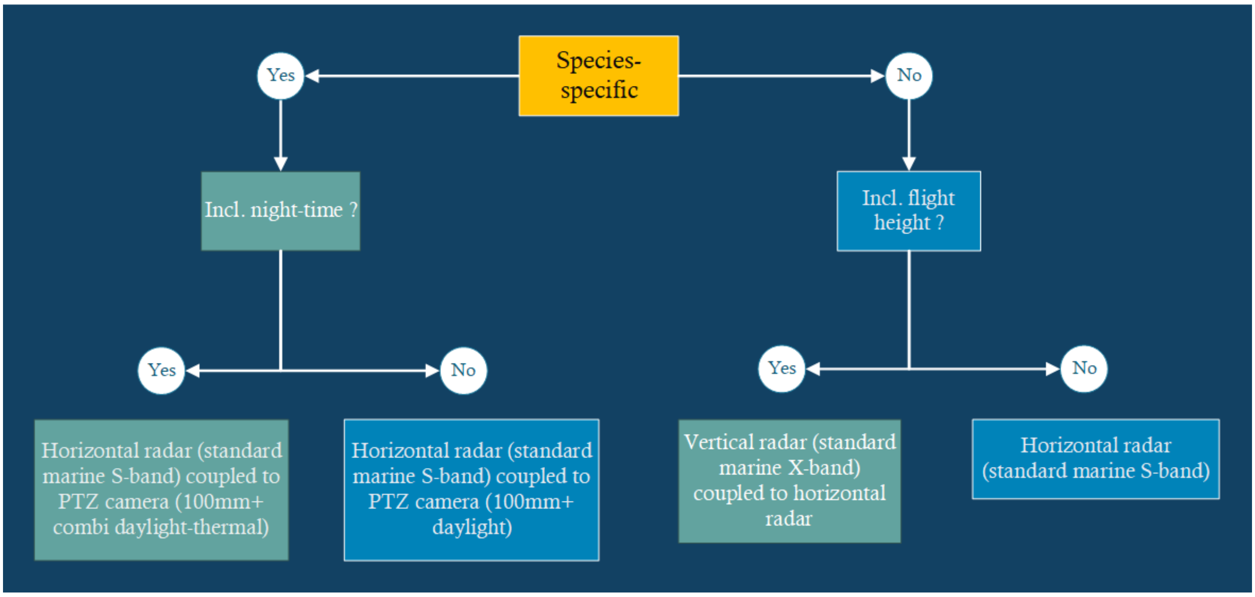
5.2 Recommended monitoring solutions

Based on the scoring results in Table 2 a number of recommended solutions for different monitoring applications are shown below. The recommended technologies have been chosen based on the highest quality/price ratio, TRL level and operational experience in offshore wind farms. Obviously, the TRL level and operational experience of several emerging technologies are likely to change in the near future. Accordingly, the recommended solutions may be seen as reflecting the status by 2022.

