OFFSHORE RENEWABLES JOINT INDUSTRY PROGRAMME (ORJIP) FOR OFFSHORE WIND

CARBON TRUST

Synthesis of evidence (D01)

Closing the Loop: Feasibility study to determine a feedback approach for post-consent monitoring to reduce consenting risk in future assessments

September 2025

orjip working to accelerate offshore consenting

ORJIP Offshore Wind

The Offshore Renewables Joint Industry Programme (ORJIP) for Offshore Wind is a collaborative initiative that aims to:

- Fund research to improve our understanding of the effects of offshore wind on the marine environment.
- Reduce the risk of not getting, or delaying consent for, offshore wind developments.
- Reduce the risk of getting consent with conditions that reduce viability of the project.

The programme pools resources from the private sector and public sector bodies to fund projects that provide empirical data to support consenting authorities in evaluating the environmental risk of offshore wind. Projects are prioritised and informed by the ORJIP Advisory Network which includes key stakeholders, including statutory nature conservation bodies, academics, non-governmental organisations and others.

The current stage is a collaboration between the Carbon Trust, EDF Energy Renewables Limited, Ocean Winds UK Limited, Equinor ASA, Ørsted Power (UK) Limited, RWE Offshore Wind GmbH, Shell Global Solutions International B.V., SSE Renewables Services (UK) Limited, TotalEnergies OneTech, Crown Estate Scotland, Scottish Government (acting through the Offshore Wind Directorate and the Marine Directorate) and The Crown Estate Commissioners.

For further information regarding the ORJIP Offshore Wind programme, please refer to the Carbon Trust website, or contact Ivan Savitsky (ivan.savitsky@carbontrust.com) and Žilvinas Valantiejus (zilvinas.valantiejus@carbontrust.com).

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- NatureScot
- Royal Society for the Protection of Birds (RSPB)

- Scottish Government Marine Directorate

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Report writing contributions:

- BioSS led the writing of this report
- ABPMer led the writing of the Review of policy, process, and data availability and Site-specific case studies sections
- James Hutton Institute led the writing of the Semi-structured Interviews section
- UKCEH led the writing of the Bird-bourne telemetry data section
- University of St Andrews led the writing of the At-sea survey data section

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List of Abbreviations

AA	Appropriate Assessment
AAI	Avoidance/Attraction Index
APHA	Animal and Plant Health Agency
BACI	Before-After-Control-Impact
BAG	Before-After-Gradient
BESS	British Energy Security Strategy
BTA	Baseline Technical Appendix
CASE	Cooperative Awards in Science & Engineering
CEF	Cumulative Effects Framework
CES	Crown Estate Scotland
CMACS	Centre for Marine and Coastal Studies Ltd
COWRIE	Collaborative Offshore Wind Research into the Environment
CRM	Collision Risk Model
DAERA	Department of Agriculture, Environment and Rural Affairs
DAS	Digital Aerial Survey
DCO	Development Consent Order
DEA	Danish Energy Agency
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment, Food & Rural Affairs
DESNZ	Department for Energy Security and Net Zero
DOI	Digital Object Identifier
EIA	Environmental Impact Assessment
ENGOs	Environmental Non-Governmental Organisations
EOR	Environmental Outcomes Report
EU	European Union
FAIR	Findable, Accessible, Interoperable, Reusable
FTRAG	Forth & Tay Regional Advisory Group
FEPA	Foreign Extortion Prevention Act
GAM	Generalised Additive Model
GAMM	Generalised Additive Mixed Model
GLMM	Generalised Linear Mixed Model
GLS	Light-based Geolocators
GPS	Global Positioning System
HMM	Hidden Markov Model
HRA	Habitats Regulation Assessment
IBM	Individual Based Model
IPMP	In-Principle Monitoring Plan
INTOG	Innovation and Targeted Oil & Gas leasing round through Crown Estate Scotland, including ‘Innovation’ projects and ‘Targeted Oil and Gas’ projects
JNCC	Joint Nature Conservation Committee
LiDAR	Light Detection and Ranging
MCAA	Marine and Coastal Access Act 2009

MCZ	Marine Conservation Zone
MD	Marine Directorate
MDE	Marine Data Exchange
MD-LOT	Marine Directorate Licencing Operations Team
MEDIN	Marine Environmental Data and Information Network
MEEB	Measures of Equivalent Environmental Benefit
MHCLG	Ministry of Housing, Communities and Local Government
MMO	Marine Management Organisation
mNCEA	Marine Natural Capital Ecosystem Assessment Programme
MNG	Marine Net Gain
MFRAG	Moray Firth Regional Advisory Group
NE	Natural England
NNG	Neart na Gaoithe
NSIPs	Nationally Significant Infrastructure Projects
NRW	Cyfoeth Naturiol Cymru / Natural Resources Wales
OEP	Office of Environmental Protection
ORD	Offshore Renewable Developments
ORJIP	Offshore Renewables Joint Industry Programme
OSW	Offshore Wind
OW	Offshore Wind
OWC	Offshore Wind Champion
OWEC	Offshore Wind Evidence and Change Programme
OWEER	Offshore Wind Environmental Evidence Register
OWEIP	Offshore Wind Environmental Improvement Package
OWEKH	Offshore Wind Evidence and Knowledge Hub
OWIC	Offshore Wind Industry Council
OWSMRF	Offshore Wind Strategic Monitoring and Research Forum
OWF	Offshore Wind Farm
PCM	Post-Consent Monitoring
PINS	Planning Inspectorate
PrePARED	Predators and Prey Around Renewable Energy Developments (OWEC)
pSPA	provisional Special Protected Area
RAG	Regional Advisory Group
RSPB	Royal Society for the Protection of Birds
RUK	Renewables UK
RTD	Red-throated diver
ScotMER	Scottish Marine Energy Research
sCRM	Stochastic Collision Risk Model
SEA	Strategic Environment Assessment
SNCB	Statutory Nature Conservation Body
SPA	Specially Protected Area
SST	Sea Surface Temperature
TCE	The Crown Estate
TDR	Time Depth Recorder

UKRI	UK Research and Innovation
VARS	Visual Automatic Recording System
WOZEP	Dutch Governmental Offshore Wind Ecological Programme

Executive summary

There is currently no strategic feedback mechanism or requirement for data collected during post-consent monitoring (PCM) to be integrated into assessments. Using these data effectively could help reduce uncertainty in the consenting process, which is crucial in the context of both cumulative and future project-based assessments.

Within the context of ornithology, the scope of the synthesis of evidence report is to identify barriers and potential solutions to using post-consent monitoring data, characterise the tools and approaches that are currently available to incorporate post-consent monitoring data into the assessment process in the context of cumulative and future project-based assessments, and consider requirements for future data collection.

