CARBON TRUST

OFFSHORE RENEWABLES JOINT INDUSTRY PROGRAMME (ORJIP) FOR OFFSHORE WIND

Best practice guidance for the collection, management and analysis of data to support post-construction seabird collision monitoring at offshore wind farms

Prevalence of Seabird Species and Collision Events in Offshore Wind (PrediCtOr) project

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orjip working to accelerate offshore consenting
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Project information

The PrediCtOr project was initiated and set up within the Offshore Renewables Joint Industry Programme (ORJIP) for Offshore Wind. The project is jointly delivered by the Carbon Trust, British Trust for Ornithology (BTO), and Waardenburg Ecology.

PrediCtOr project partners include: Equinor Energy AS; Ørsted Wind Power A/S; Rijkswaterstaat Water; Verkeer en Leefomgeving; RWE Offshore Wind GmbH; Shell Global Solutions International B.V.; The Scottish Ministers; TotalEnergies OneTech; and ScottishPower Renewables (UK) Limited.

The project forms part of the Offshore Wind Evidence and Change Programme (OWEC), led by The Crown Estate, in partnership with the Department for Energy Security and Net Zero and the Department for Environment, Food and Rural Affairs. The Offshore Wind Evidence and Change programme is an ambitious strategic research and data-led programme. Its aim is to facilitate the sustainable and coordinated expansion of offshore wind to help meet the UK’s commitments to low carbon energy transition whilst supporting clean, healthy, productive and biologically diverse seas.

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The document has been produced with input and review from DMP Stats, who have been subcontracted as a statistical expert for the PrediCtOr project.

We would also like to thank the bird monitoring equipment suppliers and consultants who shared their insights on data considerations for bird collision monitoring studies.

Who we are

Our mission is to accelerate the move to a decarbonised future. We are your expert guide to turn your climate ambition into impact.

We have been climate pioneers for more than 20 years, partnering with leading businesses, governments and financial institutions to drive positive climate action. To date, our 400 experts globally have helped set 200+ science-based targets and guided 3,000+ organisations and cities across five continents on their route to Net Zero.

Executive summary

Background

The ORJIP PrediCtOr project seeks to reduce uncertainty surrounding seabird collision risk in offshore wind farms. As offshore wind expands to meet Net Zero targets, robust data are needed from monitoring studies to help quantify this risk. This Data Best Practice Guidance sets out practical, consensus-driven recommendations for how data are collected, managed, processed, transmitted, stored, and responsibly disclosed, so that results are more robust on individual projects and more readily combined and compared across sites, years, and jurisdictions.

The recommendations are based on a review of existing and planned monitoring studies and structured engagement with SNCBs and regulators, developers, and monitoring equipment suppliers. The emphasis is on offshore feasibility, the monitoring parameters most important for collision risk analysis, and standardising practice where appropriate while recognising different project contexts.

What the guidance covers

Core monitoring parameters and definitions

This document focuses on the parameters most relevant to post-construction collision studies: collision events, micro and meso scale avoidance behaviours, flux through the rotor swept zone, flight height, flight speed, and species-specific information. Consistent definitions for these parameters, including avoidance scales, are essential to align instrument placement, analytical assumptions, and comparability across projects.

Data integrity from acquisition to delivery

High quality monitoring outcomes depend on planning that reflects offshore realities. Projects should define monitoring duration and coverage relative to the rotor swept zones, and confirm system capabilities against the required parameters. Practical constraints such as bandwidth, buffering, and power need to be addressed up front to avoid data gaps. Precise time synchronisation across sensors, complete metadata, and use of MEDIN aligned formats with recognised taxonomies support clarity and traceability. Performance should be validated offshore, equipment calibrated on installation, and routine QA implemented, with targeted checks to identify and manage false positives and false negatives.

Interoperable datasets and reproducible processing

To enable re-analysis and cumulative assessment, raw data should be retained alongside processed outputs. Version control and clear change logs for hardware, firmware, and analytical models are required. Spatial and temporal resolutions, frame rates, and processing steps should be chosen to reflect monitoring objectives and system limitations. Interoperable raw and processed data structures make it easier to combine results across sites and years and to revisit analyses as methods evolve.

Transmission, storage, and secure handling

Transmission and storage approaches should be selected to match available infrastructure and data governance constraints. Options include fibre optic links where capacity can be reserved, as well as 4G or 5G, Wi-Fi, or satellite connections routed through secure VPN. Sufficient on-site storage and local buffering reduce the risk of data loss during access interruptions offshore. Automated backups, redundancy, and clear retention practices help maintain continuity and support timely access for processing. Alignment with developer IT and OT policies, including network segregation and firewall rules, is a prerequisite for reliable data transmission.

Responsible management of sensitive information

Where information may be commercially sensitive or operationally confidential, proportionate anonymisation, aggregation, and access controls should be applied. Confidentiality conditions need to be documented clearly. Teams should test whether sensitive details could be reconstructed or inferred from summary outputs, particularly where turbine status, hub-height wind data, or collision-related counts are involved.

Supporting effective long term data sharing

Early, simple data sharing arrangements help create harmonised datasets for future analysis while safeguarding sensitivities. Agreements should identify data owners, define data categories and permitted uses, and set access conditions that accommodate new partners over time. Where public bodies are involved, Freedom of Information (FOI) and similar risks should be managed explicitly so that evidence can be used while protecting confidential material.

Applying best practice across varied project contexts

Implementation is context based. Recommendations are intended to be adopted where practicable, acknowledging jurisdictional, technical, and cost constraints. Across different project conditions, the priority remains data consistency, quality, and comparability so that results are robust within projects and can be synthesised across sites, years, and jurisdictions.

Expected outcomes

Applying the recommendations set out in this document is expected to improve data quality and reproducibility, reduce uncertainty in downstream analyses, and make it easier to move data through transmission, storage, and access steps. Using interoperable approaches also supports cumulative assessments and cross-project comparisons, while proportionate confidentiality measures protect commercially sensitive information without compromising scientific value.

Who should use this guidance

- Developers, project owners, and researchers planning or managing monitoring programmes
- Monitoring equipment suppliers who configure monitoring systems and data pipelines
- Regulators and environmental authorities reviewing methods, data submissions, and evidence standards

In summary, the PrediCtOr Data Best Practice Guidance offers practical recommendations to standardise data practice for offshore seabird collision monitoring. It links collection, processing, governance, and delivery of data so projects can produce reliable, comparable, and re-usable evidence as the sector grows. The key recommendations summary in Section 9 frames these principles as clear actions and considerations for future collision monitoring studies.

It is important to note that this guidance reflects the best available evidence and expert judgement at the time of writing. As technologies and industry standards continue to evolve, users should revisit assumptions and confirm applicability for their project context.

How to use this document

This document provides best practice for handling data in post-construction seabird collision monitoring. It is intended to sit alongside project-specific monitoring plans and system documentation, offering a common approach to data collection, processing, storage, and responsible disclosure.

The material is organised to support planning and delivery from offshore acquisition through to data sharing. Chapters set out practical data considerations; they are not step-by-step instructions but high-level recommendations that can be adapted to different project contexts, system types, and regulatory requirements.

The monitoring parameter ranking in Section 3 helps prioritise what to measure by identifying parameters that are essential, important, or lower priority, and by setting consistent definitions for key behavioural and contextual variables. Using this ranking at an early stage can help align study objectives with instrument placement and analytical assumptions, and ensure that the data collected are suitable for collision monitoring.

Subsequent sections outline expectations for data integrity and reproducibility (synchronised timestamps, complete metadata, interoperable raw and processed formats, calibration, validation, routine QA), as well as transmission, storage, and access within offshore and IT/OT constraints, and proportionate approaches to confidentiality.

The recommendations summary (Section 9) brings the key messages together as actionable points mapped to typical stages of a collision-monitoring study, from scoping and procurement through deployment, operation, processing, and reporting. It can be used to check that the main data-related elements have been addressed at each stage.

Abbreviations

3D	Three-dimensional
AIS	Automatic identification system
AOWFL	Aberdeen Offshore Wind Farm
BSH	Federal Maritime and Hydrographic Agency of Germany
BTO	British Trust for Ornithology
CRM	Collision risk modelling
Defra	Department for Environment, Food & Rural Affairs
ECMWF	European Centre for Medium-Range Weather Forecasts
EIA	Environmental Impact Assessment
EOWDC	European Offshore Wind Deployment Centre
FOI	Freedom of Information
IT	Information technology
MEDIN	Marine Environmental Data and Information Network
NAS	Network-attached storage
NRW	Natural Resources Wales
O&M	Operations and maintenance
OT	Operational technology
ORJIP	Offshore Renewables Joint Industry Programme for Offshore Wind
OSW	Offshore wind
OWF	Offshore wind farm
PAG	Project Advisory Group
PCM	Post-construction monitoring
PrediCtOr	Prevalence of Seabird Species and Collision Events in Offshore Wind
RPM	Revolutions per minute
RSPB	Royal Society for the Protection of Birds
RSZ	Rotor-swept zone

RWS	Rijkswaterstaat
SCADA	Supervisory Control and Data Acquisition
SFTP	Secure file transfer protocol
SNCB	Statutory Nature Conservation Body
WP	Work package
WTG	Wind turbine generator

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1. Introduction

As the offshore wind (OSW) sector continues to expand, a key environmental concern is the potential risk of bird collisions with wind turbine blades. This has led to the use of Collision Risk Modelling (CRM) during the consenting process; however, the reliability of CRM outputs is currently limited by a lack of validation against empirical data from post-construction monitoring (PCM).

To date, there has been limited experience with large scale post-construction bird collision monitoring in offshore environments. Where monitoring has occurred, the absence of strategic oversight and coordination has made it difficult to compare results across projects, hindering the development of a robust evidence base to inform future assessments and policy. However, early collision monitoring efforts have exhibited innovative solutions carried out on a smaller scale and have provided a number of valuable learnings that can inform future monitoring campaigns and evidence-based decision-making.

Work Package 4 (WP4) in the **Prevalence of Seabird Species and Collision Events in Offshore Wind (PrediCtOr)** project aims to address common monitoring challenges by developing best practice guidance for data collection, management, and use in the context of seabird collision monitoring offshore, drawing on a combination of stakeholder engagement and literature review and analysis to identify practical recommendations and promote alignment across the industry.

The guidance covers the definition and prioritisation of relevant monitoring parameters, requirements and specifications for offshore data acquisition, raw and processed data formats, resolutions, and processing methods. The document also covers existing concepts for data transmission and off-site storage, approaches to managing commercially sensitive data, and includes actionable recommendations for future bird collision monitoring studies at offshore wind farms (OWFs).

This guidance document has the following objectives:

- Identify the needs of environmental and regulatory authorities with respect to data from seabird collision monitoring studies at offshore wind farms.
- Review lessons learned from previous studies.
- Provide recommendations for a harmonised approach to data collection, relevant monitoring parameters, as well as data resolutions, formats, processing, and quality.
- Investigate issues regarding the confidentiality of commercially sensitive data.
- Define best practice for data collection, storage and transmission to provide clarity and guidance to the offshore wind industry.
- Provide recommendations for improvements in data transmission infrastructure.

In order to achieve these objectives, we:

- Examined 30 existing and planned post-construction monitoring studies and relevant research studies, across the UK, Germany, the Netherlands, Denmark, and the US, looking for information on which bird parameters and additional parameters were monitored and the reasons behind their selection.

- Obtained study parameter checklists from 11 studies across eight wind farms, asking to indicate which monitoring parameters are included in the studies. This was also cross-checked with reports from the same monitoring studies, where available.
- Reviewed available best practice guidance for bird collision monitoring, with a focus on data considerations.
- Engaged with statutory bodies in the UK (Natural England, Natural Resources Wales, NatureScot, the Scottish Government's Marine Directorate), Germany (Federal Maritime and Hydrographic Agency (BSH)) and the Netherlands (Rijkswaterstaat (RWS)) to gather input on relevant monitoring parameters and data considerations. This involved individual interviews with each statutory body, followed by a workshop to discuss the proposed monitoring parameter rankings.
- Conducted interviews and/or obtained written questionnaire responses from four offshore wind farm developers who have experience with bird collision monitoring studies.
- Conducted interviews and/or obtained questionnaire responses from seven monitoring equipment suppliers.

The expected outcomes of this guidance document are:

- A more co-ordinated approach for data collection, transmission and storage in connection with seabird collision monitoring in offshore wind farms.
- Increased understanding of existing data requirements, including the needs of consenting authorities.
- Data from collision monitoring studies can be more easily harmonised/combined, enabling more powerful conclusions to be drawn from the data, and, in turn, providing better evidence to support decision-making and reduce uncertainties around offshore wind impacts.

It is important to note that this data best practice guidance and the PrediCtOr project as a whole are primarily focused on seabirds and daytime monitoring. While it is acknowledged that migratory land birds can also be susceptible to collisions with offshore wind farms, migratory species can be difficult to monitor as migration occurs predominantly at night and broad front corridors are used in assessment (although it is known that birds will pass through footprints in discrete time windows, depending on the weather conditions). Although in some jurisdictions migratory birds are the primary focus of bird collision monitoring (e.g. Germany), conducting detailed research and developing best practice guidance that would also include migratory land birds is not feasible within the scope of the PrediCtOr project.

Considering that the project focus is on seabirds, daytime focus is more feasible. Due to factors such as limited use of camera equipment, lower visibility, less vessel activity, collecting night-time data would make any study considerably more complicated, requiring different monitoring specifications and equipment. However, some considerations for migratory birds and night-time monitoring have been included where available and relevant.[1]

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[1] In current practice, this is typically considered using nocturnal activity adjustments to collision risk estimates, as discussed in Cook *et al.* (2023) and Garthe and Hüppop (2004).

2. Overview of typical monitoring equipment

This section outlines the primary technologies currently used for seabird collision monitoring at OWFs, focusing on how different systems support the collection, management, and analysis of data relevant to post-construction collision monitoring. While multiple technologies can detect, record, or contextualise collision events, the choice and configuration of systems also strongly influence the type, quality, and volume of data produced. The overview below reflects typical approaches across the sector and highlights developments relevant to offshore PCM.

A range of collision monitoring systems have been deployed at OWFs to date. Many use integrated, multi-sensor configurations, combining cameras, radar, and visual observations to capture bird movements across spatial scales (e.g. meso- and micro-avoidance). Additional technologies such as acoustic sensors, LiDAR, and bird-borne telemetry have been used in supporting roles where relevant to study objectives. Experimental approaches, including blade-mounted acoustic or vibration sensors, have seen limited offshore application but are of growing interest as potential tools for detecting collision events.

Across all systems, the evolution of offshore collision monitoring has been driven by advances in both hardware (e.g. higher-resolution cameras, improved thermal imaging, small-target tracking radars) and data-processing capabilities, including rapid progress in machine-learning-based image and signal analysis. These developments influence not only detection performance but also data formats, bandwidth requirements, and data handling, all of which are key considerations in this guidance.

System development is largely driven by market demand, with some suppliers continuing to focus on onshore applications, while others are increasingly targeting development of equipment for use offshore. Additional drivers include involvement from research institutes and wind farm developers, for example through funded deployments or collaborative projects that encourage coordination across stakeholders. Increasing coordination and shared learning has been identified as important for system acceptance in the onshore sector (Gottlieb et al., 2025) and is likely to play a similar role offshore, alongside trials, independent validation, and transparent sharing of results.