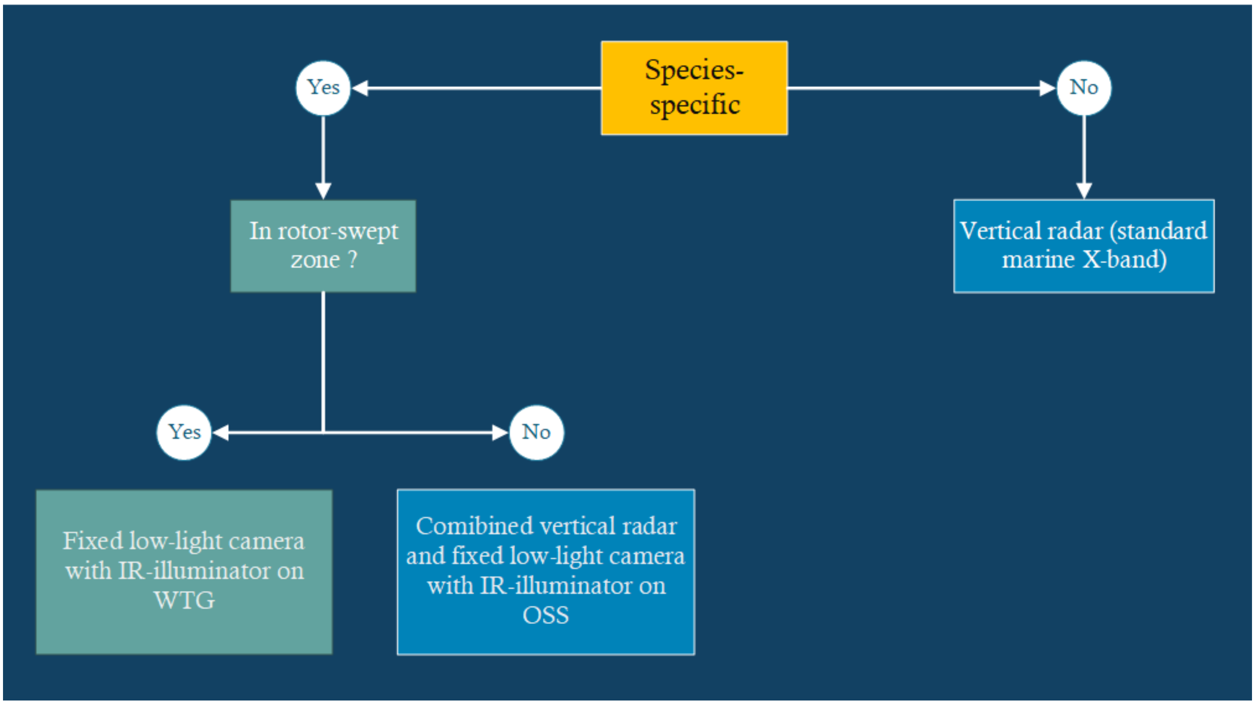
5.2.1 Baseline



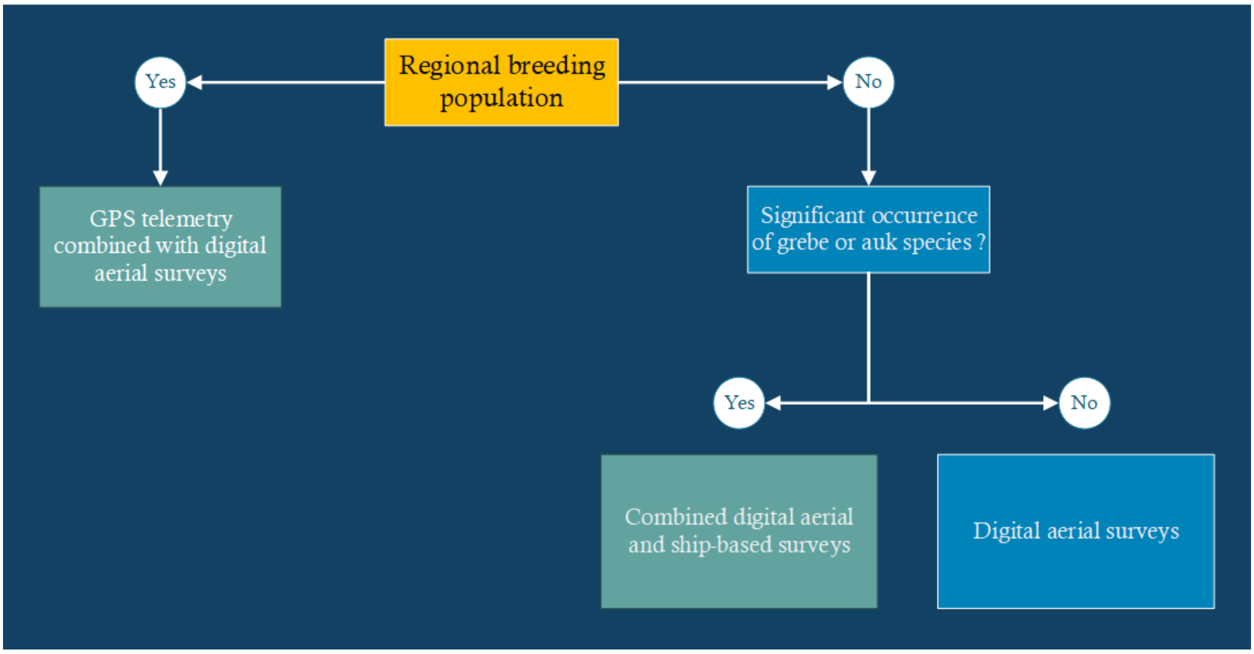
5.2.2 Post-construction flight behaviour



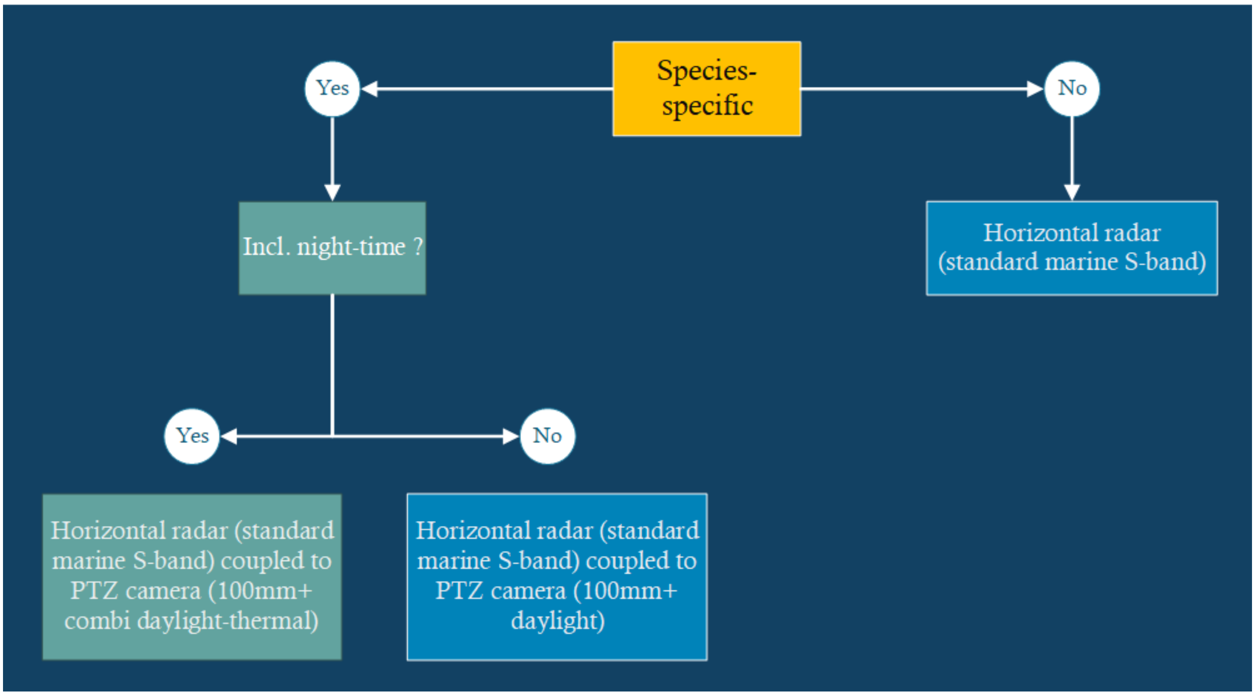
5.2.3 Post-construction flux



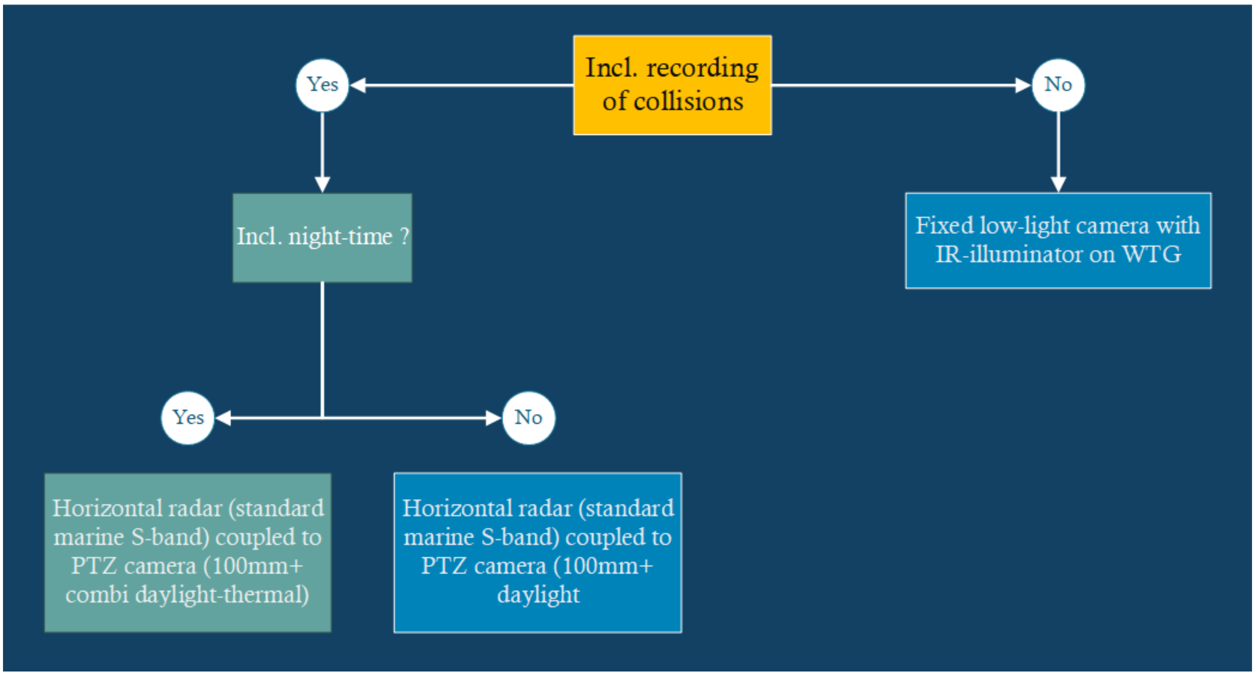
5.2.4 Macro avoidance and barrier effect