The approach focuses on identifying procedural and scientific barriers that prevent effective data use and developing potential solutions to bridge this gap. Through an interdisciplinary methodology combining a review of policy and processes, stakeholder engagement, and case studies, the research explores the limitations of current PCM practices and potential solutions.

Key activities include evaluating policy and process bottlenecks, analysing scientific and technical challenges using seabird case studies, and engaging stakeholders through semi-structured interviews and a focused group workshop. Future work will produce recommendations and propose a roadmap to facilitate better PCM data use in decision-making.

The synthesis of evidence highlights key barriers and challenges in PCM for offshore developments. A lack of centralised oversight and coordination results in inconsistent data collection, reporting, and accessibility. Resource limitations and unclear governance structures further hinder effective PCM processes. Additionally, data findability remains a significant challenge, with inconsistencies in metadata and storage locations affecting accessibility. While efforts are being made to align data management frameworks, including the expansion in remit of the Marine Data Exchange (MDE), gaps remain in standardisation and the integration of PCM data into impact assessments.

Potential solutions emphasise improved coordination among stakeholders, enhanced data management policies, and investment in expertise and infrastructure. Strengthening governance, establishing clearer reporting requirements, and resourcing dedicated data managers can help improve PCM processes. Additionally, ensuring better integration of PCM data into evidence-based decision-making requires a strategic approach, improved metadata standards, and methodologies for data aggregation. The next phase of this project involves assessing the feasibility and priority of these solutions through stakeholder engagement, leading to the development of targeted recommendations to enhance the use of PCM data in offshore renewable impact assessments and consenting processes.

To read this report quickly: In Section 1 the Introduction sets the context of the report, Section 2 Approach details the pluralistic research approach we took, and Section 3 Synthesis of Evidence details the outcomes from this report in the form of identifying barriers and setting out potential solutions for 'closing the loop'.

For a more in-depth read: Sections 4 - 8 detail the weight of evidence we have gathered to support the Synthesis of Evidence. Section 4 is a Review of current policy, process, and data availability, Section 5 is a summary of Semi-structured interviews with stakeholders, Section 6 is a Seabird Case Study discussing types of data and analysis, and using site-specific case studies, Section 7 is an Interactive App to explore scenarios relating to decision-making, and Section 8 is a summary of the focused group workshop.

1. Introduction

The UK government is committed to accelerating to net zeroNet Zero, delivering clean power by 2030, and to restoring nature. The Clean Power Action Plan sets out an ambition for the UK is to deliver 43-50 GW of offshore wind by 2030. To meet the Department for Energy Security and Net Zero (DESNZ) 'Clean Power Capacity Range' will require deployment at an accelerated scale and pace (Clean Power 2030 Action Plan, 2024). Deployments are constrained on the requirements for planning approval, so these barriers must be overcome to secure the sector's full potential. Environmental assessments for offshore renewable developments are undertaken with respect to the EIA Directive (2011/92/EU), Marine Strategy Framework Directive (EC/2008/56), Habitats Directive (EC/92/43), Birds Directive (EC/79/409) and derived legislation. However, there is broad acknowledgement that environmental assessment regimes, namely Environmental Impact Assessments (EIAs), Strategic Environmental Assessments (SEAs) and Habitats Regulations Appraisals (HRAs) are not operating as well as they should within the UK. Although there is variation in how assessment processes work between nations, a report released by the Office for Environmental Protection (OEP, 2023) concluded there were three fundamental root causes responsible for poor performance: i) data accessibility, ii) post-consent monitoring, and iii) evaluation, reporting and access to the necessary expertise. The report set out that these issues are '*well-recognised, deep-seated and not susceptible to easy, or indeed, legislative fixes',* arising less from the law itself, but more from shortcomings in the wider planning system. These issues affect all industries, although there is a need to remedy this situation so that offshore wind consenting can accelerate, and regulators are able to make timely decisions based on the best available data and evidence. Further, a recent report from the Offshore Wind Industry Council (OWIC) set out recommendations for a revised architecture to address key policy and legislative barriers to offshore wind consenting, although it was noted that regulatory reforms would be unlikely to address consenting risks (OWIC, 2024).

There is currently **no strategic feedback mechanism** or requirement for data collected during post-consent monitoring to be integrated into assessments. Using these data effectively could help **reduce uncertainty** in the consenting process, which is crucial in the context of both **cumulative** and **future project-based assessments**. Using PCM data within the same project could also be of benefit in terms of mitigation and compensation through adaptive management. Compensation is not the specific focus of this project, but the outcomes will feed directly into cumulative assessments and future project-level assessments. Here, **we focus on the barriers and potential solutions to incorporate post-consent monitoring data back into the consenting process through existing tools**, thereby 'closing the loop' as part of the wider and essential adaptive management paradigm. This is particularly important to the offshore wind sector because developers are typically required to conduct post-consent monitoring of offshore wind farms (OWF) impacts as part of their license conditions, which is costly and may be challenging to implement.

Post-consent monitoring can be a broad term so here we define it to include data that are currently collected, or could plausibly be collected in future, as part of post-consent requirements (i.e. excluding baseline data that are collected to inform the consent process). This can include data that are collected during pre-construction, during construction, or post-construction periods. It excludes other relevant data that are collected during these periods through publicly funded long-term monitoring programmes or research projects. Collected data and the lessons learned are invaluable to the further development of the industry. For example, using these data effectively could reduce uncertainty in the consenting process and be crucial in the context of cumulative assessments, where the large numbers of projects will typically translate into high levels of uncertainty, and where impact estimates for a development will be used repeatedly across multiple assessments.

We have defined three distinct sets of issues involved in closing the loop. Firstly, **procedural** barriers, which encompass policy, process, and data availability. These barriers are complex and likely seated within institutions although with scope for inconsistencies to be applied. The identification and resolution of these barriers involves a clear understanding of how decision-making processes around assessments currently operate, and of the potential mechanisms for adapting these processes.

Secondly, there are substantive **scientific**, technical, and statistical issues involved in using post-consent monitoring data to provide information that is of relevance to the assessment process. This process involves the transfer of evidence across time, space and/or species, which requires an evaluation of the extent to which transferability is possible and defensible. The process will frequently also involve the synthesis of multiple types of evidence, or of evidence from multiple sites/times. Challenges around transferability may create barriers to the incorporation of evidence from post-consent monitoring data into updated Statutory Nature Conservation Body (SNCB) guidance. The final set of issues concern the potential for **future changes** to the requirements around collection of post-consent monitoring data, to modify the types or amounts of data being collected.