A variety of automated monitoring systems are currently in operation onshore; however, these systems cannot be directly transferred offshore, where turbine specifications, target species, and environmental and regulatory conditions differ substantially. As a result, onshore performance metrics such as detection range or classification accuracy may not translate to offshore environments, due to factors including limited options for system placement, larger turbine dimensions that can constrain relative camera coverage, variation in camera types and detection capabilities, and the influence of environmental conditions on system operation. In addition, testing/demonstrating equipment in an offshore environment is more costly and logistically challenging than onshore.

Aside from performance and environmental constraints, application of monitoring systems offshore may also be limited by project-specific technical considerations, such as power availability and data access (including confidentiality requirements), implications of mounting systems on turbine structures, and developer-specific practices or ways of working. Many of these factors are inherently project specific and will therefore require tailored, site-specific solutions. However, despite these challenges, there are clear indications of continued technical progress, with increasing offshore-specific technology development, targeted trials, and growing experience informing more robust and practical monitoring solutions.

2.1. Cameras

Camera systems often involve multiple cameras, which can be of varying designs. These typically involve high resolution cameras used in daylight and low-light or thermal infra-red imagery for nocturnal detection and 24-hour monitoring (Tjørnløv *et al.*, 2023), with further use of cost-effective daylight CCTV systems also used (Equinor & Spoor, 2024). Camera systems also include capabilities for tracking targets using artificial intelligence, improving species detection and recognition. Stereo system camera set ups have also now been installed at some sites (such as in the ATOM system) providing more precise information on 3D activity of birds (Wilmott *et al.*, 2023), including flight height and speed, more so than mono camera setups but require more complex data processing (Boersch-Supan *et al.*, 2024, Brighton *et al.*, 2025).

Cameras may be mounted at different turbine locations depending on monitoring objectives and field-of-view requirements. While installation considerations vary by project, it is important that camera positioning and stability take into account influence on data quality and the consistency of outputs.

2.2. Radars

Radars can be deployed either as standalone units or in combination with cameras. While radar alone is not typically sufficient for collision monitoring (largely due to limited ability to achieve species-level identification), it provides valuable information on bird movement patterns, flight heights, and activity across wider spatial scales.

Common configurations include horizontal and vertical radars (e.g. S- and X-band), or 3D radars capable of integrated vertical and horizontal tracking. These systems can support the identification of meso- and macro-scale avoidance behaviour and guide camera tracking when integrated into multi-sensor systems.

Placement of radar systems varies (e.g. turbine platforms, transition pieces, stand-alone structures), and positioning affects the extent of clutter, shadowing, and blind-spots, all of which have implications for the completeness of data coverage. Radar data typically require substantial processing and filtering to remove noise from the environment. The quality of processed radar datasets depends on system sensitivity, filtering algorithms, and calibration procedures.

2.3. Acoustic sensors

Acoustic monitoring has played a more limited role offshore to date, but contributes useful supplementary data in certain contexts. Two broad applications exist:

- Nocturnal flight-call monitoring, where automated recording units capture species-specific calls from nocturnally migrating birds. These datasets support presence and species-occurrence information, though they generally lack precise spatial localisation. Evidence on reliable detection ranges is very limited; effective detection distances can be relatively short, with maximum ranges for some species of around 100 m (ORJIP Offshore Wind, 2022).
- Blade-mounted acoustic or vibration sensors, which have been trialled onshore as potential direct collision-detection tools (Clocker *et al.*, 2022). Offshore application remains limited due to practical issues related to turbine integrity, maintenance constraints, and ensuring data accuracy.

Nevertheless, such systems have potential to provide turbine-specific collision indications or screening data.

Overall, acoustic monitoring outputs are useful for supporting species-level information and contextualising collision risk assessments, particularly in jurisdictions where nocturnal migration is a significant consideration.

2.4. Bio-logging (animal tracking)

Among other methods, biologging has been used alongside the main methods outlined above in some studies, such as the MOTUS tracking system (Robinson Willmott, 2023) and at the Gemini wind farm off the coast of the Netherlands (Dutch Research Council, 2023). Often this is part of wider programme of research depending on study aims and is usually not sufficient on its own to provide the necessary wider PCM. The use of bird-borne telemetry can, however, give valuable perspectives on behaviour of individual animals in and around wind farms and footprints, providing information on spatial and temporal usage or areas, flight height, speed, avoidance, behaviours engaged in (e.g. foraging, commuting, resting), and contextual importance of areas used by specific populations through links back ('connectivity') to breeding colonies or wider biologically-defined geographic areas outside of breeding periods.

3. Ranking of monitoring parameters

3.1. Monitoring parameter background

There has been a great deal of variability in which parameters have been deemed relevant for bird collision monitoring at offshore wind farms. These parameter choices depend on the environmental and ecological properties of the wind farm site and the surrounding areas, relevant consent requirements, specific monitoring objectives and the intended use of monitoring outputs, and the type of monitoring system that may be used. This variability has led to inconsistencies in data collection across locations and regulatory contexts, resulting in difficult comparison and limited transferability of monitoring outputs.

A more strategic approach for bird collision monitoring across broader spatial scales could include the use of common metrics for data collection to enable standardised methods across countries and regions, and/or the aggregation of data (and/or metadata) for bird collision monitoring studies, to better communicate the ongoing work and draw robust conclusions. For this to be possible, it is necessary to identify what key parameters should be collected as part of bird collision monitoring studies for reliable and efficient monitoring, but also taking into account related costs and other practical difficulties (such as technological limitations or requiring to monitor an unfeasible number of parameters).

In addition to bird parameters, there is also a need to identify which additional parameters, such as metocean conditions and wind farm operational parameters, are important for understanding collision risk and should be collected as part of collision monitoring studies. From a practical perspective, sensor design, wind farm layout (e.g., increased distances between turbines), and weather conditions can influence the effectiveness of different monitoring technologies (e.g., for cameras, the sampled airspace depends on field of view parameters and quality of footage is typically limited during low visibility conditions; some radar may not be able to reliably operate above certain wind speeds, creating gaps in monitoring coverage). This is in addition to intrinsically variable detection probabilities of all methods, which are difficult to quantify (Feather *et al.*, 2025). Furthermore, weather conditions are clear drivers of bird behaviours relevant for PCM, and radar-based studies have long examined these factors in migration research, including the effects on timing, distribution, and track density around wind farms. Many of these studies summarise data collected locally around wind farms and observations of bird interactions with objects like vessels or other birds (Feather *et al.*, 2025; Krijgsveld *et al.*, 2011).

Thorne *et al.* (2023) discussed how bird behaviour and metocean parameters interact at different scales. At fine scales, wind speed and direction, together with bird morphology, influence flight speeds, behaviour, and the energetic cost of different flight modes. At meso-scales, wind can strongly affect when, where, and how seabirds fly during both central-place foraging and migration. In addition, a study by Davies *et al.* (2024) on black-legged kittiwakes breeding in Aberdeenshire found that increasing wind speed reduced the proportion of flight time spent at collision-risk height and overall collision risk, although uncertainty remains high and effects depend on wind direction. Among the more recent bird collision monitoring studies, locally collected weather patterns have been used to help explain avoidance and behaviour, as seen at Alpha Ventus; some of the other proposed studies also emphasise the importance of gathering local weather information, such as at Baltic Eagle and Kincardine.

Given the importance of both bird parameters and additional parameters for bird collision monitoring, this section has the following objectives:

- Identify and describe bird parameters relevant for bird collision monitoring, as well as additional monitoring parameters that can influence the presence, distribution, and risk of bird collisions in offshore wind farms, based on the findings of earlier work packages, literature review, and stakeholder engagement.
- Provide information on the relevance of these parameters and practical considerations for optimising their applicability for bird collision risk assessments.
- Develop a ranking of the parameters by relevance, to highlight which parameters should be considered priority to include in future bird collision risk assessments.

3.2. Defining avoidance scales

Understanding and defining the spatial scales at which seabirds respond to OSW turbines is essential for interpreting collision risk, designing monitoring programmes, and ensuring comparability across studies. Avoidance behaviour is typically described across three nested spatial scales (micro, meso, and macro), each reflecting different behavioural processes and implications for collision risk. Figure 1 provides a simple visual representation of the different avoidance scales around turbines.

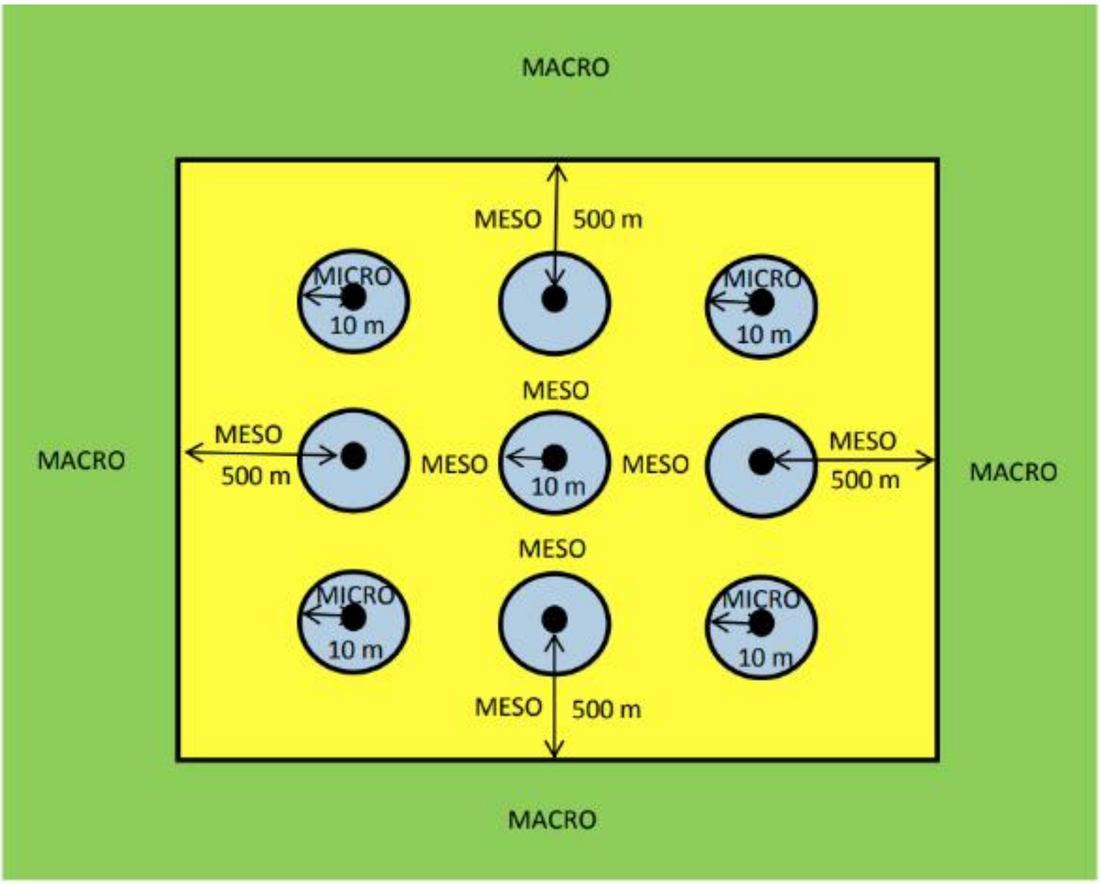


Figure 1. Schematic illustrating the horizontal spatial scales over which micro-avoidance, meso- and macro- responses operate. Dots refer to turbine tower locations (not to scale). Source: Cook *et al.*, 2014.

The different avoidance scales are commonly defined as follows (adapted from Cook *et al.*, 2014):

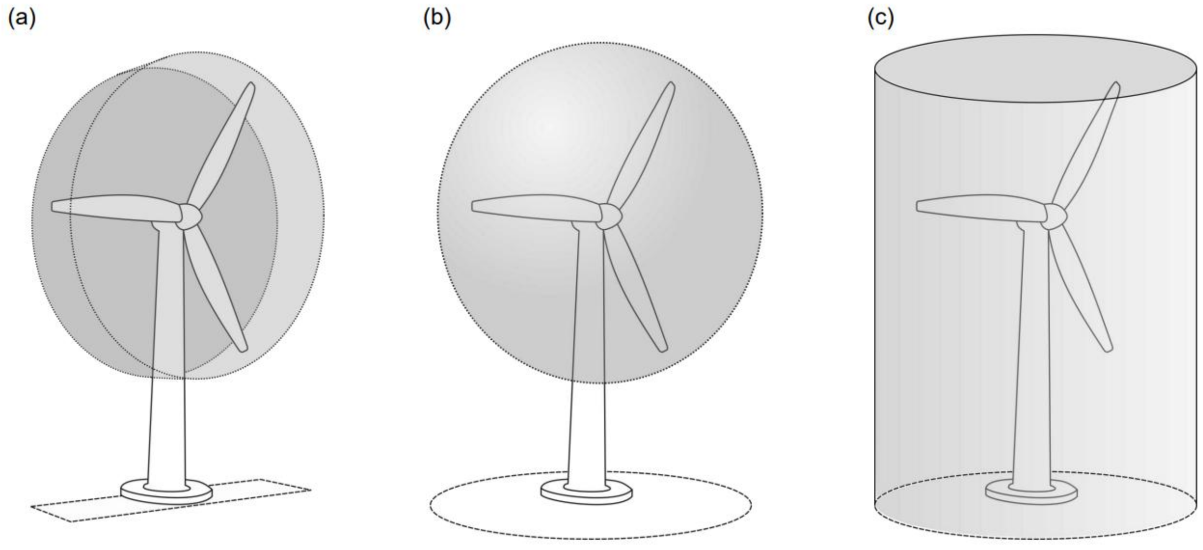
- **Macro** avoidance reflects all behavioural responses to the presence of the wind farm that occur at distances greater than 500 m from the base of the outermost turbines, representing functional habitat loss. These may include birds rerouting around the entire array, altering commuting routes, or reducing use of foraging areas in proximity to the development. Macro scales are relevant for collision risk modelling mainly prior to wind farm construction; for example, by affecting potential exposure via bird density or presence in the area, and, in turn, passage rate. Post-construction, any birds monitored inside the wind farm using PCM methodologies, have already made macro-scale decisions. Macro avoidance is thus contextual on pre- and post-construction, observation scale and how population density data are collected.

- **Meso** avoidance is defined as behavioural responses, including attraction, to the presence of turbines, occurring more than 10 m from the rotor blades and within the perimeter of the wind farm (500 m from the base of the outermost turbines).
- **Micro** avoidance refers to 'last-second' action taken to avoid collision. For the purposes of observational studies, such last-second avoidance would be expected to occur in a 3-dimensional (3D) space within 10 m of the turbine blades (i.e. at distances of 10 m horizontally or vertically from edges of the turbine blades). However, this distance (and consequently the appropriate definition of micro-avoidance) may be refined based on advances in monitoring techniques.

It is also important to differentiate between horizontal and vertical avoidance. Much of the research into the avoidance behaviour of seabirds in relation to offshore wind farms has focused on horizontal avoidance, whereby birds alter their flight paths to fly around turbines or to not enter the perimeter of the wind farm (i.e. Desholm & Kahlert, 2005, Masden *et al.*, 2009). These data have been collected using a variety of methodologies, notably visual observations (i.e. Krijgsveld *et al.*, 2011) and radar observations (i.e. Petersen *et al.*, 2006).