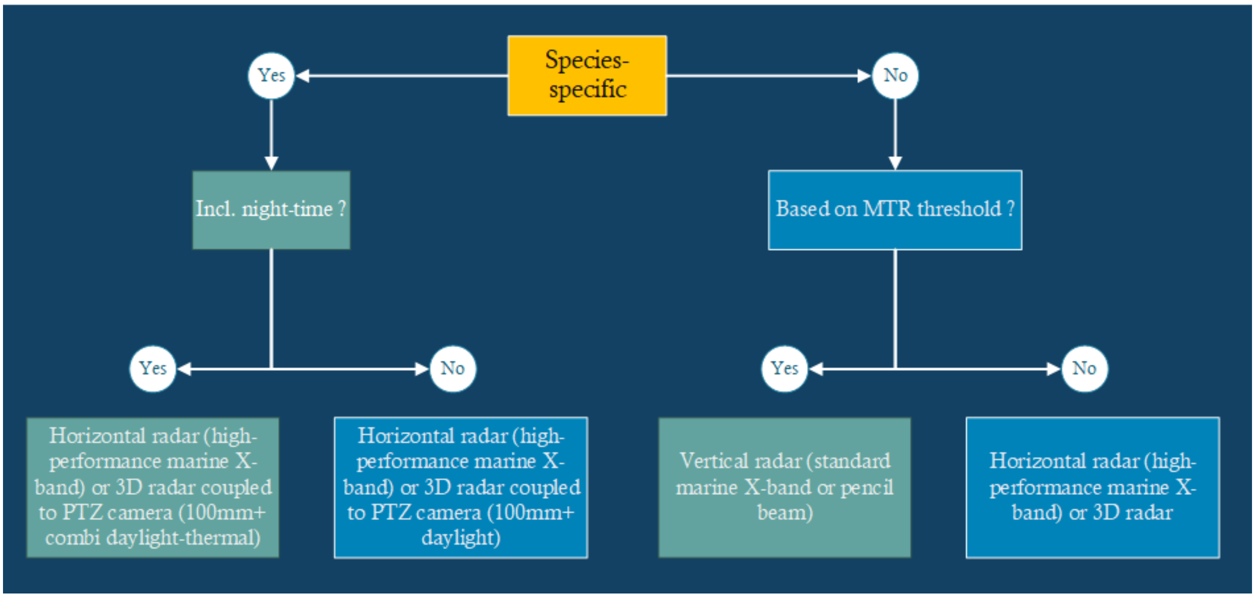
5.2.5 Meso avoidance



5.2.6 Micro avoidance and collisions



5.2.7 Shutdown



5.3 Species

5.3.1 Identification

The requirement for collection of species-specific data on the occurrence of birds inside and outside the wind farm during pre- and post-construction periods calls for equipment capable of providing species identification in either an automated way through AI-based camera solutions or a semi-automated way.

Human-based manual surveys offer some of the best means for collecting data on bird species composition at OWFs (Figure 5-1). Both aerial and ship-based surveys are undertaken using line-transect and distance sampling methods[84]. In addition, observations of bird movements with the aid of radar can be undertaken from an anchored boat[85]. Recent developments of drone-based and un-crewed aerial vehicle (UAV) surveys have focused on bird counts in colonies[86] and applications for offshore surveys are yet in their infancy with TRL levels below 8. Both visual and digital (still/video) aerial surveys can provide detailed quantitative data on species composition of local seabirds for a larger sector around the wind farm site, while observations from anchored boat can provide detailed quantitative data on species composition of bird migration at the site.

With the development of digital survey and image processing technology it has become apparent that the granularity of digital aerial surveys exceeds that of traditional visual aerial surveys with a higher proportion of recorded birds determined to species[87]. For that reason, digital surveys based on videos and still images are now a standard technique implemented in bird monitoring at wind farms in all OWF development zones in Europe, and several vendors offer digital survey technologies at TRL 9 along the Atlantic coast, in the North Sea and the Baltic Sea.

Although less area can be covered during the same time using boat-based surveys, these types of surveys may be required in situations where separation of smaller species of auks (little auk/Atlantic puffin/black guillemot) as well as the larger species of auks (common guillemot/Brünnich's guillemot/razorbill) is required. Results from digital surveys clearly document that identification of these species is constrained during these surveys[88, 89,90]. In such situations, an optimal solution for monitoring auks at OWF would be to apply a combination of digital aerial and ship-based surveys using the latter as a means for collection of robust data on species composition of auks.

Data on species composition of local seabirds and bird migration inside the OWF collected through aerial or ship-based surveys can potentially be complemented through the use of visual observers on OSS platform or WTGs. Experience with past projects[28] has highlighted the challenges associated with the use of visual observers in OWF. Health and safety considerations mean that access to the turbines will be limited to calm weather conditions, introducing potential biases into the data collected. Furthermore, access to turbines is likely to be further restricted as maintenance workers often take priority for space on vessels travelling to the wind farm.

Cameras mounted on the transformer platform or turbine transition pieces provide means for collection of species-specific data by either using automated AI-based species recognition or by analysing the image data

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[84] Buckland et al. 2001
[85] Bundesamt fur Seeschifffahrt und Hydrographie 2013
[86] Dunn et al. 2021
[87] Meller & Maher 2008
[88] Connelly et al. 2015
[89] Weiss et al. 2016
[90] Zydelis et al. 2019

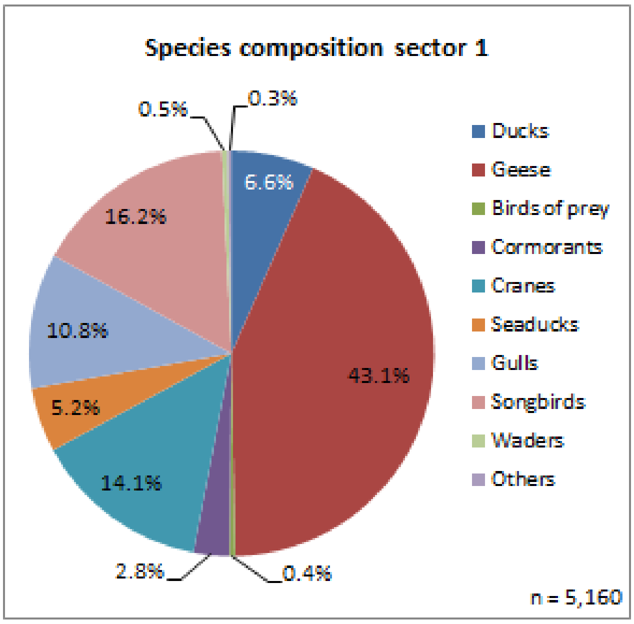
using human observers[30]. Image data can be recorded as either stills or videos with videos providing additional clues on species identification through information on movement patterns. Compared to aerial and ship-based surveys long-term deployment of cameras provides the optimal data on species composition inside the wind farm, as aerial and ship-based surveys have reduced capacity for picking up short-term movements like migratory peaks or feeding events in the OWF. The sample sizes obtainable using moving cameras are approximately 4-5 times larger than those from fixed cameras (DHI data). For these reasons moving cameras provide the optimal solution for documentation of species composition of birds inside the OWF. Fixed and moving cameras can be used to determine the species composition of birds in OWFs, however the proportion of birds identified to species level will depend on the optical zoom capacity of the cameras applied.