The underlying motivation and urgency for 'closing the loop' is common across different receptors, including seabirds and marine mammals, as are the general challenges that can prevent the realisation of this objective. Ecological risk in relation to both taxa is a key element of consent risk, whilst collection of post-consent monitoring data is expensive and time consuming in both cases. This creates the potential for major benefits if information derived from monitoring data can be fed back into the assessment process and into decision making. However, there are missed opportunities potentially leading to incorrect decision making through over or under estimation of effects if benefits are not delivered through uptake of effective mechanisms for exploiting post-consent monitoring data within the decision-making process. There is, however, a need for high-level conceptual framing of the benefits and challenges associated with 'closing the loop' to be interpreted and implemented in substantially different ways in the two taxa, given the substantive differences in both the scientific evidence base and the decision-making processes. For seabirds, the key priority is to understand the specific barriers that exist to the use of post-consent monitoring data within decision making, and to formulate the mechanisms, and associated roles and responsibilities, required to overcome these barriers. For seabirds, the starting point is a bottom-up process, specifically to understand the specific technical and organisational issues that prevent uptake. By contrast, for marine mammals the issues and potential solutions are clearer so the key focus is on operationalising a specific mechanism for evidence transfer and uptake. Work within this project uses an 'evidence bridges' approach to facilitate this mechanism. For example, evidence-based decision-making is essential for conservation and management, relying on the best available science to inform policy and planning. However, a gap exists between researchers, who produce rigorous but time-consuming studies, and decision-makers, who operate under time constraints, leading to challenges in translating evidence into practice and highlighting the need for a structured process to bridge this divide. The 'evidence bridges' approach is derived from a conceptual framework that has been used extensively in other areas (e.g. evidence-based medicine) and so is likely to ultimately also be of relevance to the use of post-consent monitoring data to inform assessments for seabirds. However, the differing contexts of the two taxa in relation to current practice mean that additional work around understanding barriers and potential solutions in relation to policy and processes is required for seabirds, and the marine mammal approach will therefore be used to inform recommendations at a later stage of the project. Therefore, this report focuses on developing a bespoke approach and applying it in the context of seabirds.

2. Approach

2.1. Context and scope

Closing the loop to better utilise post-consent monitoring data in the assessment process is a significant and complex problem. The scope of this project is to understand the procedural and scientific barriers of why and how post-consent monitoring data is not currently integrated into the assessment process, and to make recommendations on how these barriers can be resolved. To be able to make recommendations and set out a roadmap as the final output of this project, we undertook a set of activities to:

- Define the problem we want to solve
- Identify key barriers and where bottlenecks occur in terms of procedural, scientific, and future changes to the requirements of post-consent monitoring data collection and integration to the assessment process
- Where possible, put forward potential solutions to the issues that have been identified

The scope of the synthesis of evidence report is to identify barriers and potential solutions to current processes of using post-consent monitoring data, characterise the tools and approaches that are currently available to incorporate post-consent monitoring data into the assessment process in the context of cumulative and future project-based assessments, and consider requirements for future data collection.

2.2. Research approach

To fully address 'closing the loop', it is necessary to understand the problem from different perspectives, given that solutions will be across a range of factors relating to **policy, process, data, and scientific considerations**. It is vital that the approach taken can capture relevant information around barriers and potential solutions using **academically rigorous methods across multiple disciplines**. The approach also needs to capture the perspectives and experiences of stakeholders to ensure the key issues are properly characterised and that potential solutions are **co-developed with stakeholders**. Participatory stakeholder engagement across the offshore wind sector is fundamental for the success of the outcomes of this project. Therefore, a co-development approach has been embedded within the project lifecycle, from identifying key issues and potential solutions with the stakeholders (the scope of this report), to the final outcomes of producing recommendations to 'close the loop' and a roadmap to set out pathways to impact (which will be undertaken in a future set of project activities).

To address the problem of 'closing the loop' within the scope and context of this project we use a pluralistic mode of research through integrating over multiple disciplines with different approaches, i.e. **one problem, multiple lenses** (Bailie et al., 2022). An interdisciplinary project team was assembled, involving experts in ecological and socio-economic statistics, social science, ecology, consultancy, policy, and science-policy communication. We used mixed method approaches (review, qualitative, and quantitative) over a range of activities to understand different aspects of the problem and develop potential solutions. However, using mixed methods approaches can mean that results can produce very different outputs in the form of literature review, qualitative findings, or quantitative information. To develop an effective holistic approach, we need to take all outputs into consideration. To achieve this, we designed the outputs from each activity to contribute to an overarching set of key points outlining barriers and potential solutions to 'closing the loop'.

2.3. Pluralistic approach

We synthesise the findings from the activities we have undertaken using bullet points of the key issues and barriers and potential solutions we are proposing. These are grouped into themes to aid readability but are currently not prioritised or evaluated. This work will be undertaken in a later phase as a necessary precursor to the co-development with stakeholders of recommendations and a roadmap that form the final outputs from this project. The remaining sections of the report build the narrative of the linked activities we have undertaken to bring thorough understanding of the key barriers and potential solutions that are proposed. Throughout the report, text is hyperlinked to aid readability and demonstrate how activities relate to each other.

The review of policy and processes and semi-structured interviews focus on the procedural barriers and bottlenecks of policy, process, and data availability in the specific context of seabirds. The review provides the context for this project, setting out legislation and guidance including roles and responsibilities for key organisations, many of whom took part in the semi-structured interviews. An examination of the planning processes across the UK aims to set out how PCM currently fits into the process, and the stages at which key decisions are made surrounding post-consent monitoring. We then discuss how PCM programmes have evolved over time, drawing on the site-specific case studies presented in the seabird case study section, before setting out current practice for PCM across the UK administrations. The review presents results of a search of the Marine Data Exchange to demonstrate potential issues with data latency and availability, and concludes with transferable learnings from other countries.

The semi-structured interviews seek to provide in-depth insight to understand the procedural barriers within organisations and identify potential mechanisms for resolving these barriers. A full report on the methodology, analysis, and outputs from the interviews is available in the **Closing the Loop – Summary report of stakeholder interviews (D04a)**. Here, we summarise the methods and provide the outputs in the Synthesis of Evidence section.

The seabird case study was conducted by the project team, focusing on the scientific, technical, and statistical barriers to how post-consent monitoring data can be used to improve cumulative (in-combination) and future project-based assessments, and the potential solutions to these barriers. We begin with the types of PCM data currently collected (at-sea survey and bird-based telemetry data) or may plausibly be collected in future, the common approaches to modelling these data, along with outlining the information that can be derived from these analyses. Linking to the review, we use two site-specific case studies (Sheringham Shoal and Lincs offshore wind farms) as examples of data gathered during the PCM phase of projects and demonstrate some of the specific issues encountered by projects that encompass technical and policy considerations. The case study on Sheringham Shoal illustrates how PCM from a R1 development addressed questions using novel techniques (in this case visual tracking). We provide an overview of the opportunities and challenges involved in using evidence from post-consent monitoring data in cumulative assessments and future project-based assessments, including a review of assessment tools.