Vertical avoidance, on the other hand, refers to birds changing flight height to fly over or under turbines or their rotor swept zones (RSZ). These behaviours are critical at the micro-meso interface, as vertical position determines whether a bird enters collision height. Notably, vertical movements, and hence vertical avoidance is usually harder to measure accurately than horizontal movements. Key limitations are typically vertical coverage of sensors, which generally have a cone-shaped or disk-shaped field of view (i.e. a forward looking sensor will measure across an OWF up to its useful range, potentially covering several turbines, whereas an upward looking sensor will be limited to the airspace immediately above it, requiring a larger number of sensors to achieve comprehensive vertical coverage across an OWF, and/or potential systematic blind spots if upward-looking sensors cannot be deployed in the space between turbines). However, developments in technology, such as modern 3D radars with dome-shaped fields-of-view can make more comprehensive sampling in three dimensions and hence the simultaneous monitoring of both horizontal and vertical movements around turbines feasible. For seabirds, meso-avoidance/attraction over the vertical rotor sweep profile has been estimated for some species using GPS telemetry data, for example (see Johnston *et al.*, 2022, Pollock *et al.*, 2024), but telemetry-based estimates of vertical positions tend to be less accurate and precise than those of horizontal positions owing to fundamental geometric constraints of GPS positioning and other sources of measurement uncertainty (Feather et al., 2025).

The exact definitions of meso and micro scales are particularly relevant in the case of vertical avoidance, given that the definition of the micro scale depends on how the RSZ is defined. For short time scales and when the orientation of the rotor is known, the RSZ may be considered a disk, with the same diameter as the rotor, plus buffer (e.g. 10 m, as discussed above), and a thickness of roughly twice the buffer. For longer time scales, i.e. when the rotor orientation is variable, or where rotor orientation is not known, the RSZ becomes a sphere around the nacelle with the same diameter as the rotor, plus buffer, representing more precautionary collision risk estimation. Sometimes (e.g. when vertical data is lacking) even more approximate shapes need to be used, such as cylinders with a diameter of the rotor plus buffer, and a height either from the sea surface to the highest point of the rotor, or between the highest and lowest points of the rotor. The 3D scales of avoidance are illustrated in Figure 2.



Philipp Boersch-Supan/BTO

Disk-shaped RSZ
Rectangular footprint

Spherical RSZ
Circular footprint

Cylindrical RSZ
Circular footprint

Figure 2. 3D representations of RSZ at the micro avoidance scale around OSW turbines: a) disk-shaped RSZ with a rectangular footprint; b) spherical RSZ with a circular footprint; c) cylindrical RSZ with a circular footprint.

Understanding the spatial scales of avoidance has direct implications for the design and interpretation of collision monitoring studies. Clear definitions of micro- and meso-scales help ensure that monitoring systems are positioned to capture the most relevant behaviours, particularly fine-scale responses within or near the RSZ, where collision risk is highest. **We recommend that future studies clearly document the assumptions and/or methodology used to define the geometry of avoidance zones, and in particular the shape and orientation of the RSZ and the associated micro-avoidance zone.** This would support consistency in reporting across projects, enabling more robust comparison of results and improving the interpretability of avoidance estimates used in collision risk modelling.

At the same time, avoidance scale definitions remain an active area of research, with advances in monitoring technology continuing to refine understanding of seabird behaviour around turbines. As empirical evidence grows, it will be important to retain flexibility in how these scales are defined and applied, allowing definitions to evolve as analytical methods mature and as more detailed examples of bird-turbine interactions emerge from recent and ongoing studies.

3.3. Parameter definitions

In order to ensure consistency throughout the best practice guidance and develop a shared understanding of the monitoring parameters, this subsection provides definitions of key parameters identified as relevant for bird collision monitoring at offshore wind farms, alongside relevant metocean, wind farm, and ancillary parameters. These definitions emphasise their significance for monitoring, associated measurement methods, equipment used, and considerations for data ownership and confidentiality.

Table 1. Definitions of bird parameters assessed.

Parameter	Description/relevance	Measuring/monitoring method, equipment	Data ownership	Data confidentiality
Presence of birds at meso-scale (in wind farm area)	The presence of individual birds recorded at the meso-scale within a wind farm between turbine rows [both the number of total birds observed and the number of birds used for data modelling/further avoidance calculations need to be reflected in the data]. Here, presence refers to the number of individuals, rather than presence-absence data.	Ship-based or aerial transect surveys or HD camera/thermal imagery with radar also used alongside, for example some systems use camera video footage to identify targets some having been detected initially from radar.	Typically owned by the party funding the research – usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties. Government-owned data is usually public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential
Presence of birds at micro-scale (around turbine)	The presence of individual birds recorded at the micro-scale directly at a wind turbine [both the number of total birds observed and the number of birds used for data modelling/further avoidance calculations need to be reflected in the data]. Here, presence refers to the number of individuals, rather than presence-absence data.	Typically, camera HD or thermal imagery aided by developments in 3D tracking algorithms.	Typically owned by the party funding the research – usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties. Government-owned data is usually public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential
Number of flights through rotor zone	Number of transits recorded crossing the 3D airspace at a wind turbine between the lower blade tip height and the upper blade tip height.	Typically, camera and radar to obtain number of passes across a space, e.g. 3D volume airspace, in this case being the rotor zone; this is also related to the bird flux rate, which is the number of 'birds' crossing a zone rather than the overall flights or 'tracks'.	Typically owned by the party funding the research – usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties. Government-owned data is usually public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential

Tracks of birds passing the rotor zone	As above, tracks and flights are used interchangeably in some definitions, but this relates to birds rather than overall tracks.	As above, but relates to spatially explicit data on the 3D movements of individual birds rather than counts of birds passing through a predefined area overall.	Typically owned by the party funding the research – usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties. Government-owned data is usually public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential
Meso-avoidance behaviour (in wind farm area)	Anticipatory or impulsive avoidance of rows of turbines within a wind farm up to the rotor swept zone and a certain buffer around the turbine.	Ship-based or aerial transect surveys, or HD/thermal imagery and radar; typical method (e.g. Vattenfall, Aberdeen, Tjørnløv *et al.* 2023); track density within the rotor sweep zone of turbines (+ buffer) relative to the density over the full monitored area within the wind farm in absence of turbines.	Typically owned by the party funding the research – usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties. Government-owned data is usually public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential
Micro-avoidance behaviour (in the vicinity of wind turbine)	Last minute evasive action or change in flight behaviour directly at a wind turbine.	HD cameras and/or thermal imagery; adjustment of flight activity in the airspace of the rotors, or actual collision; rate estimates through proportion adjusting flight in relation to total (i.e. those not adjusting, adjusting or colliding, Tjørnløv *et al.* 2023).	Typically owned by the party funding the research – usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties. Government-owned data is usually public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential
Bird collision events	Recorded collisions having occurred at wind turbines.	Either through direct detection/observation or later discovery, for example through evidence of carcass discovery [latter not relevant for offshore wind turbines]; offshore, equipment may include HD and/or thermal cameras viewing the turbine sweep, aided by use of AI tracking algorithms, or other sensors within blades or on the turbine, such as vibration sensors.	Typically owned by the party funding the research – usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties. Government-owned data is usually public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential
Flight heights of individual birds	The altitude recorded at which birds are in flight, often then combined to form a full distribution for further use in collision risk modelling.	From a range of methods; e.g. rangefinders from observers on platforms to give proportion of birds at rotor height; video analysis of birds within wind farms; radar (not species-specific); airborne LiDAR;, animal-borne GPS or barometric telemetry.	Typically owned by the party funding the research - usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties; also statutory bodies, eNGOs, academic researchers.	Generally confidential

			Government-owned data is often public, while confidential data may become public after a set period or due to regulatory requirements.	
Flight speeds of individual birds	The speed that birds are travelling whilst in flight.	As above, a range of methods, but typically direct from camera video analysis based on frame rate movements, and radar classification of tracks of birds to gain perspective of wider scale speed movements; note can also be obtained from other methods that could be used concurrently, such as LiDAR or bird-borne telemetry; the same approaches can inform flux.	Typically owned by the party funding the research - usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties; also statutory bodies, eNGOs, academic researchers. Government-owned data is often public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential
Species-specific information	Information obtained on the identification of the animal observed to species-level taxonomy.	Camera methods. Radar does not provide fine-grained species-specific information. Acoustic registration may provide presence of specific species, although data often of limited use for seabirds specifically.	Typically owned by the party funding the research – usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties. Government-owned data is usually public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential
Presence of birds at macro-scale (within a defined buffer around the wind farm)	The presence of individual birds recorded at the wider macro-scale around a wind farm [both the number of total birds observed and the number of birds used for data modelling/further avoidance calculations need to be reflected in the data]. Here, presence refers to the number of individuals, rather than presence-absence data.	Ship-based or aerial transect surveys, or radar to record tracks of individual animals across a wider geographic area, e.g. the wind farm footprint and buffer, and also a reference area with no planned development activity for further comparison of movement activity.	Typically owned by the party funding the research – usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties. Government-owned data is usually public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential
Macro-avoidance behaviour (around the outside of the wind farm)	Change in flight patterns in relation to an offshore wind farm at wider scale.	As with meso, the relative density of tracks within the wind farm footprint+buffer relative to tracks over a wider area in absence of the wind farm; flux is proportional to density of birds.	Typically owned by the party funding the research – usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties. Government-owned data is usually public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential

Vertical flight activity (e.g. of bird migration)	Typically referring to the distribution of birds in the vertical air volume whilst in flight, but also a catch-all term for all activity in flight, e.g. finer-scale flight behaviour, soaring/flapping, and the speed of travel.	Camera (HD, thermal) or radar, but can also be obtained by other methods, such as LiDAR or bird-borne telemetry.	Typically owned by the party funding the research – usually developers, but sometimes governments (e.g. WOZEP in NL) or other funding parties. Government-owned data is usually public, while confidential data may become public after a set period or due to regulatory requirements.	Generally confidential

Table 2. Definitions of metocean parameters assessed.

Parameter	Description/relevance	Measuring/monitoring method, equipment	Data ownership	Data confidentiality
Wind speed	The rate at which air is moving horizontally past a specific point. Can influence flight speed, height, direction, behaviour; high wind speeds can affect seabird flight stability and increase wind turbine rotor speed.	Measured directly at wind farm site (Anemometers, LIDAR, SODAR) or using modelled data.	Normally wind farm developers, but depends on the source of data	Generally confidential
Wind direction	The compass direction from which the wind is blowing. Can influence flight speed, height, direction, behaviour of seabirds.	Measured directly at wind farm site (wind vanes, LIDAR, SODAR) or using modelled data.	Normally wind farm developers, but depends on the source of data	Generally confidential
Visibility at hub height	The distance one can clearly see at the height of the wind turbine hub. Reduced visibility can disrupt normal flight patterns and foraging behaviour, and impair ability to detect and avoid rotor blades and other infrastructure. Poor visibility can also negatively impact camera performance and detectability of birds.	Visibility sensor installed in the studied OWF, or a combination of some of the other metocean variables (precipitation, cloud cover).	Normally wind farm developers, but depends on the source of data	Generally not confidential
Precipitation	Any form of water, liquid or solid, falling from the atmosphere. Affects visibility at wind farm site, in turn affecting flight patterns. Can also directly affect flight behaviour. Presence/absence of precipitation and/or categorical rating are important for radar studies and especially for interpreting video imagery from cameras.	Various (rain gauges, disdrometers, weather radars). Indication of presence/absence and categorical rating (i.e. none, light, moderate, heavy) are useful.	Normally wind farm developers, but depends on the source of data	Generally not confidential

Visibility at transition piece height	The distance one can clearly see at the height of the transition piece of the wind turbine. Reduced visibility can disrupt normal flight patterns and foraging behaviour, and impair ability to detect and avoid rotor blades and other infrastructure.	Visibility sensor installed in the studied OWF, or a combination of some of the other metocean variables (precipitation, cloud cover).	Normally wind farm developers, but depends on the source of data	Generally not confidential
Sea state	The condition of the sea surface, including wave height and frequency. Can affect flight patterns and foraging behaviour; turbulent conditions may increase collision risk.	Usually observational measures of Beaufort scale; also wave buoys, radar altimeters, marine radars.	Normally wind farm developers, but depends on the source of data	Generally not confidential
Air pressure	The force exerted by the weight of air in the atmosphere. Changes in air pressure can influence seabird flight altitude and behaviour.	Barometers, weather stations.	Normally wind farm developers, but depends on the source of data	Generally not confidential
Temperature	The degree of hotness or coldness of the air. Can affect seabird behaviour.	Thermometers, weather stations.	Normally wind farm developers, but depends on the source of data	Generally not confidential
Cloud cover	The fraction of the sky covered by clouds. Can affect visibility at wind farm site, in turn affecting flight patterns.	Ceilometers, sky cameras.	Normally wind farm developers, but depends on the source of data	Generally not confidential
Ambient light levels	The amount of natural light present in the environment. Can affect visibility at wind farm site, in turn affecting flight patterns.	Photometers, sky cameras.	Normally wind farm developers, but depends on the source of data	Generally not confidential
Tidal state	The stage of the tidal cycle, including rising (flood), falling (ebb), or slack tide. Can influence seabird flight height, foraging behaviour, and presence near sea surface.	Usually obtained via tide gauges, satellite altimetry, or hydrodynamic models.	Normally wind farm developers, but depends on the source of data	Generally not confidential

Table 3. Definitions of wind farm parameters assessed.

Parameter	Description/relevance	Source of data/information	Data ownership	Data confidentiality
Turbine status (in operation / not in operation)	Indicates whether the turbine is in operation or not. Wind turbine operational status can influence bird collision risk.	SCADA systems, operational logs.	Wind farm developers	Can be confidential

Turbine orientation	The direction the turbine is facing.	SCADA systems, operational logs.	Wind farm developers	Can be confidential
Turbine model/specification	The make and model of the turbine, which determines its size, blade length, and other physical characteristics.	Manufacturer specifications.	Wind farm developers and/or WTG manufacturers	Generally not confidential
Turbine RPM	The rotational speed of the turbine blades. Higher RPM can increase the risk of collision for seabirds.	SCADA systems, operational logs.	Wind farm developers	Can be confidential
Turbine density and layout	The number and arrangement of turbines in the wind farm, influences the overall risk area for seabirds. Higher densities result is smaller safe passage areas for seabirds.	Wind farm design documents.	Wind farm developers	Generally not confidential
Turbine markings present	Visual markings on turbines, such as colour bands or lights, that can help seabirds detect and avoid them.	Visual inspection, design specifications.	Wind farm developers	Generally not confidential
Service vessel activity in wind farm area	The presence and movement of vessels within the wind farm area. Increased activity can disturb seabirds and alter their flight paths.	AIS data, vessel tracking systems.	Wind farm developers	Can be confidential
Turbine noise levels	The sound produced by the turbines. Noise can deter seabirds from approaching or interfere with their navigation.	Acoustic sensors, manufacturer specifications.	Wind farm developers	Generally not confidential
Locations of sub-stations and other infrastructure	The positions of additional structures within the wind farm. These can also affect seabird flight paths pose a collision risk.	Wind farm design documents.	Wind farm developers	Generally not confidential

Table 4. Definitions of other parameters.