If radar systems are applied without combinations with other sensors the general requirement for collection of species-specific behavioural data cannot be met. This is the case for all radar systems, and whether radars are used with rotating antennas like surveillance radars or in fixed modus like fixed-beam radars. Radar-cross sections and echo-signatures of tracked birds from both types of radars can be measured and used to indicate the size of the bird. However, as the radar cross-section and signature of a given target is not constant and changes with the aspect of the bird to the radar beam this measure only provides an indication of the type of bird[42]. However, the measure is a reliable classifier for differentiation between bird and insect echoes. Wing-beat frequencies can be measured from fixed radars and can be used to separate birds from insects and obtain indications of types of birds. Yet, due to the overlap of the wing-beat frequency between different species of birds the measure only provides limited information at the species level[91]. If radar systems are applied in combination with cameras the capacity of cameras for identification of species may be enhanced by the higher detection capacity of the radar. This will especially be the case if the radar is integrated with moving cameras which will improve the spatial coverage of the cameras[30].

Acoustic systems may be used to provide insight into the species composition of birds and bats during pre- and post-construction. During pre-construction, microphones are typically applied from ships[85], while microphones are installed on the turbine railing or in the nacelle during post-construction[92]. Sonic microphone recordings may add information on bird species during night hours. Yet, it should be stressed that the recordings most likely will be biased towards bird species which call frequently and birds flying at lower altitudes. Ultrasonic microphone data are likely to provide useful data on the species composition of bats. Due to the constraints imposed by the different strength of sounds emitted by different species of bats the acoustic data cannot be used for quantification of the presence of bats.

[91] Bruderer et al. 2010

[92] Kulik et al. 2020



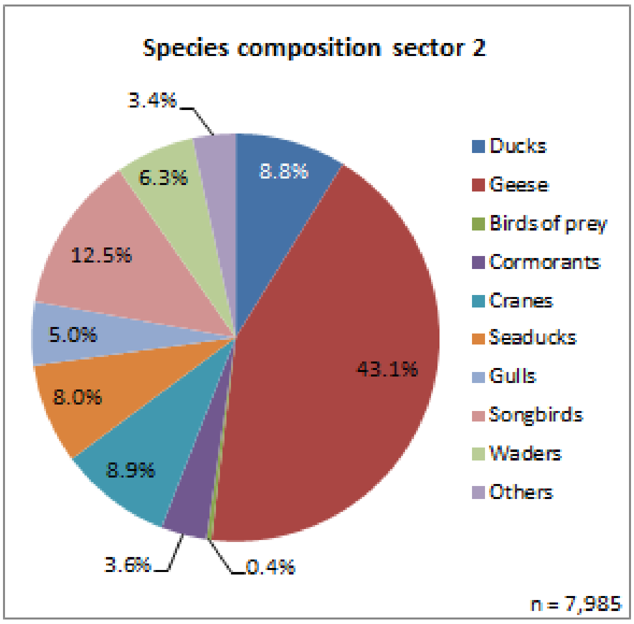


Figure 5-1*. Example of bird species composition deduced from visual observations from boat at the perimeter of the Wikinger Offshore Wind Farm in the Baltic Sea (Iberdrola) during Autumn 2019 (Kulik et al. 2020). The graphs show % dominance in sector 1 (facing towards wind farm) and sector 2 (facing away from wind farm).*

5.3.2 Distribution and behaviour

Aerial and ship-based surveys provide the optimal means for collection of data on seabird distribution over larger areas of sea around the OWF with aerial surveys providing the best coverage/time ratio. Inside the wind farm human observers may provide additional data on spatial and temporal variation. However, data collected from both surveys and observer-based monitoring possess limited capacity for describing the spatio-temporal distributions of birds during adverse conditions, introducing potential biases into the data collected.

In order to obtain detailed data on the temporal variation of birds in the relatively small area occupied by the wind farm continuous recordings from deployed equipment are needed. An integrated design with a radar in digital communication with moving cameras will ensure the maximum number of combined video and radar tracks with birds identified to the species level. Specifically, large sample sizes of reactive behaviours of each of the target species of birds both in the meso zone and in close proximity to operating rotors will be obtainable. With large samples it will be possible to resolve how behaviours change with distance to turbines and rotors, weather conditions, seasonality and time of day[30]. Thus, the use of integrated radar and moving cameras in the wind farm will ensure that the main aims of bird monitoring in the meso zone can be met (Figure 5-2).

Due to the amount of static and dynamic noise close to turbines radars are generally incapable of recording behavioural details of birds in the rotor-swept zones. Cameras mounted on WTGs offer means for collection of a large amount of detailed data on the behaviour of flying birds in the rotor-swept zone, including data on collision rates. Fixed cameras cover less than 1/4 of the rotor-swept zone of the installation WTG, which means that in order to cover a sufficiently large and representative part of the rotor area at least four cameras have to be installed per WTG. Fixed and moving cameras can monitor movements of birds in an entire rotor-swept zone at a neighbouring turbine, the degree of behavioural detail depending on the optical zoom capacity.

Using single fixed or moving cameras alone to monitor the behaviour of birds in the rotor-swept areas has the disadvantage that behavioural data cannot be collected with positional information and consequently the assessment of micro and meso avoidance behaviour may be flawed (see below). Through integration of multiple cameras 3-dimensional tracking is possible and is offered by vendors like Spoor[54] at TRL 7-8.

Monitoring of birds in the rotor-swept areas may be constrained by the low number of birds expected to enter the areas close to the turbines[28]. Monitoring at Nysted Wind Farm in Denmark based on a fixed thermal camera mounted on a WTG during 124 days in 2004 and 2005 recorded a total of just 9 birds close to the rotor blades[93].