We then acknowledge the importance of post-consent monitoring data within the context of baseline conditions and external factors such as climate change and disease, considering ways in which post-consent monitoring data can be used in conjunction with baseline monitoring data (and data collected as part of research projects and long-term monitoring programmes) to provide evidence that can lead to improvements in the assessment process. The development of recommendations (at the later stage in the project) around future data collection requirements will necessarily also consider types of data collected within the post-consent period that go beyond the monitoring data that are currently required to be collected as part of licensing requirements. Recognising the constraints around increasing PCM requirements, there will be a particular focus on the potential for (a) strategic approaches that use data sharing and pooling, (b) maximising the use and analysis of existing post-consent monitoring data, and (c) integration of post-consent monitoring data collected as part of licensing requirements with broader data relevant to the post-consent period, in order to allow requirements for project-level data collection to be more focused and more closely linked to the resolution of key knowledge gaps. Transferability of evidence across time, space and/or species requires careful evaluation, with the drive for rapid deployment of renewable energy needing to be reconciled with the scientific requirement for multiple (expensive) long-term studies to understand complex, highly variable (and changing) marine ecosystems. To inform this process, an interactive app, designed to allow stakeholders to explore how pre- and post-consent monitoring data can be used in decision-making, is used to facilitate and structure stakeholder discussion in a focused group workshop around future data collection requirements and the use of post-consent monitoring data within the assessment process. The interactive app provides users with scenarios using simulated data to engage with some specific scientific and statistical barriers that were identified through the case study work in the project, and which required additional discussion with the stakeholders. Finally, a summary of the focused group workshop is included for completeness. The workshop was held for participants of the semi-structured interviews with the aims of gathering high-level feedback on the key issues and potential solutions presented here, and inputting on the feasibility of potential solutions put forward, as well as facilitated structured discussions, motivated by comparison of scenarios in the interactive app.

3. Synthesis of evidence

Synthesising the results of the pluralistic approach with findings from the different activities, this section brings together the outputs from these activities and presents a consolidated view of how the current processes are working, which barriers have been identified, where bottlenecks occur, and sets out potential solutions. When considering groups of stakeholders, we considered organisations with responsibility for oversight and delivery management (hereafter 'oversight managers'), who have a key structural role in enabling and promoting the use of post-consent monitoring data. This group comprises of The Crown Estate (TCE), Crown Estate Scotland (CES), and the Offshore Wind Evidence and Knowledge Hub (OWEKH).

3.1. Summary of key barriers and issues identified

3.1.1. Procedural issues

- The collection and management of PCM reporting and data involves multiple stakeholders, including developers, consultants, subcontractors, regulators, oversight managers and statutory nature conservation bodies (SNCBs). Each of these actors has different roles, responsibilities, areas of operation, and potential uses for PCM data, presenting a governance challenge in relation to using PCM data to improve assessment processes.

- Whilst there is a legal requirement to carry out PCM to discharge consent conditions, once the monitoring report has been signed off, there is no legal requirement to utilise the information gathered during PCM. No single organisation has responsibility for overseeing or coordinating PCM reports and data: there is no central coordination or oversight of reporting that is due, and no formal process for informing relevant organisations when reporting and data have been received and uploaded. The formal discharge of consent conditions is managed between the relevant regulator and developer; but reporting is also valuable to SNCBs, oversight managers, and other stakeholders for understanding the effects and impacts of OWFs as reports and data become available.

- The phase of offshore wind development prior to consent is driven by statutory deadlines and obligations, as well as expectations of transparency. The same does not apply to post-consent monitoring and reporting, resulting in an effectual downgrading of the importance of PCM data (which are effectively deprioritised in terms of staffing and resourcing), and mixed practices on data transparency.

- In Principle Monitoring Plans (IPMPs) are provided at application and agreed at consenting stage, but are often high-level, and often require subsequent discussion with regulators and SNCBs about approaches and methodologies before monitoring begins. Final proposals for Monitoring Plans are then submitted by developers before monitoring is due to begin (according to timelines indicated in consent conditions), sometimes requiring additional review especially when new technologies or methodologies have been proposed, which can be an additional workload pressure on regulators and SNCBs. (In the current Scottish context, monitoring plans are discussed with relevant stakeholders at Regional Advisory Group (RAG) meetings before being submitted to regulators for approval).

- SNCBs and other organisations have internal processes for reviewing evidence and updating guidance; some of these processes are relatively formal (e.g. regular meetings of internal specialist networks); others are more informal and can rely on individuals taking the initiative to disseminate information to relevant colleagues. All these processes work to ensure staff are as up to date as possible on the latest knowledge and insights, but the reliance on individuals can leave processes vulnerable to staff turnover.

- The sign-off of PCM reporting can be delayed by review processes within regulators, with revisions and additional levels of sign-off often required, causing delays to PCM data and reporting becoming more widely available.

- Resource and capacity limitations within organisations across the industry, and especially within SNCBs, combined with the rapid expansion of offshore wind developments, means staff and expertise is stretched.

3.1.2. Data management and data management frameworks

- Data management is currently inconsistent and dispersed. Some systems are being used for purposes other than that for which they were originally developed (e.g. the MMO's public-facing database was originally an internal case management system) leading to challenges in knowledge about what data are available, and where they are stored.
- Data findability and accessibility is a significant challenge across systems. Even when knowing project names, it can be hard to track down raw data or reporting on existing systems, as search terms and metadata are unclear, and search terms return inconsistent results. PCM reporting and data often appear not to be uploaded after approval.
- Since 2024, The Crown Estate (TCE) and Crown Estate Scotland (CES) have been working to align more closely on data management. The Marine Data Exchange (MDE), created in 2013 by TCE as a purpose-built data management system, is now established as the UK platform for offshore industry data. TCE and CES are working to migrate existing data held by CES to the MDE.
- TCE and CES are working to establish common data clauses in lease agreements, and implementing clear publication policies, aiming to provide greater consistency to operators across the UK. Both organisations are implementing stakeholder engagement activities to communicate and raise awareness of the MDE, and ensure developers can fulfil their data requirements in relation to lease agreements for establishing the site.
- There is a need across the board to improve metadata standards, and to ensure data uploads adhere to FAIR principles (that data are Findable, Accessible, Interoperable and Reusable). Data practices adopted by the Marine Environmental Data and Information Network (MEDIN), including the use of digital object identifiers (DOIs) for long-term data accessibility, were welcomed.
- Investment in data management infrastructure is necessary to build resilience for the future, especially given large amounts of data, and large data files needing to be stored.
- Investment is also needed in expert Data Manager roles, to design, implement, and support data management frameworks and to provide support to users and stakeholders with handling and accessing data.