Parameter	Description/relevance	Source of data/information	Data ownership	Data confidentiality
Fishing vessel or marine activity (AIS data) in and around wind farm area	The presence and movement of vessels in and around the wind farm area. Increased activity can disturb seabirds and alter their flight paths.	AIS data, vessel tracking systems.	Public	Generally not confidential
Human activity in or nearby the wind	Human presence and operations in or nearby the wind farm (e.g. maintenance	Observation, operational logs.		Generally not confidential

farm which might disturb, or especially attract, seabirds	activities, surveys, recreational boating, etc.) that might disturb or attract seabirds.			
Lighting specification	The type and intensity of lighting used on turbines and other structures. Lighting can attract or deter seabirds, affecting collision risk.	Design specifications, visual inspection.	Wind farm developers	Generally not confidential
Airborne traffic in wind farm area	The presence of aircraft in the wind farm area (e.g. helicopter flights, drone surveys, etc.). Airborne traffic can disturb seabirds and influence their flight behaviour.	Radar, flight tracking systems.		Generally not confidential

3.4. Overview of monitoring parameters assessed

3.4.1. Bird parameters

A study matrix reviewing existing and planned collision and avoidance monitoring studies was compiled to compare which parameters are most commonly collected (see Figure 3). While there are uncertainties in the data due to limited information on some of the studies, it is evident that a large number of studies focus on flight height and flight speed data, as well as general migration measures, collision data, micro avoidance, and 3D flight data. All of the indicated parameters were considered when ranking parameters by relevance, in addition to several others, which were included based on feedback from stakeholders and as indicated in the monitoring parameter checklists received from wind farm developers: Presence of birds at macro-, meso-, and micro-scale; Number of flights through rotor zone; Tracks of birds passing the rotor zone; Vertical flight activity (e.g. of bird migration); Species-specific information.

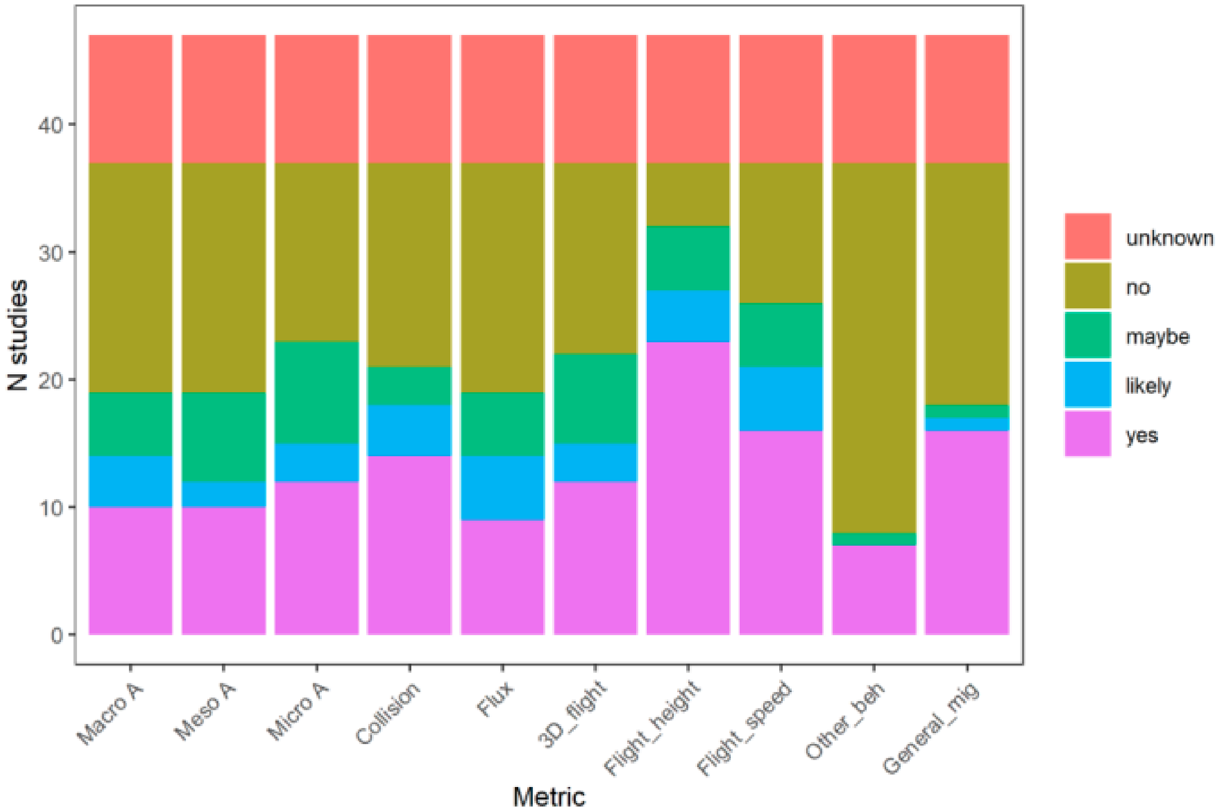


Figure 3. Simplified breakdown of the number of studies assessing different study metrics such as collision, avoidance, flux, and other activity such as flight height, 3D activity, other behaviours (e.g. commuting, foraging, resting) and general migration; maybe = uncertain, associated mainly with studies at planning stage with potential for systems that were mentioned to be deployed thus not guaranteed to collect data; likely = not specifically stated or presented but data deemed likely collected from a system, alongside other data specifically stated; unknown = no information obtained or known from a particular study.

3.4.2. Additional monitoring parameters

An overview of which additional monitoring parameters are deemed relevant in existing and planned bird collision and avoidance studies, as indicated in the reviewed reports and study parameter checklists (30 studies in total), is provided in Figure 4. It is important to note the numbers shown are indicative only and provide a high-level overview, as there were uncertainties in a lot of the reports on whether some of the additional parameters were measured, or the specific measurement details. For example, it was normally not indicated which specific variables were used to assess visibility, and at what height (transition piece or hub height). In addition, several studies only indicated “weather conditions”, without details of specific parameters, their relevance, or measurement methodology.

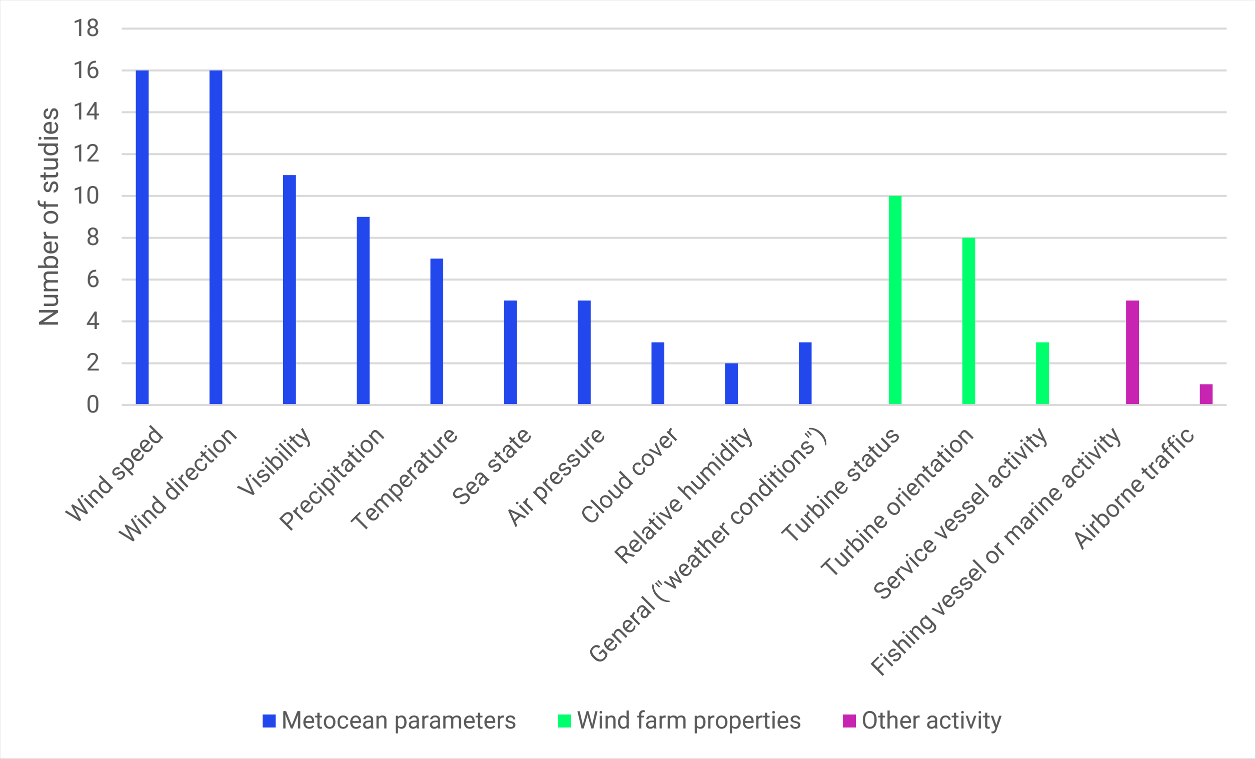


Figure 4. Additional monitoring parameters mentioned in existing and planned post construction monitoring studies and relevant research studies (30 in total).

The outcomes of the review indicated that wind speed and direction were the most frequently mentioned additional parameters, followed by other metocean parameters, such as visibility, precipitation, and temperature. Wind farm operational properties, such as turbine status and orientation, were mentioned as important in around a third of the reviewed studies. However, it is recognised that all wind farm operators will have access to information on the wind farm’s operational properties, and therefore it may be that they were not highlighted as parameters to be measured in the context of PCM studies specifically.

Some of the parameters were not explicitly measured but were still reflected in the data or flagged as important. For example, airborne traffic and service vessel activity were filtered out from the data in the Horns Rev II (2008) study. Vessel activity was also not measured but was identified as a potentially important factor in the Thanet ORJIP Bird Collision Avoidance (BCA) study.

In addition to wind speed and direction, a couple of studies also emphasised the importance of turbulence and wake effects. In the EOWDC Bird Collision Avoidance Study, conducted at Vattenfall’s Aberdeen Offshore Wind farm (AOWFL), turbulence was recognised as having a strong effect on the flight speed profile for all target species, as the tendency to reduce speed on approach to the rotor was most clear in situations with low levels of turbulence. Turbulence influenced the flight height of all target species more significantly than other weather parameters, with the tendency to increase in flight height near the rotor observed only during high turbulence levels. Wind speed affected the distance at which this increase in flight height occurred, with the response happening well beyond 100m at low wind speeds. There was also a predicted tendency for all target species to fly at higher altitudes during tail winds in situations with a combination of low turbulence and high wind speed. These patterns were evident regardless of whether the birds were feeding or commuting. In addition to the AOWFL study, the Alpha Ventus 2 StUKplus study recognised that air pressure differences and wake effects, even though not measured in the study, are potentially important for avoidance behaviour.

While wind turbulence intensity can be inferred from wind speed measurements, turbulence as it was defined in the Aberdeen Bay study relied on a combination of modelling approaches, also taking into account wake effects. Although the approach and the findings are interesting and informative, it does not give sufficient basis for including turbulence modelling, or recommending a specific approach for it, as part of recommendations for future bird collision monitoring in the PrediCtOr guidance. However, it should be considered as an important area for future research.

Only very limited information on additional monitoring parameters was found in existing best practice guidance. In the Ørsted & DHI bat and bird monitoring guidance (DHI & Ørsted, 2023), wind direction and service vessel activity are mentioned, but the impact of these parameters on bird collision is not explicitly discussed. In the Natural England & Defra Offshore Wind Marine Environmental Assessments: Best Practice Advice for Evidence and Data Standards (Parker *et al.*, 2022), weather conditions and other environmental covariates are mentioned as potentially important, but no additional or parameter-level information is provided.[2]

Insights from stakeholder engagement have also suggested that a lot of the identified additional parameters, in particular metocean parameters, are measured for other purposes at OWFs and these data are normally sufficient for bird monitoring studies. Data on other wind farm properties, such as turbine status and orientation, although rarely mentioned in the reviewed studies, are also likely to be available as part of general wind farm operations and monitoring.

3.5. Ranking of monitoring parameters by relevance

We reviewed existing and planned PCM studies and relevant research studies, supplemented with study parameter checklists across a range of wind farms, to identify parameters relevant for bird collision monitoring. The ranking of these parameters was primarily informed by stakeholder engagement: Monitoring parameter ranking tables were completed by relevant statutory bodies in the UK (Natural

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[2] Other guidance documents reviewed included:

- Ballester, C., Dupont, S.M., Corbeau, A., Chambert, T., Duriez, O. and Besnard, A., 2024. A standardized protocol for assessing the performance of automatic detection systems used in onshore wind power plants to reduce avian mortality. *Journal of Environmental Management*, *354*, p.120437. Accessed at link.
- JNCC, Natural England, Natural Resources Wales, NatureScot. 2024. Joint advice note from the Statutory Nature Conservation Bodies (SNCBs) regarding bird collision risk modelling for offshore wind developments. JNCC, Peterborough. Accessed at link.

England, Natural Resources Wales, NatureScot, Sottish Government's Marine Directorate), Germany (BSH), and the Netherlands (Rijkswaterstaat) to identify the most important parameters for bird collision monitoring studies across all relevant categories (bird, metocean, and wind farm parameters, as well as other relevant data). A workshop was held to further discuss and reach consensus on the importance of different monitoring parameters for bird collision monitoring studies, especially where initial individual rankings differed. A subsequent workshop was held with the PrediCtOr Partners and the Project Advisory Group to finalise the rankings.

Parameters across four categories (bird, metocean, wind farm, other) were ranked as:

- **Essential** – recommended for all collision risk monitoring studies (where the relevant data can be obtained); not including these parameters would significantly impact the reliability of the outputs.
- **Important** – would considerably improve the accuracy and relevance of monitoring outputs; data should be obtained if possible.
- **Fairly important** – 'good-to-have' parameters; would be helpful for more precise monitoring outputs and/or wider understanding of seabird behaviour and relevant environmental conditions, but are not central to bird collision monitoring.
- **Not included** (not used) – parameter either isn't considered to be relevant for bird collision monitoring studies or currently available information is not sufficient to assess its relevance.

The different rankings indicate the importance of a given parameter for understanding seabird behaviour in and around wind farms and undertaking bird collision monitoring. The rankings themselves do not necessarily indicate the ease of obtaining data, technological limitations in currently available equipment, or other practical considerations – these are noted in the comments, where relevant. For example, there is currently no known quantitative methodology to directly measure bird collision events; however, this parameter is labelled as essential since it would be very informative for understanding collisions, and the required methodology could be developed in the near future if prioritised as a focus area.

Engaging with statutory bodies in Germany, the Netherlands, and the UK has indicated that few parameters are strict consent requirements currently. The rotor area (micro avoidance, collisions) must be monitored in Germany and the Netherlands, as well as in parts of the UK (required in Wales and 'preferred' in England and Scotland, based on feasibility). Micro and meso avoidance also must be monitored in Germany and the Netherlands, as well as parts of the UK (in Wales; seen as preferred/useful in England and Scotland, for example in decomposing different scales of avoidance). Monitoring the wider wind farm area (meso and macro avoidance) is required in Germany and identified as relevant but difficult to achieve in Netherlands; it is seen as useful with the UK as well, but not prescriptive.

These countries vary in their approaches to PCM, and variation can arise in the prescriptive nature of certain monitoring techniques and/or the means in which data may be collected, leading to differences in bird collision monitoring information available for offshore wind farms across countries. For example, in Germany, PCM focuses on migration with some specific recommendations for camera technologies and monitoring periods, and emphasis on curtailment. The Netherlands prioritise curtailment and cumulative impacts for seabirds and migrants, noting expectations for horizontal and vertical spatial coverage, but without mandating specific technologies. In the UK, PCM is driven by assessment needs and potential impacts on species and protected sites, with fewer specific requirements; as a result, monitoring programmes in the UK are usually developed on a case-by-case basis through collaboration between developers, regulators, and consultants. Therefore, both the importance and the practicality of obtaining any given parameter can still be subject to variation based on factors such as the aims of the specific study, wind farm location, environmental factors, species of interest, and the regulatory context.