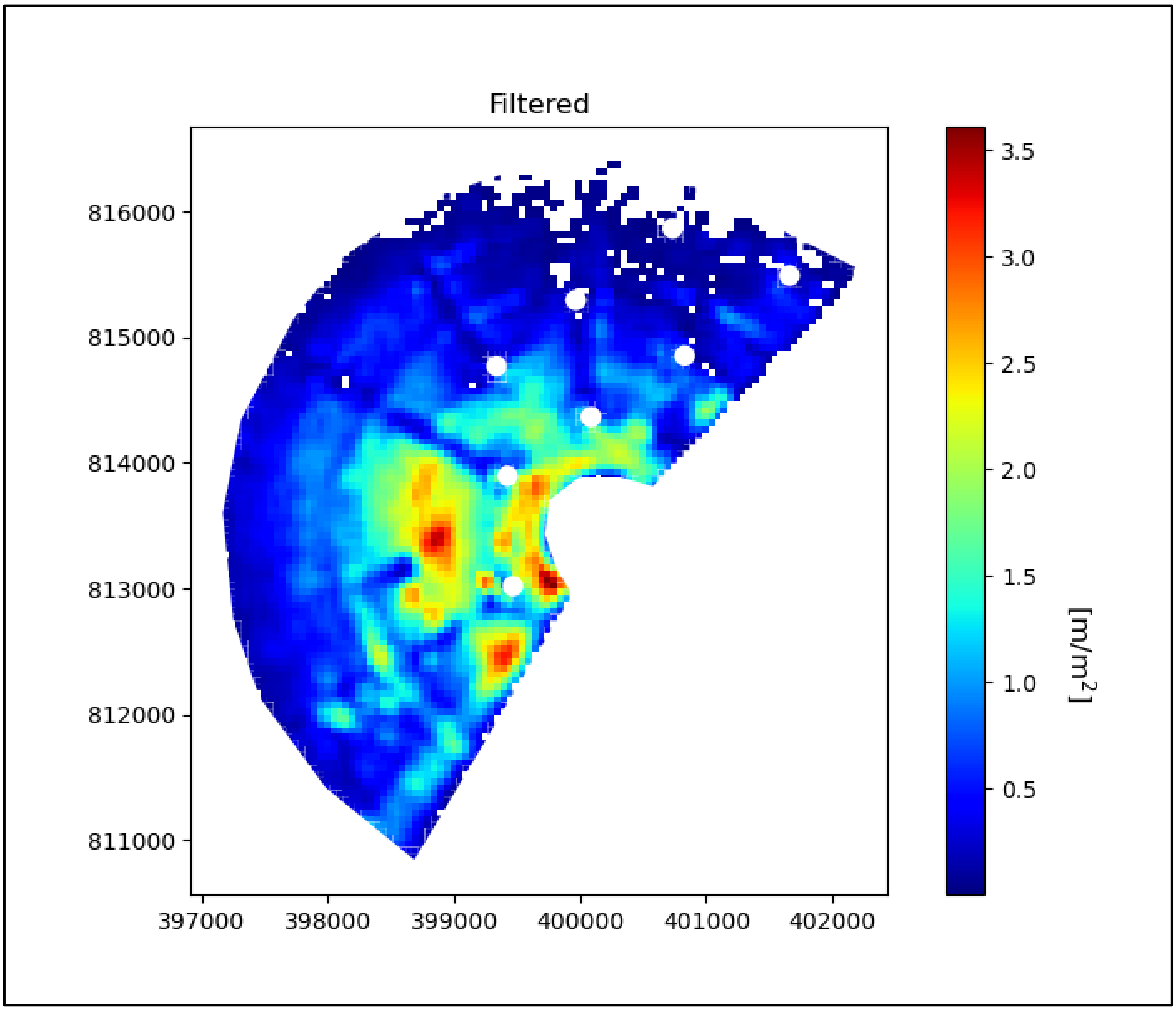


Figure 5-2. ***Example of the distribution of flying birds as recorded by radar tracking in the Aberdeen Offshore Wind Farm (Vattenfall, Tjørnløv et al. 2022). The map shows mean densities during September 2021.***

[93] Desholm 2005

5.3.3 Flight speed

Flight speeds recorded for birds inside wind farms are significantly lower than indicated by published data[30]. More valuable sources of information on more realistic mean flight speeds and associated variability in OWF are necessary for improving estimates of the flux of birds for the bird species in question.

Both 2D and 3D flight and track speed can be calculated from high-resolution radar, stereoscopic cameras, GPS tags or rangefinder measurements. Flight speed can be calculated using single track segments. Track speed can be calculated using multiple track segments where the euclidean distance from start to end of the track is divided by the duration of the recording. The track speed is used to estimate an actual mean flight duration taking into account that birds are not flying straight all the time.

It should be noted that currently only one speed parameter is used in the Band CRM model although it would be more appropriate to use the track speed for flux calculation and the flight speed for calculation of the speed through the rotor.

Radar applications which monitor bird movements continuously within a wind farm provide the largest sample sizes of high-resolution track data for estimation of realistic flight and track speeds. For GPS tracking data with high positional accuracy (PDOP) should be selected for speed estimation[37].

5.3.4 Flight height

Most of the existing evidence on bird flight heights comes from observers on boats, assigning birds to height categories, which can be used to generate flight height distributions[32], albeit with unknown accuracy. More reliable methods for obtaining continuous flight height distributions from individual bird tracks are rangefinders[28], GPS satellite tags[94], digital aerial surveys[95] and radar[30] .

Rangefinder measurements require human observers operating the equipment from a boat or a platform inside the OWF and may therefore be biased towards calm conditions. Rangefinders can only be applied during the day, and rain or fog prevents successful measurements. As they are operated by observers, data tend to be negatively biased against low (less than 10m above sea level) and very high flight heights[96]. Although the accuracy of rangefinder height measurements has been assessed as relatively high (2m)[96], accuracy limitations are caused by the distortion of the digital compass of the rangefinder due to the magnetism from metal structures on boats and offshore platforms[28].

Flight height estimates from digital aerial surveys are relatively variable[97]. However, the collection of precise estimates of the flight altitude of birds in flight from these surveys has recently advanced using lidar. Validation of flight height measurements of Northern Gannet and Black-legged Kittiwake from lidar and digital aerial photography indicate that the height of birds in flight could be measured using lidar to an accuracy of within 1 m[98]. Furthermore, flight heights are estimated relative to the sea surface, helping to overcome difficulties associated with negative flight heights that may be recorded when using digital aerial surveys, GPS tags or laser rangefinders[67, 96,97,99]. A key limitation of lidar estimates of bird flight height is that

[94] Thaxter et al. 2016
[95] Buckland et al. 2012
[96] Borkenhagen et al. 2018
[97] Johnston & Cook 2016
[98] Cook et al. 2018
[99] Corman & Garthe 2014

sea-swell may interfere with the detection of birds in flight within the lower 1-2 m above the sea surface, resulting in a high false positive rate (Figure 5-3).

GPS tags and altimeters may provide flight height measurements of birds for large areas comparable to what can be obtained from digital aerial surveys. The measurement errors from GPS vary from approximately 3 m to 14 m depending on factors such as the sampling rate that is used[96] with a similar level of error for estimates derived from altimeters[94]. For optimal resolution and accuracy for continuous height measurements tags have to apply a fast sampling rate, which impacts on battery life. The inherent 2D perspective of GPS devices relative to the satellites from which positional data are derived means that GPS-derived height data can be subject to large inaccuracies[100], although the precision of estimates increases with faster sampling schedules[101,102]. Alternatively, barometric altimeters may be incorporated into tags to quantify height; these, however, require continuous calibration to account for barometric drift, associated with spatial and temporal changes in atmospheric conditions[103]. An additional limitation to these individual-based methods is that they have to be collected during the breeding season. It should also be noted that detailed prior confirmation of the birds' use of the sea area surrounding the OWF is required to ensure that a useful sample can be collected from the area of interest. As for digital aerial surveys the large area coverage and the short temporal coverage of the OWF mean that the height measurements from telemetry data are most useful for collision risk modelling, and less useful for obtaining detailed continuous flight height data within the OWF.