3.1.3. Moving from data -> evidence -> guidance

- Ensuring the better use of PCM data is not just about data availability. The challenge of turning data into evidence and then advice requires time, funding, resource and expertise.
- SNCBs are required to ensure any updates to generic guidance are based on robust evidence. Guidance cannot be updated based on one-off reporting, or peer reviewed academic papers based on one case study.
- Updating guidance involves internal review processes and consultation and sign-off across different work areas, and sometimes senior-level staff or scientific advisers; issuing joint SNCB guidance requires additional levels of sign-off across multiple organisations. All these processes mean reviewing evidence and updating guidance and advice can take time.
- SNCBs must manage the timing of guidance updates, recognising such updates have implications elsewhere in the consenting process. Some SNCBs in our study have started to introduce an annual update system, to provide a consistent approach for developers.

- Funding is needed to build the evidence base, including financial support for longer-term academic research and more strategic-level PCM monitoring, or consolidation of project-level monitoring into detailed aggregated evidence.

- There is a lack of consensus around a vision for PCM. Some interviewees indicated support for a more strategic or regional approach to monitoring, while others emphasised the substantial resource implications for developing and governing such an approach. Single project PCM reporting delivers important evidence and reporting, but at a spatial scale which may not be informative or provide the necessary evidence for understanding cumulative impacts. However, any framework for future PCM should be flexible enough to accommodate a combination of both strategic and project-level monitoring.

- The developing role of the Offshore Wind Evidence and Knowledge Hub (OWEKH) was considered a potential source of expertise for translating evidence to insights and disseminating information across industry, but this will require sustained resourcing, and input from a wide range of stakeholders and experts.

3.1.4. Statistical and technical

- Data are collected on a project basis, leading to potential issues with data integration, aggregation, and reuse.

- If the survey area is not large enough to encompass areas of future wind farm construction, outputs cannot be used to empirically estimate the cumulative effects of multiple wind farms.

- Where there is not high enough temporal resolution in the data, inter-annual (yearly) and intra-annual (within year, including breeding or migration) variation cannot be understood and external shocks cannot be accommodated.

- Changes in abundance will not arise solely from OWF effects, so the effects of external shocks (e.g. disease, extreme events) and a shifting baseline (e.g. through climate change) need to be accounted for when translating spatial changes in abundance into estimates of displacement or avoidance.

- Habituation may lead the magnitude, form and scale of OWF-bird interactions to alter systematically over time.

- There is a potential confounding effect of the advancement of wind technology (e.g. increasing turbine numbers, wider spacings, further offshore) with improvements in survey design (e.g. larger survey areas), which may lead to changes over time in the power to detect distributional changes around OWFs, and in the estimated magnitude of these effects.

- Tracking data are valuable in PCM as they can investigate changes in flight heights for collision risk and sub-lethal risks such as displacement and barriers effects through understanding changes in movement, behaviour and space-use of individuals as a result of OWFs and the demographic consequences of these changes. The accumulation of these individual-level changes drive population-level consequences.

- The spatial extent of surveys must be sufficient to be able to detect displacement/avoidance across the scales at which these processes occur.

- Parameters within assessment tools may have a complex interpretation and be challenging to relate to empirical evidence (e.g. avoidance rates include a correction to account for model misspecification, and so are not straightforward to relate to empirical evidence on avoidance).
- Assessment tools typically make strong simplifying assumptions (e.g. that the magnitude of displacement is not dependent on direction) that may conflict with the empirical evidence derived from PCM, creating challenges for the incorporation of this evidence into future assessments.

3.2. Potential solutions to help close the loop

3.2.1. Procedural

- Stakeholders across the industry work to establish greater clarity on the governance of and responsibility, aiming to co-develop a way of working for smoother management of PCM data and reporting, and how new information is taken forward.
- Relevant regulators and oversight managers aim to develop a comprehensive overview about when monitoring reporting is due at a strategic level, and improve communication between key stakeholders when reporting becomes available, across projects. This overview would need to consider that the initiation of PCM may vary depending on construction and commissioning timeframes, so a mechanism would be required for keeping timeframes updated.
- SNCBs, regulators, and other relevant stakeholders work to develop an annual programme of evidence review (in addition or in conjunction with the Offshore Wind Environmental Evidence Register (OWEER)); an additional opportunity would be producing a brief annual summary to update stakeholders on the latest evidence.
- To show the value of making data and reporting more open, SNCBs and others develop examples of how and where PCM data and reporting has been used to help update and improve their advice.
- SNCBs, regulators, and other relevant organisations resourced to invest in new staff to facilitate the scale of assessments needed with the continued expansion of offshore wind. SNCBs and other relevant organisations such as MMO and MDE resourced to invest in data managers, people with skills and expertise to help manage and facilitate access to and use of PCM data.

3.2.2. Data management & policy

- TCE and CES continue to invest in the Marine Data Exchange to ensure it can fulfil its role as a resilient data management framework, able to cope with the continued expansion offshore wind off the UK coastline and continue to work with MEDIN on joint data and metadata standards.
- TCE and CES continue implementing commitments to work closely with developers to ensure data are uploaded and made available in an open and FAIR manner.
- The MDE team work to further improve the searchability of its records, working with developers and researchers to improve the use of search terms.
- The wording of site leases and marine licencing conditions developed such that FAIR data expectations and formats are clearly defined, and conditions include upload of data to the MDE within a defined timescale. Such conditions are also included in contracts for data collection.

- Governments across the UK consider whether there are any policy tools or mechanisms that could be developed to improve the use of PCM data, such as statutory instruments from the Energy Act 2023.

3.2.3. Dissemination and translating data to guidance

- The developing role of OWEKH includes focus on ensuring better use of PCM data and potentially take on the role of disseminating information on PCM when papers and reporting becomes available.

- Stakeholders consider working with intermediary and representative organisations, such as OWEKH communities of practice or technical topic groups, to consolidate data across multiple projects, contributing to stronger opportunities for collation of regional or meta-analysis projects.

- SNCBs and regulators work together to co-produce a regular schedule for evidence review across all parts of the UK. This need not be resource intensive – it could be a database or a short summary document of key findings (e.g. species studied at each site; which potential impacts were/were not identified for each species).

- To ensure that improved access to data results in the delivery of better evidence and advice, invest in strategic research projects to enable academic researchers to undertake relevant meta-analyses drawing on PCM and other data sources, continuing to build the evidence base and better understand the impacts of Offshore Wind Farms (OWFs) on environmental receptors. This investment could be through programmes such as the Offshore Wind Evidence and Change Programme (OWEC), Offshore Wind Industry Council (OWIC) Pathways to Growth, and ORJIP, or through established academic funding sources such as UK Research and Innovation (UKRI) or Cooperative Awards in Science & Engineering (CASE) studentships. The UK's engagement in the Horizon Europe research programme could be identified as a potential resource for international collaborative research in this area.