The following subsections list the monitoring parameters across four groups (bird, metocean, wind farm, other) according to their relevance/importance for bird collision monitoring, as indicated by the aggregated feedback from statutory bodies, PrediCtOr Partners, and the Project Advisory Group.

3.5.1. Bird parameters

Table 5. Ranking of bird parameters by relevance.

Parameter	Proposed ranking	Additional considerations
Bird collision events	**Essential**	Conditional on the availability of measurement methodology, as quantitative methodology such as vibration sensors and acoustic monitoring to reliably measure bird collision events is not yet fully developed within the offshore environment.
Presence of birds at micro-scale (around turbine)	**Essential**	Specific variables could be dictated by what monitoring approaches are used, i.e. there are multiple ways in which the parameter could be captured.
Presence of birds at meso-scale (in wind farm area)	**Essential**	Specific variables could be dictated by what monitoring approaches are used, i.e. there are multiple ways in which the parameter could be captured.
Number of flights through rotor zone	**Essential**	This needs to be understood in the context of other bird activity in the relevant area, e.g. as a percentage of total flights. In Dutch EIAs, collision models and rates are based on seabird density maps.
Micro-avoidance behaviour (in the vicinity of wind turbine)	**Essential**	N/A
Meso-avoidance behaviour (in wind farm area)	**Essential**	N/A
Flight heights of individual birds	**Essential**	N/A
Flight speeds of individual birds	**Essential**	N/A
Species-specific information	**Essential**	This could include species type, age data, but there are difficulties with obtaining any species-specific information. Some of the data could be obtained via cameras, potentially linked with radar and supplemented with DAS data. Particularly difficult to obtain any species-specific information at night. In Dutch EIAs, all modelling is done by species, thus, any species-specific information is implicit in the modelling.

Presence of birds at macro-scale (within a defined buffer around the wind farm)	**Important**	This could potentially be derived from other parameters. As with other 'presence' variables, there are multiple ways in which the parameter could be captured.
Macro-avoidance behaviour (around the outside of the wind farm)	**Important**	N/A
Tracks of birds passing the rotor zone	**Important**	'Tracks' relate to spatially explicit data on the 3D movements of individual birds rather than counts of birds passing through a predefined area overall. Number of flights is the more important variable for collisions; there are uncertainties in how the tracks data would be processed. However, this is still valuable information for understanding how birds behave close to wind farms.
Vertical flight activity (e.g. of bird migration)	**Important**	N/A

3.5.2. Metocean parameters

Table 6. Ranking of metocean parameters by relevance.

Parameter	Proposed ranking	Additional considerations
Wind speed	**Essential**	Wind speed measurements can also be used to derive wind turbulence intensity, which could also influence collision risk (see Section 3.4).
Wind direction	**Essential**	N/A
Visibility at hub height	**Essential**	Could be captured via a combination of some of the other metocean variables (precipitation, cloud cover), although preferably obtained via a visibility sensor installed in the studied OWF. Important to consider how seabirds perceive their environment and in turn which variables are most relevant.
Precipitation	**Important**	Could affect flight activity, but mostly relevant for visibility.
Visibility at transition piece height	**Important**	Same considerations as for visibility at hub height.
Sea state	**Fairly important**	N/A
Air pressure	**Fairly important**	N/A
Temperature	**Fairly important**	N/A
Cloud cover	**Fairly important**	Relevant for visibility.

Ambient light levels	**Fairly important**	Relevant for visibility.
Tidal state	**Fairly important**	Not directly relevant for collision monitoring, but of interest for effects on seabird behaviour, particularly in shallower areas. Generally easily obtainable via tidal models or tables.

3.5.3. Wind farm parameters

Table 7. Ranking of wind farm parameters by relevance.

Parameter	Proposed ranking	Additional considerations
Turbine status (in operation / not in operation)	**Essential**	Monitored by the wind farm operator outside of the bird collision monitoring study, but it is essential to have access to this information for bird collision monitoring.
Turbine orientation	**Essential**	Monitored by the wind farm operator outside of the bird collision monitoring study, but it is essential to have access to this information for bird collision monitoring.
Turbine model/specification	**Essential**	This information should be readily accessible.
Turbine RPM	**Essential**	Nominal RPMs should be readily available per turbine model. Time/location specific data during operational phase should be available from the wind farm operator but may be commercially sensitive.
Turbine density and layout	**Essential**	This information should be readily accessible.
Turbine markings present	**Essential**	Expected to be gathered as part of wider monitoring at wind farms.
Service vessel activity in wind farm area	**Important**	Monitored by the wind farm operator outside of the bird collision monitoring study, but it is essential to have access to this information for bird collision monitoring.
Turbine noise levels	**Fairly important**	N/A
Locations of sub-stations and other infrastructure	**Fairly important**	This information should be readily accessible.
Floating vs. fixed	**Not included**	Not including this as a parameter, but important to note likely differences between impacts of floating and fixed wind farms – partly because of different distance to shore. Currently not clear what the differences in impact will be.

3.5.4. Other data

Table 8. Ranking of other parameters by relevance.

Parameter	Proposed ranking	Additional considerations
Fishing vessel or marine activity (AIS data) in and around wind farm area	**Important**	N/A
Human activity in or nearby the wind farm which might disturb, or especially attract, seabirds	**Important**	N/A
Lighting specification	**Important**	This information should be readily accessible.
Airborne traffic in wind farm area	**Fairly important**	N/A

4. Requirements and specifications for offshore data acquisition

This section aims to collate and define requirements and specifications for collecting data for bird collision risk assessments at OWFs. The content in this section is informed by requirements specified by regulators and consenting bodies, existing best practice guidance, as well as engagement with offshore wind developers and bird monitoring equipment suppliers. The review is mostly focused on the UK, German[3] and Dutch waters and projects, due to the large number of projects (both operational and in development) concentrated in the North Sea; learnings from other geographies are included where available and relevant.

The developers' approach to bird collision monitoring is primarily dictated by the relevant regulatory requirements, which over the past decade have shifted from ad-hoc, model-based collision assessments towards more empirically based and coordinated post-construction monitoring, with more emphasis on uncertainty reduction, cumulative effects, and in some cases mitigation. Current requirements usually specify the required outputs from bird collision monitoring studies, with varying detail around exact specifications for monitoring (in terms of data, equipment, etc.). In the UK, for example, specific requirements for bird collision monitoring studies are limited, with most specifications agreed upon with developers on a case-by-case basis. In Germany and the Netherlands, more defined requirements exist, including the use of both radar and camera systems to track bird movements and collisions; specific requirements are discussed in this section, where relevant.

The specifications outlined in this section are broad guidelines and can vary on a case-by-case basis, with multiple approaches to bird collision monitoring potentially being suitable based on the specific context.

4.1. Duration of monitoring activities

The following requirements are specified by consenting bodies and regulators Germany, the Netherlands, and the UK:

- Germany: BSH requirements state that monitoring is required for 3-5 years (and up to 10 if a significant impact is determined/established) and for at least 6 migration phases (note that monitoring in Germany is primarily focused on migratory birds, rather than seabirds).
- Netherlands: RWS requirements state that monitoring must cover all seasons for at least two years; however, longer monitoring duration (3-4 years) is preferred. At least 4 turbines with equipment are required.
- UK: Generally, at least 2-3 years of monitoring are necessary to meet the desired statistical power (the number of monitoring 'units' deployed at a wind farm – or units such as track segments observed in the RSZ – are also important for statistical power, but are determined on a case-by-case basis) and to capture seasonal variation.

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[3] As mentioned previously, the primary focus of collision monitoring in Germany is on migratory birds and therefore some learnings from the German context are less relevant for monitoring seabird collisions.

Based on engagement with monitoring equipment suppliers, a minimum of 1 year of monitoring is required to capture the full annual life cycle of the target species and varying environmental conditions. 2-3 years of monitoring are recommended to capture interannual variation in bird activity and environmental conditions.

Recommendations:

- Aim to conduct monitoring for at least 2-3 years to capture interannual variations (longer monitoring durations preferable). Use at least one full annual cycle as a minimum where longer monitoring is not feasible.
- Align monitoring duration with focal species, behaviours of interest, and study objectives.
- Consider the sample size (e.g. monitored turbines, rotor-zone track segments) and statistical power requirements for the research questions in focus.

4.2. Use of specific monitoring systems and technologies

The choice of monitoring systems needs to balance regulatory expectations, technological feasibility, the behavioural parameters required for collision risk assessment, and system costs.

In the UK, equipment requirements are not prescriptive and are typically agreed on a case-by-case basis with regulators and SNCBs. Similarly, the Netherlands do not generally impose strict equipment specifications; however, means to reduce collision casualties may be mentioned under qualitative criteria within the Ministerial Order containing rules in the granting of permits, including some specification of how collision victims are monitored, i.e. the equipment used, location, number of turbines, validation and recognition at the species-level, and mention of shutdown of turbine operation based on flight altitude and flight speed of targets.

In Germany, BSH requirements state that for migratory bird collision monitoring, the wind farm developer must use bird radar systems and at least five cameras to carry out bird collision monitoring studies in and above the wind farm area up to an altitude of 1000 m. It is expected that wind farm operators will use high resolution cameras, ideally able to identify species groups up to the upper RSZ, able to handle precarious conditions, and cover the entire RSZ. For radar, vertical and horizontal observations of airspace are required, capable of recording small songbirds up to 1 km.

Radar data can be collected using simultaneous horizontal and vertical radar to provide information on flight patterns as well as flight heights. Alternatively, 3D radars use a single radar to collect both horizontal and vertical data simultaneously. Dedicated software for processing the signal to recognised and record the tracks of birds and filter out clutter is advisable. Furthermore, field observations to validate the radar, particularly for newer systems or novel environments, is essential for understanding the limits of the system. Field observations can also be used to validate and improve filtering and categorisation algorithms.

While cameras are essential for species identification, systems based on cameras alone are typically more limited in their ability to reconstruct exact flight trajectories, due to the difficulty of ranging free-flying birds using imagery alone (Brighton *et al.*, 2025; Boersch-Supan *et al.*, 2024). Maximum detection distances are dependent on the employed lenses and sensor resolution, as well as species body size and typically range from c. 100m to 1000m.

From the monitoring equipment suppliers' perspective, monitoring systems can generally be adapted for the purposes and requirements of a given study. Suppliers also indicated that monitoring specifications depend on the wind farm layout and the distances between the turbines (e.g. higher camera resolution is needed if looking at rotors from turbines that are further apart).

System choice and configuration should account for turbine spacing, mounting options, available platform space, and the required detection range. Overall, integrated multi-sensor systems, supported by AI-based tracking where feasible, represent current best practice for capturing relevant parameters for collision monitoring.

Where multi-sensor systems are used, it is important to recognise that different components typically operate over different spatial ranges (e.g., radar at longer distances, optical sensors over more limited ranges). In practice, the effective monitoring coverage is often constrained by the range at which reliable visual detection and identification can be achieved. Detection performance may vary with distance from the sensor and between species, and these limitations should be well understood prior to study design. A clear understanding of sensor performance beyond headline specifications is essential for informing equipment placement, configuring sensor arrays, interpreting false positive and false negative rates, and assessing the reliability and statistical power of downstream analyses. Equipment performance characterisation and validation is inherently difficult due to limited offshore deployments to date, challenges with testing equipment offshore, and the lack of accepted procedures for such assessments; these issues will be explored further in the roadmap for commercial acceptance of offshore seabird collision monitoring technology[4], currently being developed in the PrediCtOr project.

Recommendations:

- Use systems capable of capturing both movement patterns and species information (often this will be combined camera-radar systems).
- Ensure systems are validated on site, including validation of the geometry of the sampled volume, filtering performance and detection accuracy.
- Select equipment based on monitoring objectives, required detection ranges, and turbine layout constraints.
- Engage suppliers early to ensure configurations align with regulatory expectations and project specific conditions.

4.3. Placement of the monitoring equipment in offshore wind farms

The placement of the monitoring equipment will be heavily dependent on the specific aims of the study, the exact monitoring equipment employed, and wind farm parameters. Cameras are typically mounted on turbine platforms or nacelles to observe the rotor-swept zone or adjacent turbines, while radar systems should be positioned to minimise structural blind spots and ensure coverage across low-altitude and rotor-height airspace.

Equipment placement must also consider turbine spacing, available mounting locations, and any constraints imposed by turbine OEMs regarding the installation of additional hardware. Regardless of

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[4] Expected to be published later in 2026.

configuration, system coverage should be validated to ensure that key monitoring zones are adequately observed.

More detailed specifications for equipment placement, installation requirements, and engineering considerations are provided in the PrediCtOr WP5 Design Best Practice Guidance.

Recommendations:

- Align equipment placement with monitoring objectives, sensor capabilities, and wind farm layout.
- Position sensors to minimise blind spots and ensure effective coverage of rotor-height airspace.
- Consider structural and OEM constraints when selecting mounting locations.

4.4. Formats for data submission and reporting

Consistent and standardised data formats are essential to ensure comparability across wind farms, facilitate regulatory review, and support long-term data integration.

In the UK, the "Offshore Wind Marine Environmental Assessments: Best Practice Advice for Evidence and Data Standards. Phase IV: Expectations for monitoring and environmental requirements at the post-consent phase" is relevant in England[5] and emphasises that data should:

- be collected and presented in a consistent format which, where possible, enables effective comparisons with other datasets and other monitoring programmes. Consistent data standards may also allow for backwards/forwards compatibility of monitoring methods over time;
- follow the MEDIN data standards and guidelines as a matter of best practice;
- follow a consistent naming convention.

It is further noted in the guidance that species should be recorded using the World Register of Marine Species (WoRMS) list of accepted scientific names and biotopes should be recorded using the European University Information Systems (EUNIS) classification system (EEA, 2019), while a consistent and comparable approach also enables effective cumulative and in-combination assessments and improves the functionality of data repositories. Further guidance may become available in the Offshore Wind Environmental Improvement Package (OWEIP), currently being developed by Defra.

In Scotland, the FAIR Data principles and long-term archiving have been noted as important.[6,7] No such regulations and requirements of formats are in place for Wales – these are agreed upon on a case-by-case basis.

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[5] The document notes that this advice does not extend to the waters of Devolved Administrations where advice is provided by the relevant SNCBs, which should be consulted on matters falling outside of English waters.

[6] More information on the FAIR Data principles: FAIR Principles - GO FAIR. These are, in principle, a priority across various arms of the UK government as part of the National Data Strategy.

[7] Recent UK government ambitions have further extended the FAIR principles to include data quality – yielding a Q-FAIR framework. Here, data quality is a measure of the fitness for purpose for the end user; therefore, in addition to satisfying the FAIR principles, data need to be assessed in terms of accuracy, precision, resolution, and completeness with respect to the end users' needs. The Q-FAIR approach in the context of geospatial data is

Germany and the Netherlands do not prescribe specific reporting formats, and requirements are generally set through discussions with regulators.

Recommendations:

- Use MEDIN-aligned formats and consistent naming conventions as default best practice.
- Apply recognised scientific taxonomies (e.g. WoRMS, EUNIS) across all datasets.
- Ensure datasets comply with FAIR/Q-FAIR principles, including metadata completeness and versioning.
- Agree formats with regulators early where national standards are not prescribed.
- Structure data to allow future re-analysis, including clear documentation of processing steps.