Continuous detailed data on flight height of birds can be obtained by 3-D radars such as the MAX radar from Robin Radar Systems[43], which measures flight heights of each recorded bird within range to an altitude of 1 km. The detection range of the radar depends on the size of the bird, i.e., the radar cross-section. Large birds like northern gannet may be detected at distances up to 10 km, while medium-sized birds like gulls can be detected at distances up to 6 km. As the MAX radar operates in X-band the relatively short wavelengths enable collection of high-resolution 3-D track data with high accuracy. Detailed and accurate 3-D track data on birds may also be obtained by combining a 2-D horizontal radar with a 2-D vertical radar or a PTZ camera. If combined with a vertically spinning radar the height measurements will be delimited to the part of the 360° area covered by the beam of the vertical radar (approximately 10%). If combined with a digital camera, the height estimates will be determined by triangulation between the distance to the birds measured by the radar and the inclination angle to the same bird measured by the camera[30].

5.4 Density

To quantify the intensity of movements of birds through an OWF a radar or stereoscopic cameras are required as they are the only technologies capable of continuous recordings of all bird movements in representative parts of the wind farm undertaken in a way that ensures that short-term variations in flux are picked up. The radar can either be operated horizontally which may be advantageous if spatial variations in the flux of birds are expected within the OWF or it can be operated vertically if bird distribution in the OWF is expected to be more even. In any case, various corrections are needed to correct for distance-related fluctuations in the detection probabilities of the radar. By ignoring the different detection probabilities, flux estimations may be wrong by as much as 400%[42]. The result of the distance correction is the unit of birds per hour and kilometre, known as the migration traffic rate (MTR)[85], which facilitates comparison of migration rates from different OWFs.

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100 Péron et al. 2020
101 Bouten et al. 2013
102 Thaxter et al. 2019
103 Cleasby et al. 2015

Depending on the wavelength and the ability of the radar system to suppress wave-induced noise while still tracking birds a variable degree of bias is also introduced in radar recordings of bird flux. The majority of bird studies by radar have applied standard marine X-band radars which are highly sensitive to noise from waves (and rain) with high levels of false positives as a consequence during adverse conditions. Marine S-band radars have also been applied in a large number of studies and provide fewer false positive recordings of birds. The use of dynamic noise filters may remove false positives efficiently but may cause issues with false negatives. Less biased radar track data may be obtained using high-performance marine radars with doppler processing like the SCANTER-5000 radar from Terma[50].

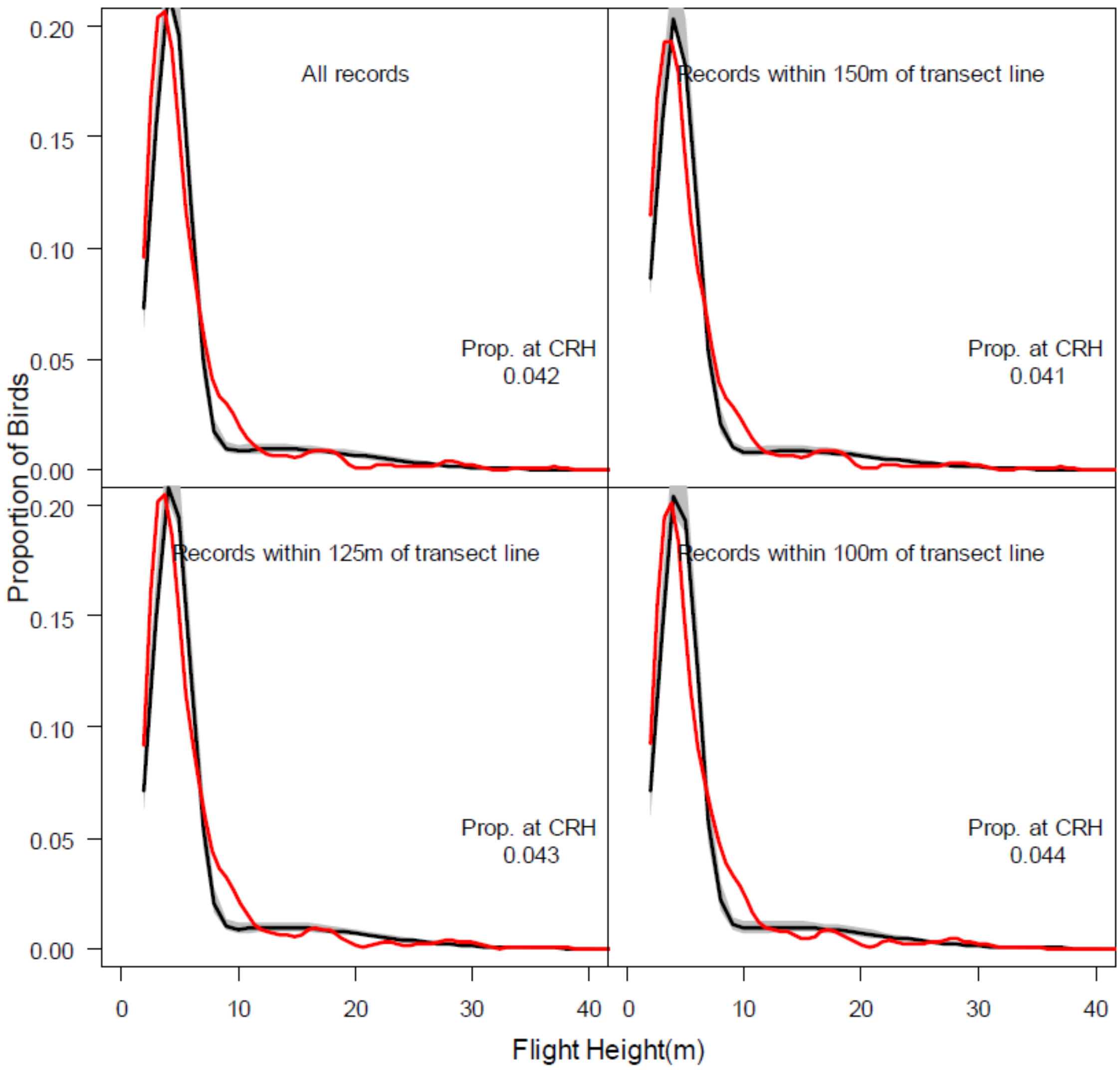

Figure 5-3. ***Example of recorded flight heights from digital aerial surveys (Cook et al. 2018). Data are modelled flight height distributions for Black-legged Kittiwakes flying at least 2 m above sea level for all birds and for birds within a horizontal distance of 150 m, 125 m or 100 m of the survey transect line. The proportion of birds at collision risk height (Prop. At CRH) was estimated for each subset of the data assuming a rotor swept area of 20-120 m above sea level (as defined in Johnston et al., 2014). Black line and grey polygon indicate fitted values and 95 % confidence intervals, red line indicates observed data.***

As identification of bird species is unattainable using radars on their own combination with species data is required in order to estimate species-specific flux rates. Cameras controlled by or integrated with a radar may supply species identifications for selected bird tracks but will generally not provide species identifications for all recorded bird tracks. Thus, estimation of species-specific flux rates requires a statistical approach for linking radar recordings with species data for specified time periods and sections of the OWF.