3.2.4. Technical and analytical

- International data standards established for typical PCM data, similar for example, as standards that have been established for underwater noise monitoring. This will provide opportunities for data aggregation (e.g. across larger areas) and pooling analysis.

- Mechanisms are in place to ensure that empirical information and learnings derived from PCM data at monitored OWFs can be transferred with levels of confidence to other OWFs.

- Capacity, expertise and processes (e.g. around commissioning, access to data and review) are required for post-processing modelling (e.g. meta-analysis, pooled analyses) so that evidence around the effects of OWFs can be used in future impact assessments.

- Protocols established for pooled analyses and meta-analyses as these analyses are likely to provide important mechanisms for synthesising data across multiple OWFs and data sources and will form the basis for updates in SNCB guidance.

- Novel methodologies reflected in best practice guidance for analyses and modelling and investigating better mechanisms for doing so.

- PCM outputs clearly link with adaptive management within the same development or in future wind farm assessments.
- A pipeline for data management developed across the OWF lifecycle.
- Clear oversight from a designated organisation of the data management pipeline across all OWFs.
- The collection of tracking data considered for PCM, where locations of developments allow, to ensure that collision risk and sub-lethal effects can be quantified and linked to long-term population consequences for key species.
- Additional or multiple data types considered as well as the timing of data collection of PCM so that relevant data can be collected throughout the period between pre-construction to post-construction.
- Establishment of the characteristics (e.g. data types, frequency) of PCM data needed to provide evidence relevant to parameter values (and uncertainty) in the assessment tools.

3.3. Next steps

The barriers and potential solutions set out above have been grouped into themes but have not yet been evaluated or prioritised. The next step in the project is to analyse the results from the focused group workshop, which provided input into the feasibility of potential solutions.

Following this, the project will begin to develop a set of draft recommendations through assessment and evaluation of the potential solutions to maximise the use of evidence in decision making and reduce consenting risk and uncertainty. These will be developed specifically in the context of seabirds and in the recommendations report, we will link in the qualitative approach of evidence bridges in the Marine Mammal case study. A final set of stakeholder engagement will seek feedback from a wide range of stakeholders in the offshore renewable energy sector, ensuring that we co-develop a final set of recommendations and roadmap to increase the likelihood of implementation, which will occur beyond the lifetime of this project.

4. Review of current policy, process and data availability

4.1. Introduction

Post-consent monitoring is typically required as a consent condition for various projects, including offshore wind farms. There are three types of post-consent monitoring undertaken for offshore wind developments (Parker et al., 2022d):

- **Compliance monitoring** – to ensure the developer adheres to specific mitigation measures to reduce impacts, for example the need to adopt JNCC marine mammal mitigation procedures during pile driving. Although it is acknowledged that sites in Moray Firth have used a marine mammal protocol that deviates from the JNCC standard, the process of agreeing a mitigation protocol and monitoring compliance is similar.

- **Validation monitoring –** intended to validate predictions made in an EIA or HRA; and,
- **Effectiveness monitoring –** intended to provide evidence on the effectiveness of mitigation measures, and in future will include compensatory measures.

Monitoring the efficacy of compensatory measures sits within with the Conservation of Habitats and Species Regulations (2017) which provides the underpinning legislation that requires PCM to ensure measures are effective in maintaining or restoring protected sites and/or species so that the realised impacts of development on a protected site results in no net loss. Measures of Equivalent Environmental Benefit (MEEB) are similar, but specific to the Marine and Coastal Access Act (MCAA) 2009 and are used when activities may impact Marine Conservation Zones (MCZs). While both compensatory measures and MEEB aim to address environmental impacts, compensatory measures are broader and are required under the Habitats Regulations, whereas MEEB are specific to the MCAA and focus on providing equivalent benefits for potential impacts on MCZs. There are feedback mechanisms between validation and effectiveness monitoring such as when realised impacts differ from predicted levels (are either higher or lower) which relates back to mitigation measures.

PCM undertaken for offshore wind typically falls within validation monitoring. In some cases, there may be a specific requirement to verify a particular EIA prediction, whilst in other cases objectives may be focussed more broadly on gathering data on a particular issue raised at assessment (e.g. monitoring to understand potential displacement effects on a particular species). The issues with PCM are not unique to offshore wind: a recent review of assessment regimes in England conducted by the Office for Environmental Protection (OEP, 2023) identified post-decision monitoring as a root cause of key barriers to the success of assessment regimes (EIA, SEA, and HRA). The aims of this section are:

- To review policy, process, and data availability around post-consent ornithological monitoring, and how these may differ across UK administrations.
- Within the context of the review, identify key issues around ornithological PCM, including identification of barriers, constraints and bottlenecks within current system.
- Understand the reasons behind the limited availability of PCM data for birds on the MDE, which is (at least at present) a constraint on improved use of PCM data.
- Where possible, identify processes adopted within other countries and other industries to utilise PCM data, and identify where there may be transferrable learning from other countries and industries around processes whereby PCM data is fed back into assessment tools.

This review will first focus on the legislation and processes which collectively underpin the requirement for post-consent monitoring, and which are common to all the UK nations. It will then examine the planning processes, including consideration of differences between the UK administrations, and the stages at which key decisions are made surrounding post-consent monitoring. To understand complexity around PCM programme design and outputs, background information on the evolution of monitoring programmes and survey techniques is provided, where site-specific case studies are used to demonstrate the types of work undertaken as PCM and to identify, where possible, how outputs have been used). Examples are also included to demonstrate where there may be transferrable learning from other countries.

The remit of the review does not cover the outputs of post-consent monitoring data but is intended to identify the processes whereby PCM programmes are designed, implemented, reported and disseminated to understand why PCM outputs are not being better utilised. This review is focussed on England, Scotland and Wales. In Northern Ireland, there are no offshore wind farms built yet, although The Energy Strategy Action Plan 2022 includes aims to 'develop an action plan to deliver 1GW of offshore wind from 2030'. Offshore renewable energy development in the marine environment will work within the framework of the Department of Agriculture, Environment and Rural Affairs (DAERA)'s Marine Plan for Northern Ireland, with planning systems devolved to Local Authorities.