4.5. Specifications for the collection and transmission of additional data

The collection and transmission of additional data (metocean, wind farm operational data, other) should leverage existing wind-farm monitoring systems wherever possible.

Collection of additional metocean data is typically not required specifically for bird monitoring, as the data collected for operational needs, such as service vessel and helicopter operations, are usually sufficient for other purposes as well, including bird monitoring. Multiple options exist for obtaining the necessary metocean data, including developers sharing backward looking metocean data which is then matched with the bird monitoring data with timestamps, obtaining data from local weather monitoring, or using modelled data (e.g. ERA5 atmospheric re-analysis dataset produced by the European Centre for Medium-Range Weather Forecasts (ECMWF)).

Although this not common, additional modular equipment can be installed to monitor wind speed and other metocean conditions; parameters such as visibility and sea-state may also be subjectively classified from the video recordings of bird flights collected by the cameras. Overall, through the stakeholder engagement conducted no strong preferences emerged for how metocean data are obtained and this generally does not cause issues for developers or monitoring equipment suppliers.

Wind farm operational data can be obtained from the turbine network/SCADA system, although this generally not an explicit requirement for collision monitoring studies and is only required for collision mitigation and wind turbine curtailment. However, there can be barriers to having direct access to these systems, mainly due to logistical considerations and security concerns from the wind farm operators' perspective; therefore, the most common approach is to provide backwards looking operational data for the purposes of bird monitoring data analysis. Additional data can be obtained as and when necessary, e.g. collecting signals from the WTGs where the collision systems are installed to filter out noise made by the turbine mechanical components.

In terms of data transmission, any additional data collected for bird monitoring will generally be transmitted using similar specifications as for the bird data – this will be covered in Section 6.

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discussed here: https://www.gov.uk/government/publications/how-fair-are-the-uks-geospatial-assets/how-fair-are-our-national-geospatial-data-assets-assessment-of-the-uks-national-geospatial-data-html

Recommendations:

- Use existing metocean data (and/or existing data collection infrastructure) and wind farm operational data as the primary source for additional parameters whenever possible. Use modelled or supplementary datasets where gaps exist in baseline monitoring.
- Obtain required operational data retrospectively from SCADA, unless real time access is needed for curtailment. Note that some data, particularly detailed wind data at hub height (wind speed and direction) and turbine operational status, can be considered sensitive.
- Ensure all additional data are timestamped and synchronised with bird monitoring outputs.
- Agree data access and sharing arrangements early to avoid IT/OT constraints delaying analysis.

4.6. Data volumes and required transmission capacities

Data volumes can vary significantly depending on the system setup, recording strategy, and bird activity levels. For example, an 8-camera system may generate around 30 GB of data per month when using event-triggered recording, whereas systems recording continuously at high resolution can produce up to 25 TB every 4-8 weeks. Radar systems typically generate between 1 and 2 TB of data per year, depending on whether 2D or 3D radar is used. AI-triggered systems can help reduce storage needs, although peak data rates may still reach up to 60 MB per second per camera. Audio systems may generate up to 5 MB per second, but event-based recording generally keeps volumes manageable.

Although not always feasible, in-situ processing can reduce the amount of data requiring transmission by sending only track reconstructions or other summaries, with full video retrieved on request. Across systems, the data volumes generated are substantial, and sufficient bandwidth is needed to support reliable transmission. If bandwidth is shared with other operational systems, limited capacity may lead to disruptions. Early information from monitoring equipment suppliers on bandwidth requirements is important for facilitating discussions around access to the wind farm network.

Bandwidth requirements reported by suppliers ranged from approximately 5-25 Mbps per equipment unit for standard uploading or downloading, up to 100-150 Mbps for some systems, and around 200 Mbps where data are fully processed onshore. Where data are pre-processed offshore, requirements of around 75-100 Mbps may be sufficient.

Recommendations:

- Assess expected data volumes early, as these vary across systems.
- Ensure sufficient bandwidth is available, especially where multiple systems share network capacity.
- Request clear bandwidth specifications from suppliers during project planning.
- Use AI-triggered or event-based recording where feasible to reduce data loads.
- Consider in-situ processing to minimise transmission requirements when suitable.

4.7. Requirements for on-site data storage and backup

Requirements for on-site data storage and backup vary depending on the system configuration, but reliable storage and retrieval processes are essential to minimise the risk of data loss. Developers often prefer real-time or near real-time transmission of monitoring data to secure onshore servers (e.g. network-attached storage (NAS) systems). Data transfer may occur via fibre-optic cables, the wind farm's internal network, or using satellite internet. However, concerns about IT/OT security may limit direct access to the wind farm network for third-party monitoring systems.

Most systems include onboard storage as a backup in case transmission is interrupted. Where necessary, data can be retrieved manually using local hard drives and uploaded onshore via a Secure File Transfer Protocol (SFTP), although this is resource-intensive and can be constrained by weather or availability of technicians. Offshore storage solutions should include adequate buffer capacity to accommodate periods when transmission is not possible.

Monitoring equipment suppliers typically define the storage and backup protocols, including drive redundancy, local and off-site backup processes, and safeguards against data loss. Developers should ensure that these protocols align with internal data management and cyber-security policies. Reliable backup procedures are particularly important in offshore environments, where physical access for maintenance or data retrieval may be limited.

Recommendations:

- Ensure systems include sufficient onboard buffer storage for periods without transmission.
- Where feasible, use real-time or near real-time transfer to secure onshore storage.
- Align storage and backup procedures with developer IT/OT security requirements.
- Use manual retrieval (e.g., hard drives offshore) as a contingency measure.
- Ensure that monitoring systems have clear data redundancy and backup protocols, provided by system suppliers.

4.8. Maintenance and data collection intervals to minimise data losses

With adequate infrastructure (such as a connection to the wind farm network or a fibre-optic link to an onshore server), data transmission and storage can be close to instantaneous. Where real-time access is not possible, regular scheduled downloads (for example, overnight or during periods of available bandwidth) provide an opportunity to verify that the system is functioning correctly and to reduce the risk of data loss.

When there is no network connection and data are stored on physical hard drives offshore, data collection is less frequent. Collection intervals must be planned in advance, based on expected data volumes, the number and capacity of hard drives, and other practical considerations. Options to extend intervals include using additional or higher-capacity storage. If storage approaches full capacity, monitoring may need to be temporarily adjusted to collect less data and avoid data loss.

Recommendations:

- Schedule regular downloads where real time data transfer is not available.
- Plan offshore data collection intervals based on storage capacity and expected data volumes.
- Adjust recording settings if local storage approaches capacity to prevent data loss. This should only be a temporary measure, due to loss of data quality and/or quantity.

4.9. Data checks to avoid poor data quality

Data quality checks depend on the specific monitoring system and the purpose of the data, but routine verification is essential to minimise data loss and maintain reliability. Curtailment systems typically require high data availability, while monitoring-only systems may tolerate occasional gaps; however, quality checks remain important in all cases.

Extensive calibration and fine-tuning protocols are required, particularly when initially setting up the equipment and beginning monitoring. It is necessary to calibrate and check the data from the separate monitoring equipment units as well as their integration, especially in systems including radars and radar-controlled cameras. Initial calibration of bird monitoring equipment is typically carried out onshore to verify sensor functionality and system performance before deployment; final calibration and integration are usually completed offshore post-installation. Calibration should cover the entire process from raw data capture through to processed outputs.

For AI systems performing data analysis, data is initially gathered and manually checked and processed to train the AI model. Once the model is tested and validated, efficacy checks are required to ensure accuracy. According to one monitoring equipment supplier, developing an initial AI model for a common bird species can require 4-8 weeks of data, with a full year recommended to ensure robustness across varying conditions; the AI models are species-specific, and once trained, can be adapted to new locations with as little as one week of data. Manual validation continues after deployment but decreases as the model matures.

In the AOWFL study, for example, because of the large sample sizes of analysed videos, it was not feasible to conduct a complete manual QA of all analysed videos, but QA was performed partially by systematically reviewing every 10th video analysis, and in addition focusing on specific parts of the video analysis that was considered particularly important (recordings of micro-avoidance and collisions, including potential collisions; recordings of vertical meso-avoidance; recordings of specific species).

In terms of routine data checks, approaches can vary considerably; key considerations include:

- Manual checks of camera footage (zoom functions, image quality, etc.), ideally via remote access to the cameras.
- Routine (e.g. weekly) data checks, either inspecting transferred data or accessing data remotely, to assess quality, missing data points, spot errors, including checking log details for captured metadata.
- Some systems employ monitoring tools where an alert is triggered in the system dashboard if the data collected is excessive or insufficient (or to flag other specific errors).
- Extensive monitoring and logging of all system components (network devices, ports, services, disk space, network traffic, etc.) can help to diagnose and correct faults more efficiently.

In addition, common challenges in bird collision monitoring are false positives and false negatives. False positives can occur when environmental noise or turbine interference is misidentified as bird activity, while false negatives may result from birds not being detected (e.g. in blind spots behind turbines). Importantly, data checks should be grounded in an established understanding of expected sensor performance, with false positive and false negative rates interpreted primarily as deviations from that baseline, rather than as indicators of inherent system limitations. System validation will be explored further in the roadmap for commercial acceptance of offshore seabird collision monitoring technology[8], currently being developed in the PrediCtOr project.

False positives can lead to inflated estimates of bird presence or collision risk, which may skew the results from monitoring studies, cause overestimates in collision risk models and have implications for consenting. In systems that employ curtailment protocols, false positives could trigger unnecessary turbine shutdowns, resulting in avoidable energy production losses and operational inefficiencies. False negatives can lead to underestimation of collision risk, which could compromise the effectiveness of monitoring and reducing confidence in the data used to inform future consenting decisions, as well as potentially resulting in inadequate mitigation measures.

Recommendations:

- Conduct system calibration at installation, including integrated sensor checks.
- Implement routine data quality checks, including footage review, log inspection, and missing-data checks.
- Use targeted QA sampling where full manual review is not feasible.
- Mitigate false positives/negatives through appropriate filtering, placement, and validation.

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[8] Expected to be published later in 2026.

5. Recommendations for raw and processed data formats & resolutions and data processing

Standardised data formats, resolutions, and processing approaches are essential to ensure comparability across studies, support data sharing, and enable reliable downstream analysis. The following subsections provide recommended practices for raw and processed data, data resolutions, and data processing workflows.

5.1. Data formats and metadata

Bird collision monitoring systems typically produce a combination of raw and processed data across various sensor types. Raw data formats commonly include video files (such as .mp4 or .avi) from optical and infrared cameras, image files (e.g. .jpg or .png) from camera snapshots or radar outputs, and audio files (e.g. .wav or .flac) from microphones. In addition, structured sensor outputs may be recorded in .csv format for event logs or metadata.

Processed data should be delivered in formats that support reproducibility, traceability, and potential re-use (e.g., open, platform-independent tabular formats such as CSV, SQL databases for storing and querying integrated datasets, PDF documents for reporting). Using platform-independent formats and avoiding software-specific features is encouraged, as it helps ensure that data remain transparent, auditable, and interoperable across tools and users, supporting good practice in data sharing.

It is not possible to be very prescriptive for metadata in the context of this guidance document, as the exact details of all devices, designs, implementations, etc. that might provide the parameters would need to be known. However, more generally, metadata must give context to the immediate use of these data, and this is expected to include:

- Time, location (where not already integral, and unambiguous in representation) and descriptors of all fields, including units.
- Details about devices, data collection platforms, protocols, with settings of immediate relevance, e.g. aspects that inform detection ranges, effort, precision, and accuracy.
- Additional/sufficient metadata to future-proof the data for ongoing use, even if not immediately relevant for analysis, e.g. device or software models/versions/settings that would allow retrospective querying of system capabilities. This would enable adjustments and comparisons of data over technological progression.

5.2. Sensor coverage and data resolutions

A clear understanding of sensor characteristics is essential for understanding the sampling and detection properties of collision monitoring systems, and ultimately interpreting the data collected by them. A key property of any sensor or system is its sampling volume, i.e. the volume of airspace in which bird movements and/or collision events can be detected and observed. The shape or geometry of this volume may be complex, and may vary with target species and/or environmental conditions (see Section 4.2). Sampling geometry parameters, e.g. sensor field of view and effective range are essential metadata to be provided for any particular monitoring system.

The sampling volume dictates which targets can be observed under optimal conditions, but detection performance within is determined by additional parameters, such as the resolution of recorded data. This varies depending on the monitoring objectives and the type of equipment used. Video footage is typically captured in Full HD (1920×1080) or at higher resolutions, such as 2560×1920, depending on the distance from the camera to the monitored area and the level of detail required. Image data from radar or camera systems is often stored in 24-bit colour or grayscale, depending on the sensor configuration.

What ultimately matters for monitoring is the relevant resolution on the imaged target, i.e. how many centimetres a pixel covers on a bird. Although quantitative studies on this are rare, the minimum requirement for most species groups seems to be around 2 cm/px (Weiß *et al.*, 2016). Whether or not this is achieved with a given sensor resolution depends on the lens choice and the range to target (body size plays a role as well). Based on the results from the EOWDC trials, species identification is typically more limiting in terms of range rather than object detection, i.e. birds are detected at far greater ranges than they can be identified (Brighton *et al.*, 2025).

Temporal sampling rate is also important for video systems. Higher frame rates tend to improve species identification and movement trajectory reconstruction, but there is a trade-off between framerates and image resolution in terms of capture, processing and data storage/transmission requirements, potentially at multiple stages. For acoustic monitoring, audio is generally recorded at sampling rates of 48 to 96 kHz, with 16- or 24-bit depth. These settings can provide sufficient detail for detecting and analysing bird calls or flight-related sounds, while maintaining manageable data sizes.

It is important to note, however, that besides resolution, factors such as the number of cameras, field of view, as well as the quality of the camera, sensor, and lens also play a role in the ability to identify individual birds and species-specific data. In addition, depending on the image recognition (and AI) models used, high resolution might not necessarily be a key prerequisite for an effective model; some models even reduce the number of pixels as part of the identification stage.

5.3. Data processing

Data processing can broadly follow two approaches: offshore-based and onshore-based. These differ in infrastructure, bandwidth needs, and other aspects, as outlined below. Note, however, that these characterisations are only indicative and not all monitoring equipment suppliers may offer solutions that support both models or align fully with the distinctions outlined below.

Offshore-based processing:

- **Lower bandwidth needs**: Only processed data is sent onshore.
- **Local compute power**: Offshore systems include CPU/GPU capabilities.
- **Specialised hardware**: Requires robust, high-performance offshore equipment.
- **Storage buffer offshore**: Can temporarily store data locally.
- **Network resilience**: Operates independently if there are connectivity issues.

Onshore-based processing:

- **High bandwidth demand**: Up to 200 Mbit/s for camera systems.
- **Network dependent**: Requires stable offshore-onshore connection.

- **No (or limited) offshore storage**: Data is streamed in real time or only temporary stored/buffered (but not processed) offshore.
- **Standard infrastructure**: Uses rackmount servers in onshore data centres.
- **Lower offshore power use**: Minimal offshore computing requirements.
- **Greater redundancy**: Easier to implement failover systems onshore.

5.4. Data synchronisation

The following outlines key considerations for achieving consistent timestamping and data integration across devices and sources, to help with synchronisation and alignment of data.