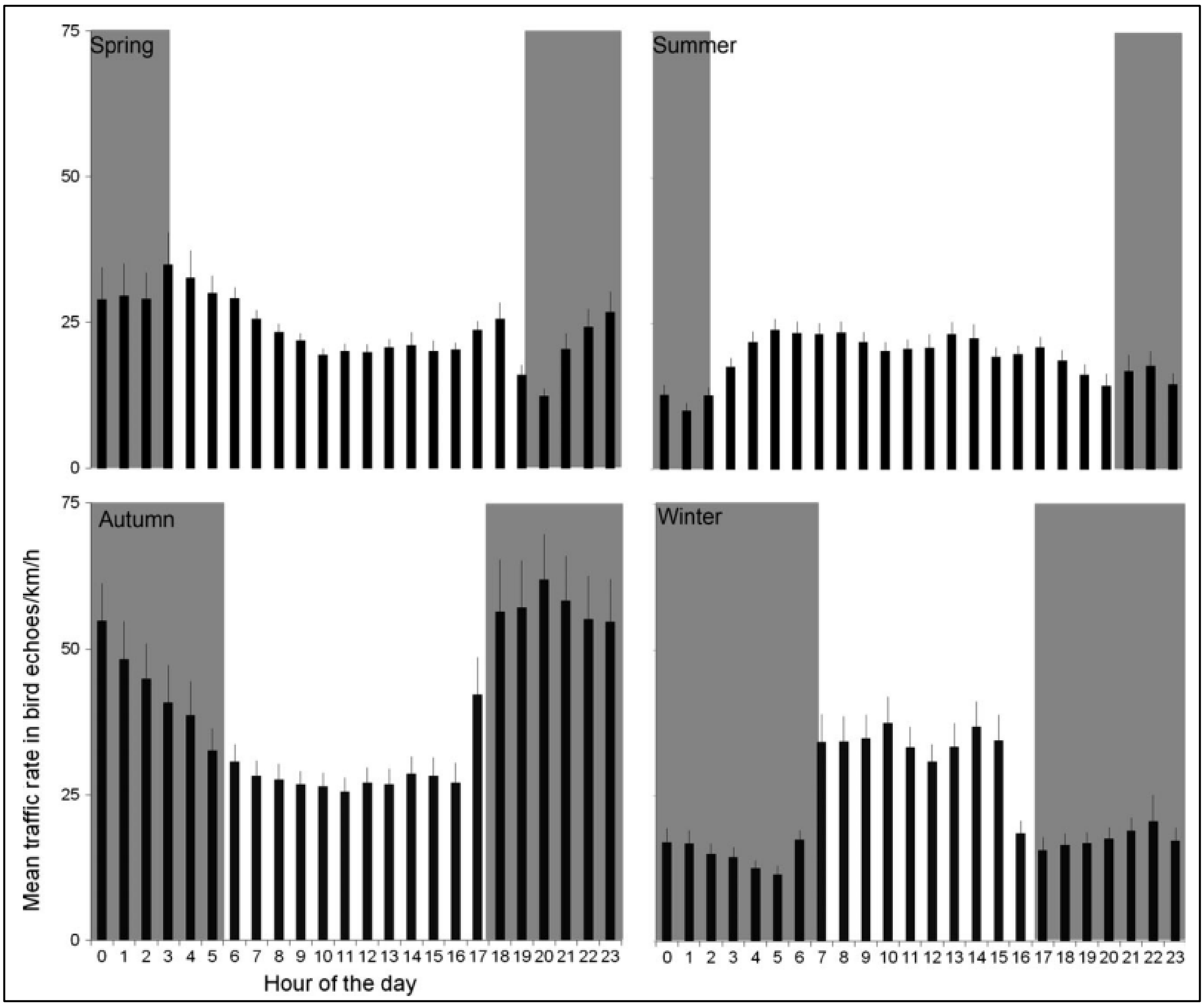

Figure 5-4*. Example of flux calculations from vertical radar recordings showing average number of bird echoes/km/h measured at the OWEZ OWF at collision risk heights (25–115 m). Grey shading indicates the timing of darkness. Results are shown by season. Error bars represent standard errors (Fijn et al. 2015).*

5.5 Avoidance

In parallel to the monitoring of collisions, the monitoring of bird avoidance, barrier effects and displacement due to OWFs has become a standard requirement in most European countries. Species-specific macro and meso avoidance behaviour can be quantified from detailed track data on flight trajectories. Micro avoidance is traditionally assessed using qualitative approaches by observers viewing video footage[28]. Each scale of avoidance demands specific capabilities of equipment in relation to identification of species, detection range and spatio-temporal coverage required for satisfying minimum power requirements. Due to the strong meso avoidance behaviour displayed by birds, sample size constraints are especially significant in relation to estimation of micro avoidance as few birds will enter the rotor-swept zone.

The deployment of human observers with radar equipment on fixed platforms within the OWF or on boats at or near the OWF is limited to relatively calm weather conditions and will generally be undertaken during a short period of time. Consequently, the collection of data by human observers in OWF is biased and include logistic and HSE shortcomings, and the short-term coverage is likely to limit the size and quality of sample sizes below what is required for safe assessments of collision rates and avoidance and displacement behaviour of birds. Observations by observers operating radars on turbines in the periphery of wind farms have been applied to assess macro avoidance, yet this approach may be biased in situations where bird's macro response takes place at distances beyond 2 km[28]. Recordings of macro avoidance by observers with radars on boats may be less biased[92], yet the efficiency of observers in terms of detecting radar-tracked birds is questionable and the costs involved in long-term monitoring using boat-based platforms will be high. Observer-based data on meso avoidance suffer from the limitations induced by poor coverage of adverse weather conditions and the inability to obtain representative data with reasonable statistical power on birds' use of the OWF area. For the same reasons and due to the low number of birds expected to enter the rotor-swept zone, assessment of micro avoidance by human observers is likely to result in insufficient data.

Aerial surveys represent the most useful platform for collection of data on macro avoidance behaviour, barrier effects and displacement. The short-term and biased coverage of the OWF area means that these surveys are less likely to provide representative data with reasonable power on birds' use of the OWF area. Thaxter et al. (2018) highlighted the importance of considering the movement of birds relative to turbines to determine the 3-dimensional response of birds involved in the meso avoidance behaviour. Data collected during surveys are rarely of sufficient resolution to investigate these fine scale movements in relation to the turbines. With respect to micro avoidance, past studies and analyses suggest that collisions and, last second micro-avoidance behaviour are likely to be rare events[28]. Consequently, the probability of detecting either a collision or micro-avoidance behaviour as part of a standard aerial or ship-based survey is extremely low.

Telemetry data may provide useful data on macro avoidance, barrier effects and displacement but require that a breeding colony of the target species of bird is located in the vicinity or at least in the region. Even if the potential spatial and temporal coverage by any individual-based approach is uncertain telemetry data will be more representative than those collected by surveys for the behavioural responses during adverse weather conditions. The sample sizes which may be obtained from individual-based approaches for assessment of meso avoidance are obviously very uncertain, and the resolution of collected behavioural tagging data will largely depend on battery capacity and duty cycle settings[100]. As for surveys, the probability of detecting either a collision or, micro-avoidance behaviour in telemetry data is extremely low.