4.2. Key legislation and guidance

A combination of the EIA Directive and various conservation legislation drives the need for PCM. These include:

- **The Strategic Environmental Assessment Directive (2001/42/EC) –** states requirement to monitor the significant environmental effects of the implementation of plans and programmes to identify at an early-stage unforeseen adverse effects, and to be able to undertake appropriate remedial action.
- **The Environmental Impact Assessment Directive (2014/52/EU)** – ensures that projects which are likely to have significant effects on the environment are properly assessed before they are allowed to proceed. The Directive was updated in 2017 to require authorities to establish procedures for monitoring significant adverse effects on the environment (including monitoring to ensure efficacy of mitigation measures). The UK has retained the core principles of the EIA Directive through the Town and Country Planning (Environmental Impact Assessment) Regulations 20171.
- **The Habitats Directive, The Birds Directive, The Marine Strategy Framework Directive, The Wildlife and Countryside Act 1981** – nature conservation legislation to safeguard protected habitats and species. The UK has retained the core principles of the Habitats Directive and the Birds Directive through the Conservation of Habitats and Species Regulations 2017, which were amended by the Conservation of Habitats and Species (Amendment) (EU Exit) Regulations 2019.
- **Marine and Coastal Access Act 2009 (superseding FEPA licensing)** – underpins the requirement for marine licencing of specified activities (including offshore wind farm development) and applies to all UK nations, although different bodies administrate the marine licencing process within the different UK administrations. The marine licensing process provides the formal mechanism whereby PCM programmes are designed and discharged as part of licence conditions.

The UK has so far retained the core principles of key EU Directives, incorporating them into domestic law. The Marine Works (Environmental Impact Assessment) Regulations 2007 implement the EIA Directive for marine projects. However, the previous UK Government intended to replace the EIA and SEA processes with Environmental Outcomes Reports (EORs) under the Levelling Up and Regeneration Bill (passed in October 2023), with the aim of streamlining environmental assessments. The new UK Government is likely to undertake significant policy reform in the coming years (Defra Planning Reform Working Paper: Development and Nature Recovery Plan, 2024). Although details are not fixed, a clear change will be government-driven responsibility for strategic compensation through the recently announced Marine Recovery Fund, with delivery plans linked to existing conservation strategies.

Although the requirement to protect habitats and species, coupled with the need to assess the potential impacts of projects and plans underpins the core requirement for monitoring, the Marine Licencing process provides the formal mechanism whereby post-consent monitoring programmes are officially agreed and discharged as part of the licencing process. The current marine licencing system provides a streamlined process whereby a licencing authority issues a single development licence. The licencing authority in England is the Marine Management Organisation (MMO), in Wales is Cyfoeth Naturiol Cymru / Natural Resources Wales (NRW) and in Scotland is the Marine Directorate Licencing Operations Team (MD-LOT). Whilst the underpinning legislation may be relatively straightforward, the way in which legislation is interpreted and written into regulations and guidance can be complex, involving multiple agencies with differing roles and responsibilities (Table 1). Complexity is increased when considering the UK administrations, which have varying processes for selecting development sites, guidance offered to developers around ornithology including assessment tools, consenting processes, and are at different stages of developing offshore wind and implementing PCM (Table 2; excluding Northern Ireland).

Table 1. Roles and responsibilities of key organisations operating within the UK and involved in offshore wind farm development

Type of organisation	Name of organisation	Key Roles & Responsibilities	Responsibilities relevant to OSW	Area of jurisdiction	Data source
Non-financial public corporation[1]	The Crown Estate (TCE)	Management of land for the benefit of the nation (including the seabed)	Leasing seabed for development, awarding rights for extensions, facilitating test and demonstration opportunities, as well as working with partners to build evidence (OWEC programme), share data (OWEKH) and support innovation	England and Wales[2]	Marine | The Crown Estate, Governance | The Crown Estate
Public Corporation	Crown Estate Scotland (CES)	Invest in property, natural resources and people for the lasting benefit of Scotland. Differs to TCE in that the Independent Framework for Transfer and Delegation (IFTD) will empower communities and local bodies to manage certain assets e.g. a community group may manage an area of foreshore	Awarding and managing leases and other types of agreements to organisations who want to build offshore wind farms in Scotland. Unlike TCE they do not identify the sites, which are identified within Scottish Government's Sectoral Marine Plan	Scotland	Key information | Crown Estate Scotland, Transfer and delegation | Crown Estate Scotland
Initiative funded by TCE	Offshore Wind Evidence and Knowledge Hub (OWEKH)	Provide tool to collate information and signpost to data resources (data from the Marine Data Exchange (MDE), MEDIN and Tethys are searchable)	Support the consenting process for offshore wind projects by providing a sector-wide online portal supporting a single point of access to data and information including the latest guidance and best practice documents	N/A	Offshore Wind Evidence and Knowledge Hub (owekh.com), Offshore Wind Evidence and Knowledge Hub (owekh.com)
SNCB	Natural England (NE)	England's Nature Conservation Agency	NE have both a statutory and non-statutory role: the former, as a consultee on Nationally Significant Infrastructure Projects (NSIPs) including offshore wind farms and marine plans; the latter, as experts and advisors of proposals that impact on protected sites and species	England	Natural England (2021), downloadable from: Natural England's Approach to Offshore Wind: Our ambitions, aims and objectives - TIN181

[1]The Crown Estate (TCE) is classified as a non-financial public corporation by the Office for National Statistics (see Governance | The Crown Estate) but may also be described as an independent commercial business set up by an Act of Parliament by UK Government (https://www.gov.uk/government/organisations/the-crown-estate). TCE can make a profit, although activities are overseen by its Commissioners, whose public function is to invest in and manage certain property assets which ultimately belong to the Sovereign.

[2] The Crown Estate owns the seabed within 12 nautical miles of the coastline but holds rights over the Exclusive Economic Zone (up to 200 nautical miles offshore) allowing them to manage lease areas for offshore wind within this area.