Centralised time synchronisation

Using an onshore Network Time Protocol (NTP; offering millisecond accuracy) or even a Precision Time Protocol (PTP; offering sub-microsecond to nanosecond accuracy) server as a central time source can help ensure consistent timekeeping across all offshore and onshore monitoring devices, such as cameras, radars, and acoustic sensors. Synchronising device clocks to a common reference supports accurate event correlation. To maintain time accuracy during network interruptions, fallback options like GPS-based time sources or low-drift internal clocks may also be considered. Centralised time synchronisation is particularly critical for multi-sensor systems, especially in the technology validation phase.

Timestamping and metadata standards

Including precise timestamps based on synchronised clocks (ideally at the millisecond level) in all recorded data, logs, and metadata is a key enabler for aligning data across systems. Synchronised timestamps enable the alignment of data from different sensors, such as matching radar detections with camera imagery. Accounting for latency in data transmission or buffering can further improve the accuracy of multi-sensor data fusion. In addition, including detailed metadata can support traceability, data integrity, and efficient downstream processing.

Using a relational database management (RDBM) system

A relational database management system can provide a structured and scalable way to store synchronised data from multiple sources. It allows for efficient querying, filtering, and linking of data by project, device, and timestamp. RDBM platforms can also integrate with dashboards and analytics tools, supporting both real-time monitoring and historical analysis.

Recommendations:

- Use consistent, interoperable, platform-independent formats for raw and processed data to support comparability, transparency, and re-use of data.
- Capture data at a resolution and frame rate appropriate for the monitoring objective, balancing detail with storage and bandwidth constraints, and document data resolution accordingly in metadata.
- Ensure processing workflows are documented and reproducible, including clear version control.

- Maintain synchronised timestamps across all sensors using a central time reference (e.g. NTP or PTP).
- Provide sufficient metadata to give context for interpretation and re-use of data, including time and location, sensor and platform characteristics, key settings affecting detection and sampling, and software or processing versions.
- Include detailed descriptions of sensor sampling geometry and effective detection volume, such as field of view and range, to support interpretation of detection performance.
- Store and transmit data in a way that preserves raw information where feasible, enabling re-analysis and future methodological improvements.

6. Existing concepts for data transmission and off-site storage

6.1. Data transmission

A range of data transmission strategies are currently in use or under development for bird collision monitoring systems at offshore wind farms. These approaches are shaped by the availability of infrastructure, cybersecurity protocols, and the technical compatibility of monitoring systems with existing wind farm networks.

Fibre optic transmission is generally considered the preferred method due to its high bandwidth, reliability, and security. It typically enables faster, safer, and more cost-effective data transfer to shore. Fibre optic transmission of data is also generally preferred to connecting to the wind turbines' SCADA systems, mainly due to the security concerns of third parties (i.e. monitoring contractors) being given access to the SCADA networks.

However, feedback from both suppliers and OSW developers indicates that unallocated fibre capacity is frequently either unavailable or not used for transmitting bird monitoring data. This underutilisation is often due to limited bandwidth availability or the absence of dedicated fibre lines for environmental monitoring purposes. Even when fibre infrastructure is present, integrating bird monitoring systems can be challenging. For example, in one project, significant internal IT support was required to resolve IP configuration and compatibility issues, delaying integration by over two months.

In the absence of fibre, internet-based transmission is commonly adopted. This includes the use of existing wind farm networks such as 4G, 5G, or Wi-Fi, as well as satellite-based solutions like Starlink. One supplier reported using a secure VPN with strong authentication protocols to enable remote access to monitoring data and system dashboards. Another supplier noted that their systems can be configured for either real-time data streaming or scheduled batch uploads, depending on the available bandwidth and project requirements.

From the developer perspective, one stakeholder highlighted that bird monitoring systems must be physically connected to the wind farm network via LAN cables and configured with compatible IP addresses. Both IT and wind farm firewalls must be adjusted to permit communication between offshore equipment and onshore control units. Compatibility issues – such as pre-configured IP settings or software mismatches – require early engagement with suppliers to ensure integration. Another developer emphasised the importance of isolating the bird monitoring system's network traffic from the wind farm's production network to reduce restrictions and improve data transfer reliability.

The following examples illustrate how different projects have implemented data transmission strategies tailored to their infrastructure and monitoring objectives:

- The AOWFL Aberdeen Seabird Study deployed a combination of radar and camera systems integrated via a central software platform (DHI MUSE). The system's architecture enabled real-time detection and tracking of birds through radar-triggered camera recordings, with data transmitted offshore-to-onshore via the wind farm's internal network. The MUSE Application Service facilitated communication between the core detection system, a centralised data repository, and external interfaces, while the MUSE WebAPI allowed secure remote access to live and historical data. According to MUSE system documentation (DHI, 2024), radar data can be transmitted to shore via low-bandwidth remote connections, while high-volume video files are typically stored locally and transferred manually due to bandwidth constraints. This hybrid transmission model can ensure continuous data collection and redundancy, with automated system recovery, remote monitoring, and time-synchronised metadata supporting data integrity and accessibility.

- In the NnG Seabird Interactions Study conducted by STRIX, a multi-source data flow was adopted, where camera and radar inputs were processed through local infrastructure nodes and then centralized in the STRIX system. From there, data was passed to two platforms: one for analysis and classification, and another for visualisation. This illustrates a modular architecture that supports integration of diverse sensors and centralised processing – relevant for projects requiring scalable, multi-source monitoring.
- In the Spoor AI Avian Monitoring with CCTV Cameras study at Equinor's Hywind Tampen Floating Wind Farm in Norway, a structured data transfer process implemented, where Equinor selected and filtered video files from multiple cameras before uploading them in batches to Spoor's AWS cloud storage (Figure 5). Only footage captured during bird monitoring positions was transferred, helping to reduce bandwidth use and avoid sharing video that may contain personal identifiable information from HSE operations. Spoor then filtered for sufficient daylight and processes the footage using AI for bird detection, tracking, and species identification, with human quality assurance at key stages.

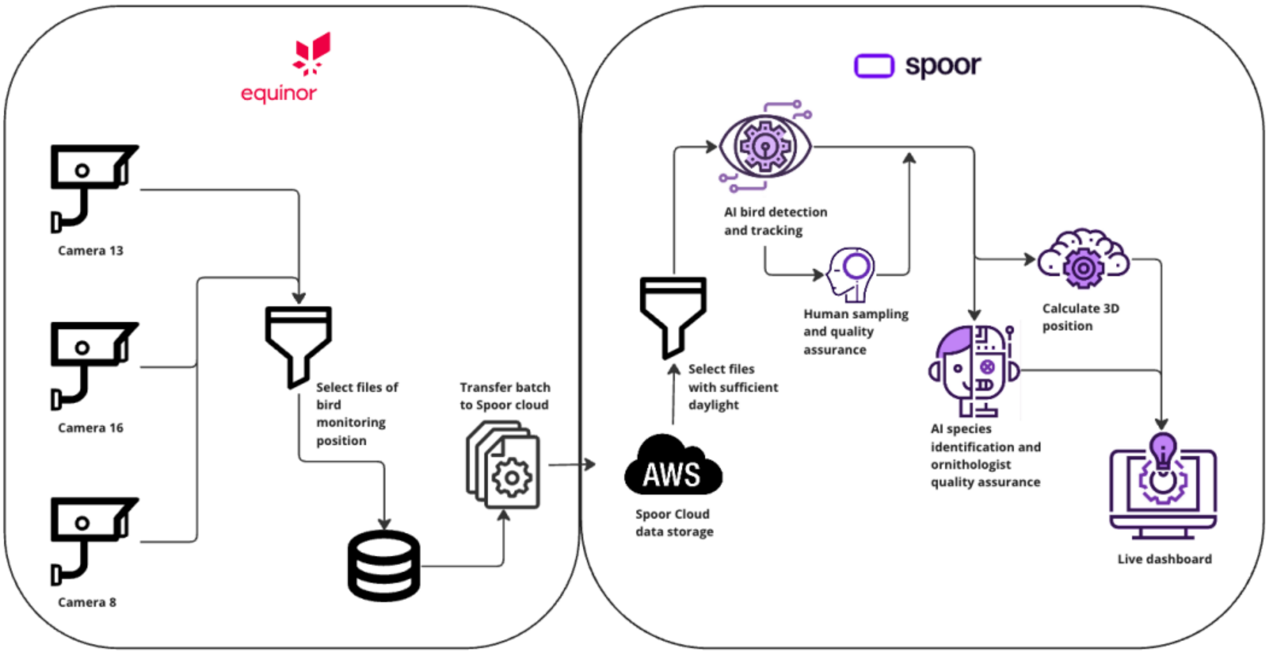

Figure 5. Data transfer process flow chart for the Spoor AI Avian Monitoring study at the Hywind Tampen offshore wind farm (Equinor & Spoor, 2024).

Overall, data transmission strategies vary with infrastructure, bandwidth constraints, and integration needs. Both real-time and batch models are used, often with local buffering and manual transfers. Compatibility with wind farm networks and cybersecurity are key factors. Data transmission should be discussed as early as possible in study design (ideally during wind farm design) to address compatibility and security, and to reserve bandwidth.

6.2. Data compatibility

Effective data transmission in seabird collision monitoring systems requires more than just selecting appropriate communication protocols or bandwidth solutions. Another critical aspect is ensuring backwards and forwards compatibility across the entire monitoring pipeline. This includes:

1. **Monitoring hardware and sensors** – such as radar units, cameras, and acoustic sensors.
2. **Firmware, software, and analytical tools** – including data acquisition systems, AI-based detection algorithms, and visualisation platforms.
3. **Deployment environment** – encompassing turbine infrastructure, SCADA systems, and offshore network configurations.

As highlighted by Jarrett *et al.* (2025) in the context of terrestrial ecoacoustic monitoring, changes in hardware, firmware, or analytical tools can introduce inconsistencies that compromise data comparability over time. Therefore, integrity and comparability depend on maintaining compatibility across evolving hardware and software generations. This is particularly relevant (and at the same time more difficult to achieve) in offshore wind farm contexts, where proprietary monitoring systems dominate and integration with existing infrastructure is often bespoke and non-standardised.

Jarret *et al.* (2025) also underscore the importance of designing systems that support re-analysis of raw data as analytical methods evolve. For offshore applications, this means ensuring that data transmission protocols preserve original data fidelity and that storage solutions retain raw formats alongside processed outputs. Transparent documentation, rigorous version control, and open standards (where feasible) are key to enabling future-proofed, interoperable monitoring systems.

For example, a supplier may update their firmware or detection algorithms, improving performance but inadvertently altering data formats or metadata structures. Without careful version control and documentation, this can compromise longitudinal studies or introduce bias in trend analyses. Similarly, changes in turbine SCADA configurations or IP addressing schemes can disrupt data flows if not anticipated during system design.

These considerations should be integrated throughout the planning and implementation of data transmission infrastructure, ensuring that systems remain robust, interoperable, and future-proofed over the operational lifetime of the wind farm.

6.3. Off-site data storage

Off-site storage solutions are designed to support secure, reliable, scalable handling of large offshore datasets. Current approaches include:

- Centralised onshore servers in secure data centres with virtualisation, drive redundancy, and automated backup. One supplier reported continuous transfer from offshore units to onshore infrastructure with built-in redundancy to ensure continuity during connectivity interruptions.
- Cloud-based storage offered by suppliers with integrated platforms. Uploads are encrypted to private clouds with restricted access; clients access data via a secure web interface with metadata tagging, performance indicators, and visualisation tools.
- Network-attached storage (NAS) solutions that synchronise daily with locally stored video footage. NAS is designed for the full project duration. Metadata for each video should include timestamps,

camera orientation, zoom level, and tracking initiation source (e.g. radar or camera) to support post-processing and traceability.

- SCADA-routed architectures, where sensor data pass through the turbine controller to the SCADA server (turbine or OSS) before onshore transmission. Although this enables centralised access, cybersecurity concerns often limit broader implementation.

Overall, the choice of storage architecture is influenced by network availability, data volume, cybersecurity requirements, and the degree of integration with wind farm infrastructure.

Recommendations:

- Plan early with IT/OT teams: Address IP/VLAN setup, firewall rules, routing, and potential fibre bandwidth allocation at the study-design stage.
- Use fibre where feasible: Use fibre-optic transmission for bandwidth, reliability, and security; avoid direct SCADA integration for third-party systems unless risks are managed.
- Adopt fit-for-site transmission modes: Where fibre isn't available, use 4G/5G, Wi-Fi, or satellite with secure VPN; choose real-time or batch/hybrid based on bandwidth and objectives; include local buffering and manual transfer contingencies.
- Design for compatibility and re-analysis: Preserve raw data fidelity; retain raw alongside processed outputs; maintain version control and clear documentation; anticipate impacts of firmware/model/SCADA changes.
- Implement robust off-site storage: Use redundant, secure onshore/cloud/NAS solutions with automated backups; ensure metadata-rich storage (timestamps, orientation, zoom, trigger source) and align with project data-management and cybersecurity policies.

7. Approaches to obscure commercially sensitive data

Certain types of data collected during bird collision monitoring studies may be considered commercially sensitive. This typically includes detailed wind data at hub height (such as wind speed and direction), turbine operational status, and potentially the number of recorded bird collisions. The sensitivity of this information often stems from its potential to reveal insights into turbine performance, operational strategies, or proprietary technologies. In some cases, detailed technical documentation, such as CAD files or engineering assessments, may also be protected due to intellectual property concerns.

However, the boundaries of what constitutes commercially sensitive data are not always clear-cut. Decisions around data sensitivity are often made at a senior level within development companies and may involve joint venture partners or other stakeholders. While some data, such as instantaneous turbine status during bird events, may be viewed as less sensitive, broader datasets on wind patterns or turbine performance are more likely to be restricted, although sometimes only temporarily. Additionally, concerns around data ownership, GDPR compliance, and site security, particularly with camera-based systems, can further complicate data sharing.

Commercial sensitivities mean that use of certain data will only be possible with obfuscation or anonymisation that satisfies the data provider. Although there are simple processes that can be applied in general, a comprehensive plan will be bespoke to the data. Here we outline the process for creating the plan and example approaches that will generally apply.

Note, creative solutions for difficult cases may be needed for an acceptable treatment. In the extreme, conflicts between desired data use and provider requirements may be irresolvable.

7.1. Scoping

The scope of data anonymity needs to be determined, which is a collaborative process involving data users and providers. This is defined by:

- What data is sought and for what purpose?
- (consequently) what elements will be necessarily exposed to what audience, and in what form?
- What level of confidentiality is required of these data exposures?
- What treatment satisfies the users and providers?

Detailed data treatment plans are only required for exposure of data that is both essential and confidential. For data that is not strictly essential (i.e. nice-to-have) but confidential, a broad and simple anonymisation might nonetheless suffice.

Note, Section 3 of this document covers elements of this scoping: relevant data is listed, along with broad confidentiality levels. Further, this data is ranked in terms of relevance. Many of the concerns might be addressed by a simple goal and treatment (obscuring of location) but generally provides a triage for the data anonymisation plan.

7.2. Data use

An informed discussion about data confidentiality requires the nature of the data exposure be known, the type of information being accessed and by which group.

A series of fundamental questions ought to be considered:

- What data, or outputs from them, are to be accessible?
- What data is necessary to produce these outputs and in what form?
- Who will have access to these outputs and through what means?
- Who is required to produce these outputs?
- What level of data access is required in steps leading to outputs?

For example, in this OWF context, full unadulterated data may be required for modelling, whereas only summary model outputs are being disseminated publicly. In this case, primary data access is restricted to an approved group and the expected modelling outputs for wider dissemination require scrutiny.