The spatial and temporal requirements of the data necessary for quantifying collision rates and avoidance behaviour mean that passive monitoring approaches from within the OWF are advantageous due to the continuous collection of behavioural data. Radar operated without combining with cameras will provide data on macro and meso avoidance, yet without any indication of the species of birds associated with the recorded tracks. Accordingly, an integrated design with a radar in digital communication with cameras is an advantage as it ensures species identification for selected radar tracks followed by the cameras, see section 4.4. However, when radar is operating without full digital integration with the cameras the coupling between collected video documentation of species and the radar tracks will have to be based on spatio-temporal matching of the two datasets with obvious uncertainties as a consequence.

With respect to macro avoidance, an integrated tracking by radar and cameras is likely to be biased in situations where a bird's macro response takes place at distances beyond the detection distance of the cameras. The detection range of medium-sized birds from long-range digital cameras varies from 1 to 3 km depending on the level of optical zoom. Thus, passive monitoring approaches are less likely to provide comprehensive data on the macro avoidance of birds. However, these approaches may provide very useful data on meso avoidance, especially if a high-performance radar is integrated with moving long-range PTZ cameras[30]. Specifically, large sample sizes (> 1000) of detailed reactive behaviours of individual species of birds may be collected in the meso zone and resolve how behaviours change with distance to the rotor-swept areas.

Due to static and dynamic clutter, the detection by radar of birds within the rotor-swept zones is inefficient. Accordingly, cameras provide the optimal means for collecting detailed flight data of the micro avoidance of birds. The video tracking in the rotor-swept zone by cameras can either be undertaken by standard cameras monitoring the rotor of the installation turbine or by cameras with strong optical zoom (100+ mm) monitoring the rotors of the turbines surrounding the installation turbine. Even if detection by the radar within the rotor is not possible, the integration of moving cameras with a radar may enable coverage of several rotor areas per camera[104].

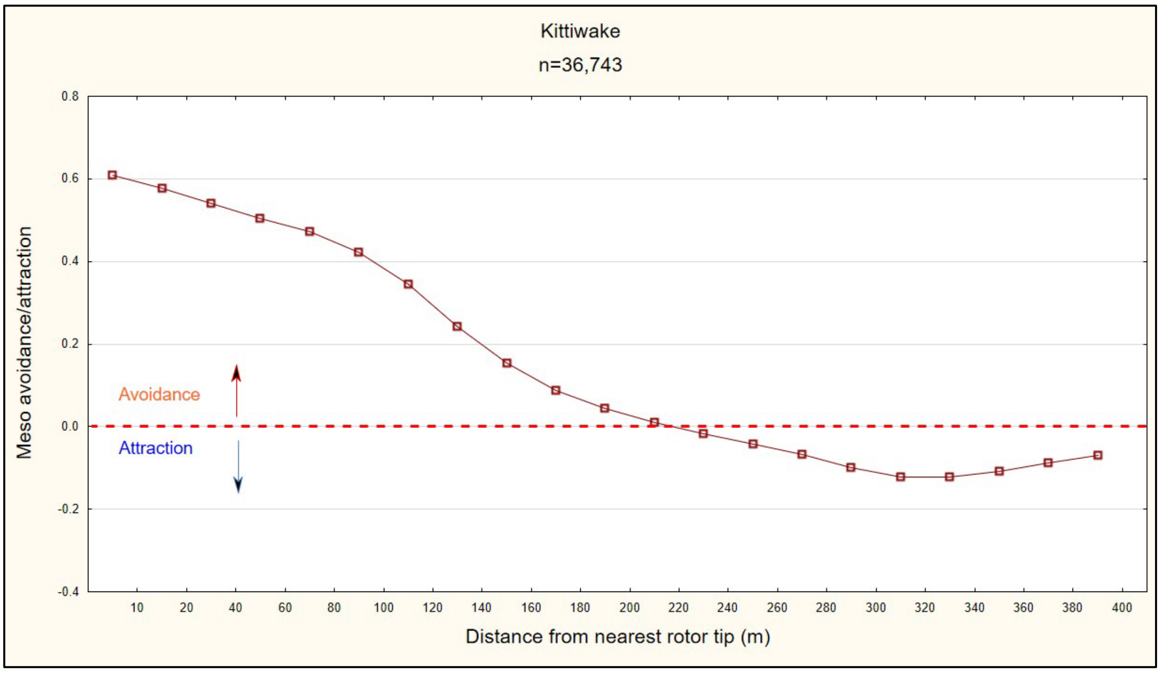

Figure 5-5. Example of meso avoidance/attraction rate of seabirds (Black-legged Kittiwake) estimated on the basis of integrated radar and PTZ camera at 10 m intervals in relation to distance from nearest rotor during daytime hours. The data are from Aberdeen Offshore Wind Farm (Tjørnløv et al. 2021).

[104] Armitage et al. 2021

5.6 Collision

5.6.1 Collision rate

For the same reasons as mentioned for micro avoidance, radar tracks are of very limited use for indicating when a collision takes place. Cameras constitute the optimal means for recording of collisions either by standard cameras monitoring the rotor of the installation turbine or by cameras with strong optical zoom monitoring the rotors of the turbines surrounding the installation turbine[28]. Due to the high level of OWF avoidance recorded for birds (0.996-0.998)[28], the sample size of recorded birds in the rotor-swept zone is likely to be very small. Examples from monitoring activities in OWFs in UK waters indicated less than 10 birds per turbine per year[28,30]. Accordingly, recorded collision rates should be expected to be associated with high levels of uncertainty, and should if possible be supplemented by estimates of collision rates obtained by using collision risk modelling based on detailed and large datasets on meso and micro avoidance.

Techniques for quantification of collisions from video tracks have so far not been developed. Innovation with respect to automated collision monitoring has been focused on development of systems based on accelerometers installed in the turbine blades (with/without coupled micro cameras), see section 4.7 and these systems are now at TRL 8.

5.6.2 Shutdown

Regulatory requirements for OWFs increasingly include solutions for interfacing between bird monitoring equipment and SCADA to enable controlled or automated shutdown through issuing shutdown-on-demand / higher cut-in speed of single or several turbines. Controlled shutdown provides the OWF with the opportunity to control the shutdown action depending on the actual bird species at risk. Two options for controlled shutdown depending on the species of bird exist. These options require the integration of radar and cameras and enable shutdown of single turbines during passage of species of birds of particular sensitivity and concern.

One option is a solution in which the OWF will be given the opportunity to control the shutdown action using an online interface to the digital cameras, requiring a human observer. Another option covers the identification of bird species based on AI-based algorithms. The benefit of the controlled solutions is that unnecessary shutdowns can be minimised, and hence more electricity can be generated. In order for the collision mitigation action to be both efficient and viable, the cameras are required to be able to identify the species of bird at a distance which offers sufficient response time by the turbine before the bird reaches the tip of the rotor. Given the flight speed of birds, this distance will typically be between 300 m and 600 m which entails that long-range cameras and AI-based species recognition software have to be applied.

Turbine shut-down is commonly promoted as THE solution to avoid bird collisions. However, evidence is lacking if this is true across the board of bird species and for offshore conditions. Among other developers, Ørsted is building an evidence database through systematic monitoring, to consolidate their knowledge about the interaction of birds with OWFs on a species level, which will enable tailoring the mitigation measures that are appropriate for the respective site and species of concern.

Ørsted

DHI

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