7.3. Level and nature of confidentiality

Once the necessary data with confidentiality concerns has been established, details of the confidentiality are needed. These will include:

- What makes the data sensitive?
- Who is not permitted to access this information?
- What obfuscation, anonymisation or restriction of access would be acceptable to the provider?

For example, in this OWF context it may be sufficient that a particular development's contribution to analysis results be unidentifiable. In this case:

- Full access to the unadulterated spatiotemporal data be restricted to an approved analysis group.
- Modelling results are ensured to be pooled estimates over multiple developments, providing parameter estimates and uncertainty, with no link to the data provenance.

Data categories and their definitions to reflect different confidentiality levels are suggested in subsection 8.1.1.

7.4. Data treatment

The data treatment or confidentiality restrictions on users depends logically on the previous considerations. Solutions to confidentiality concerns are likely to be addressed broadly by:

- Restrictions on users.
- Simple anonymisation of data – swapping/coding of informative elements with alternatives via a lookup table, e.g. development names.
- Standardisations, e.g. spatial information reduced to distances from a common abstract origin.

- Addition of stochasticity, with random seeds managed confidentially if reconstruction is needed.
- Modelling, summarising or aggregating of data, e.g. summarising values over developments to means and variances to obscure data provenance.

7.5. Cautions

Care is needed that the information disseminated cannot be easily back-engineered to infer its confidential underpinnings. In this OWF context, spatiotemporal information is clearly informative of data origin. However, even if obscured, cross-referencing model outputs with published species distributions might be more subtly informative. These are context specific and require careful examination.

Recommendations:

- Define scope early with data providers: what data are needed, for what purpose, and who will access them.
- Restrict access to essential confidential data and use anonymisation/obfuscation (e.g. coding, aggregation, standardisation) where required.
- Retain full raw data only for an approved analysis group; share pooled or summarised outputs externally.
- Document confidentiality requirements and ensure treatments cannot be easily reverse-engineered.
- Review data treatment iteratively, recognising that some conflicts between data needs and confidentiality may not be resolvable.

8. Data sharing agreements

It is widely acknowledged that more comprehensive data are required in order to quantify empirical collision rates and reduce uncertainty in collision risk models. In order to reach a sufficient number of turbine years' worth of data to reduce uncertainty in collision risk, results from bird monitoring studies need to be able to be combined into larger harmonised datasets, in order to draw robust conclusions which are widely accepted and applicable. To achieve this, data sharing agreements are often required to faciliate the sharing of data and agree the terms upon which they are shared and can be used. The PrediCtOr project has itself put in place a data sharing agreement to facilitate the gathering of data into a harmonised dataset for analysis. In this section, we discuss the key challenges and learnings from the process of implementing a data sharing agreement, with the aim to help reduce the time and complexity for others putting data sharing agreements in place in future.

8.1. Considerations for agreement structure

It is important to begin the negotiation process by identifying all relevant parties that need to review and agree to the terms, and their expected role and motivations for participating. In addition to the data provider(s), this is likely to also include the party(ies) who will be compiling and analysing the data, and potentially also consenting bodies who will benefit from accessing the dataset. It is important to identify which parties own the data from bird collision studies, as this may not be the wind farm operator, and there could be ownership structures which require multiple shareholders to approve release of data.

It is recommended to draw up 'heads of terms' based on initial discussions with the relevant parties, where key structures and principles are agreed prior to more detailed drafting of the agreement. At this stage it can also be useful to involve other stakeholders in discussions, for example, those that expect to use the complied dataset, to ensure the terms meet the needs of use.

There are two key areas to consider when agreeing the heads of terms: Data categories and Permitted purposes.

8.1.1. Data categories

Some research questions will relate closely to information that is commercially sensitive for reasons not related to collision risk (such as turbine operational status). To maximise the likelihood of having such data available for research and analysis purposes, it can be beneficial to split the data to be provided into categories, particularly if some data are more sensitive than others. This allows for different data categories to have different permitted uses, which can be defined in the agreement.

An example of potential data categories is as follows:

a) ***Public data*** – data already in the public domain, including reports, articles, conference proceedings, other published documents and datasets.
b) ***Restricted data*** – data which are not publicly available but are not considered to be commercially sensitive, including granular monitoring data such as bird presence in wind farm area, bird presence in vicinity of turbines, bird tracks, flight heights, species information, and weather data which is not publicly available.
c) ***Sensitive data*** – any data which is not publicly available and is considered commercially sensitive, including wind farm operational data (such as turbine status and turbine

orientation data), wind direction and wind speed (at hub height), and any recorded raw data that has been grouped, formatted, and/or analysed in a way that makes it commercially sensitive.

8.1.2. Permitted purposes

It is important to define the permitted use for each category of data. The permitted use could vary between each party in the agreement, depending on their role. The highest level of restriction will be on the sensitive data, and it may be that only a limited number of parties in the agreement are able to access and/or use that part of the dataset. This will need to be agreed with those providing the data.

It may be that additional parties wish to join the data sharing agreement after its execution. For example, this could be additional data providers, or third parties requesting access to all or part of the collated dataset. To reduce the need for additional negotiations or amendments post-execution, it is recommended to have built in appendices containing terms agreed by all parties, which allow new parties to adhere to the agreement or obtain a license to use the data without the need for a new agreement to be signed by all parties. In the main part of the agreement, there should be a corresponding clause to clarify responsibilites for approving adherence of new parties and actioning the signature of the deed of adherence.

8.2. Key challenge areas

We have identified the following areas which can increase the length and complexity of negotiating data sharing agreements.

8.2.1. Freedom of Information requests

If any public bodies are party to the agreement (either as recipients of the data or as data providers), they may be subject to Freedom of Information (FOI) requests, or the equivalent for the region in question. This could result in data provided as part of the agreement needing to be released in some form. As it is a requirement for public bodies to respond to these requests (unless an exemption is agreed), they will need a provision for this to be included in data sharing agreements they sign up to. On the other hand, those providing data may have concerns about the potential need to release information. A careful balance is needed to meet the obligations of public bodies whilst reducing risk to data providers, which can make the negotiations of these clauses more complex. A potential mitigation is to reduce public body access to the most sensitive data, otherwise the FOI request risk could reduce the research effectiveness by prohibiting any sensitive data being shared within the agreement (as this could be a red line for many data providers). However, it is recognised that in some cases the analysis will be conducted by public bodies themselves, so for these scenarios an alternative approach will be needed. In all cases it is recommended that a clear process is agreed for dealing with FOI requests; for example, the public body promptly notifying the relevant parties in the agreement of any request they receive, consideration of possible exemptions and disclosing the minimum amount of Confidential Information necessary to comply with the public body’s obligations under the legislation.

The local legislation and reporting requirements for all potential parties should be identified and understood as early in the process as possible to ensure the terms can be considered and agreed in good time.

8.2.2. Review periods

There are likely to be a number of different parties in the agreement with differing roles and interests. This can result in different legal perspectives needing to be navigated, and therefore there can be a number of back and forths between parties to reach agreement on the terms. Lack of available resource within legal teams can further increase the timescales over which these discussions take place. To reduce the number of iterations, it is recommended to set up calls between the legal teams of parties with conflicting views in order to reach agreement on the wording together, rather than coordinating various written responses until agreement is reached. It is also recommended to set out expected review periods and timescales at the beginning of the process, so the relevant parties can coordinate with their legal colleagues to allocate resource ahead of time, rather than reacting to requests as capacity allows.

Recommendations:

- Identify all relevant parties and data owners early, and agree heads of terms before drafting detailed legal text.
- Define clear data categories (e.g. public, restricted, sensitive) and set permitted uses for each to enable sharing while protecting commercially sensitive information.
- Include simple mechanisms for new parties to join (e.g. deed of adherence) without renegotiating the whole agreement.
- Address FOI risks up front where public bodies are involved, including notification procedures and minimum-necessary disclosure.
- Streamline legal review by agreeing review timelines and using joint legal calls to resolve issues efficiently.

9. Key recommendations

This section summarises key recommendations for the collection, management, processing, transmission, storage, and sharing of data from seabird collision monitoring at offshore wind farms. The recommendations are grouped to support planning and interoperability, data quality and reproducibility, secure transmission and storage, and confidentiality and access control, reflecting practices identified through stakeholder engagement and review of existing studies in PrediCtOr.

The recommendations are intended as guidance rather than strict requirements. Practical constraints such as infrastructure and IT/OT security policies, bandwidth and storage limitations, technology availability, costs, and jurisdiction-specific approaches (e.g. UK, Germany, the Netherlands) may limit full implementation. OSW developers, monitoring equipment suppliers, and regulatory and environmental authorities should aim to adopt these recommendations wherever practicable, emphasising consistency and comparability of data across projects, efficient and secure data transmission and storage processes, and robust metadata and version control for re-analysis.

The guidance reflects the best available evidence and expert judgement at the time of writing. As technologies and industry standards continue to evolve, users should revisit assumptions and confirm applicability for their project context.

Category	Recommendations
Monitoring parameters	➢ Refer to the parameter definitions and ranking in **Section 3** to prioritise which bird, metocean, operational, and other parameters to measure. This will help align monitoring procedures with the study objectives, and inform equipment placement as well as data collection and analysis approaches. ➢ Clearly document the assumptions and/or methodology used to define the geometry of avoidance zones, and in particular the shape and orientation of the RSZ and the associated micro-avoidance zone.
Monitoring duration	➢ Aim to conduct monitoring for at least 2-3 years to capture interannual variations (longer monitoring durations preferable). Use at least one full annual cycle as a minimum where longer monitoring is not feasible. ➢ Align monitoring duration with focal species, behaviours of interest, and study objectives. ➢ Consider the sample size (e.g. monitored turbines, rotor-zone track segments) and statistical power requirements for the research questions in focus.
System selection and validation	➢ Use systems capable of capturing both movement patterns and species information (often this will be combined camera-radar systems). ➢ Ensure systems are validated on-site, including filtering performance and detection accuracy. ➢ Select equipment based on monitoring objectives, required detection ranges, and turbine layout constraints.

	➢ Engage suppliers early to ensure configurations align with regulatory expectations and project-specific conditions.
Data formats and reporting	➢ Use consistent, interoperable, platform-independent formats for raw and processed data, aligned with MEDIN standards and consistent naming conventions, to support comparability, transparency, and re-use of data. ➢ Apply recognised scientific taxonomies (e.g. WoRMS, EUNIS) across all datasets. ➢ Ensure datasets comply with FAIR/Q-FAIR principles, including metadata completeness and versioning. ➢ Agree formats with regulators early where national standards are not prescribed. ➢ Provide sufficient metadata to give context for interpretation and re-use of data, including time and location, sensor and platform characteristics, key settings affecting detection and sampling, and software or processing versions. ➢ Include detailed descriptions of sensor sampling geometry and effective detection volume, such as field of view and range, to support interpretation of detection performance. ➢ Design for compatibility and re-analysis: preserve raw data fidelity; retain raw alongside processed outputs; maintain version control and clear documentation.
Additional data (metocean, wind farm operational data)	➢ Use existing metocean data (and/or existing data collection infrastructure) and wind farm operational data as the primary source for additional parameters whenever possible. Use modelled or supplementary datasets where gaps exist in baseline monitoring. ➢ Obtain required operational data retrospectively from SCADA, unless real-time access is needed for curtailment. Note that some data, particularly detailed wind data at hub height (wind speed and direction) and turbine operational status, can be considered sensitive. ➢ Ensure all additional data are timestamped and synchronised with bird-monitoring outputs. ➢ Agree data access and sharing arrangements early to avoid IT/OT constraints delaying analysis.
Data volumes and bandwidth	➢ Assess expected data volumes early, as these vary across systems. ➢ Ensure sufficient bandwidth is available, especially where multiple systems share network capacity. ➢ Request clear bandwidth specifications from suppliers during project planning. ➢ Use AI-triggered or event-based recording where feasible to reduce data loads. ➢ Consider in-situ processing to minimise transmission requirements when suitable.

Data storage and backup	➢ Ensure systems include sufficient onboard buffer storage for periods without transmission. ➢ Where feasible, use real-time or near real-time transfer to secure onshore storage. ➢ Align storage and backup procedures with developer IT/OT security requirements. ➢ Use manual retrieval (e.g., hard drives offshore) as a contingency measure. ➢ Ensure that monitoring systems have clear data redundancy and backup protocols, provided by system suppliers. ➢ Implement robust off-site storage: Use redundant, secure onshore/cloud/NAS solutions with automated backups; ensure metadata-rich storage (timestamps, orientation, zoom, trigger source), and align with project data-management and cybersecurity policies.
Maintenance and data collection intervals	➢ Schedule regular downloads where real-time data transfer is not available. ➢ Plan offshore data-collection intervals based on storage capacity and expected data volumes. ➢ Adjust recording settings if local storage approaches capacity to prevent data loss. This should only be a temporary measure, due to loss of data quality and/or quantity.
Data quality assurance	➢ Conduct system calibration at installation, including integrated sensor checks. ➢ Implement routine data quality checks, including footage review, log inspection, and missing-data checks. ➢ Use targeted QA sampling where full manual review is not feasible. ➢ Mitigate false positives/negatives through appropriate filtering, placement, and validation.
Data transmission and network integration	➢ Plan early with IT/OT teams: Address IP/VLAN setup, firewall rules, routing, and potential fibre bandwidth allocation at the study-design stage. ➢ Use fibre where feasible: Use fibre-optic transmission for bandwidth, reliability, and security; only implement direct SCADA integration for third-party systems if risks are managed. ➢ Adopt fit-for-site transmission modes: Where fibre is not available, use 4G/5G, Wi-Fi, or satellite with secure VPN; choose real-time or batch/hybrid transmission based on bandwidth and objectives; include local buffering and manual transfer contingencies.
Commercial sensitivities and confidentiality	➢ Define scope early with data providers: what data are needed, for what purpose, and who will access them.

	➢ Restrict access to essential confidential data and use anonymisation/obfuscation (e.g. coding, aggregation, standardisation) where required. ➢ Retain full raw data only for an approved analysis group; share pooled or summarised outputs externally. ➢ Document confidentiality requirements and ensure treatments cannot be easily reverse-engineered. ➢ Review data treatment iteratively, recognising that some conflicts between data needs and confidentiality may not be resolvable.
Data sharing agreements	➢ Identify all relevant parties and data owners early, and agree heads of terms before drafting detailed legal text. ➢ Define clear data categories (e.g. public, restricted, sensitive) and set permitted uses for each to enable sharing while protecting commercially sensitive information. ➢ Include simple mechanisms for new parties to join (e.g. deed of adherence) without renegotiating the whole agreement. ➢ Address FOI risks up front where public bodies are involved, including notification procedures and minimum-necessary disclosure. ➢ Streamline legal review by agreeing review timelines and using joint legal calls to resolve issues efficiently.

This PrediCtOr Data Best Practice Guidance is intended to support more consistent, comparable, and interoperable data across offshore seabird collision monitoring studies. The recommendations are intended to improve data quality and reproducibility, reduce uncertainty in downstream analyses (including collision risk modelling), and streamline transmission, storage, and access while respecting commercial sensitivities and cybersecurity. Continued collaboration and alignment between developers, suppliers, regulators and SNCBs, including clear data-sharing arrangements, robust metadata and version control, and early IT/OT engagement, will be essential to maintain confidence in results, enable re-analysis as methods evolve, and ensure that data practices keep pace with the evolving needs of the sector.

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