Type of organisation	Name of organisation	Key Roles & Responsibilities	Responsibilities relevant to OSW	Area of jurisdiction	Data source
SNCB	NatureScot	Scotland's Nature Conservation Agency	Provides guidance and advice on offshore wind. In relation to marine planning, NatureScot have a role as an advisor on aspects related to nature conservation, as a steering group member and as a consultee on assessments which are part of the Sectoral Marine Plan development process	Scotland	Marine planning in Scotland | NatureScot
SNCB	Joint Nature Conservation Committee (JNCC)	The public body that advises the UK Government and devolved administrations on UK-wide and international nature conservation. The JNCC brings together, under an Independent Chair, members from the nature conservation bodies for England, Scotland, Wales and Northern Ireland and independent members appointed by the Secretary of State for the Environment, Food and Rural Affairs	JNCC are involved in identifying priority evidence needs. They maintain the Offshore Wind Environmental Evidence Register (OWEER) and manage the Offshore Wind Strategic Monitoring and Research Forum (OWSMRF), an industry-led collaborative forum that aims to better understand the impact of large-scale offshore wind development on marine birds	UK	OWEER launch | JNCC - Adviser to Government on Nature Conservation, OWSMRF | JNCC - Adviser to Government on Nature Conservation
Regulator & SNCB	Cyfoeth Naturiol Cymru / Natural Resources Wales (NRW)	SNCB and regulator for Wales with responsibility for air quality, green spaces, climate change, energy, water, forestry, waste, agriculture and health and well-being	Guidance, evidence & data, consenting & assessment advice, guidance on receptors, guidance on data for assessments, NRW evidence priorities, research and reports, also marine licencing, responsibility for design and delivery of post-consent monitoring	Wales	Natural Resources Wales / Marine renewable energy developments
Regulator & SNCB	Department of Agriculture, Environment and Rural Affairs (DAERA)	Various responsibilities, in the marine sector this includes legislation, licensing and permits and conservation activities	Marine Licensing responsible for assessing the development of any OWFs within Northern Ireland's marine environment (providing guidance on EIA to applicants), provides applicants with guidance & advice throughout the lifetime of the project	Northern Ireland	Marine Licensing | Department of Agriculture, Environment and Rural Affairs (daera-ni.gov.uk)

Type of organisation	Name of organisation	Key Roles & Responsibilities	Responsibilities relevant to OSW	Area of jurisdiction	Data source
Regulator	Marine Management Organisation (MMO)	To protect and enhance the marine environment and support UK economic growth by enabling sustainable marine activities and development. The MMO has responsibility for fisheries management, including the Fisheries and Seafood Scheme. They also have responsibility for marine planning and marine licencing	The MMO is responsible for marine licensing in English waters and for Northern Ireland offshore waters (alongside DAERA). In relation to NSIPs, it acts as a statutory consultee during the pre-application stage, and interested party during the examination stage, and a licensing and consenting body. The MMO issues marine licence under the Marine and Coastal Access Act 2009 for successful applicants. It is responsible for enforcing, post-consent monitoring, varying, suspending, and revoking any deemed marine licence(s) as part of the Development Consent Order (DCO)	England, Northern Ireland	About us - Marine Management Organisation - GOV.UK (www.gov.uk)
Regulator	Department of Environment, Fisheries & Rural Affairs (DEFRA)	Government department responsible for improving and protecting the environment, growing a green economy and sustain thriving rural communities. DEFRA also support food, farming and fishing industries	DEFRA develops policies and regulations to ensure that offshore wind projects are environmentally sustainable, working closely with the devolved administrations. DEFRA is implementing a new Offshore Wind Environmental Improvement Package (OWEIP) to support the Clean Power 2030 Action Plan. The OWEIP includes: • Reforms to HRAs for offshore wind • Establishing a Marine Recovery Fund to deliver strategic environmental compensation • Delivering Offshore Wind Environmental Standards • Implementing a strategic approach to environmental monitoring. The Energy Act 2023 will enable the implementation of the OWEIP.	Primarily England, but close collaboration with administrations in Wales, Scotland, and Northern Ireland	Energy Security Bill factsheet: Offshore wind environmental improvement package - GOV.UK (www.gov.uk)

Type of organisation	Name of organisation	Key Roles & Responsibilities	Responsibilities relevant to OSW	Area of jurisdiction	Data source
Regulator	Scottish Government (MD-LOT, MD-Science)	The Scottish Government has a range of responsibilities. The departments most relevant to offshore wind consenting are the Marine Directorate Science (MD-Science) and Research Division, and the Marine Directorate Licensing and Operations Team (MD-LOT)	Marine Directorate Science provides scientific advice on marine renewable energy, and the aquatic environment. It also provides evidence to support the policies and regulatory activities of the Scottish Government through a programme of monitoring and research and performs regulatory and enforcement activities. MD-LOT is the regulator responsible for determining marine licence applications on behalf of the Scottish Ministers in the Scottish inshore region (0-12 nautical miles) under the Marine (Scotland) Act 2010, and in the Scottish offshore region (12-200 nm) under the Marine and Coastal Access Act 2009. MD-LOT also has responsibility for post-consent monitoring	Scotland	Marine licensing: overview - gov.scot (www.gov.scot), Marine Directorate science - gov.scot (www.gov.scot)
Executive Agency	Planning Inspectorate	Planning appeals, national infrastructure planning applications, examinations of local plans and other planning-related and specialist casework in England	Decision on planning applications and appeals	England and Wales	National Infrastructure Planning (planninginspectorate.gov.uk)

Table 2. Offshore wind farm development processes, guidance and status of PCM data of UK administrations.

Administration	Processes, guidance and status of OWF development				
	Strategic Environmental Assessment	**Site selection**	**Consenting process**	**Guidance for survey and assessment**	**Status of offshore wind farm development (and PCM)**
England	Conducted by Department for Energy Security and Net Zero (DESNZ)	The Crown Estate	50-100 MW: Section 36 Consent from the Local Planning Authority. For sites >100 MW a Development Consent Order application is submitted to the Planning Inspectorate	Parker et al., 2022a, b, c, d)	29 operational offshore wind farms in English waters[3] with developments regularly commissioned since 2000[4]
Scotland	Conducted as part of the Sectoral Marine Plan: SEA of Sectoral Marine Plan for Offshore Wind Energy	Undertaken as part of the Sectoral Marine Plan: Draft Sectoral Marine Plan for Offshore Wind Energy (2019)	Section 36 Consent and Marine Licence from the Marine Directorate. This is issued under the Town and Country Planning Act, through the Local Authority	Advice on marine renewables development | NatureScot	8 operational offshore wind farms with developments regularly commissioned since 2007
Wales	Conducted by DESNZ	The Crown Estate	Up to 350 MW: Section 36 Consent, >350 MW application goes to the Welsh Government for a Marine Licence	Natural Resources Wales / Offshore wind developments	3 operational offshore wind farms commissioned since 2003

4.3. Planning Process

Various regulatory and non-regulatory organisations are involved throughout the stages of a project life, with differing processes between the UK administrations resulting in a complex planning system. An overview of the planning process is shown in Figure 1. Data is gathered within the pre- and post-consent phases of a project and is passed between various organisations with different role and responsibilities. This section focusses on a description of the processes as they have been designed to operate, with an emphasis on elements relevant to PCM. However, work to improve systems has been ongoing since the outset of the offshore wind industry, and due to the long timescales involved in projects, even changes made around five years ago may not yet be at the PCM output stage. For example, recent guidance from Natural England tackles issues raised in previous case work but is too recent to be fully realised (Parker et al., 2022a, b, c, d).

[3] List of offshore wind farms in the United Kingdom - Wikipedia

[4] 26 of these offshore wind farms have been commissioned since 2019 and should therefore have associated PCM data available on MDE.

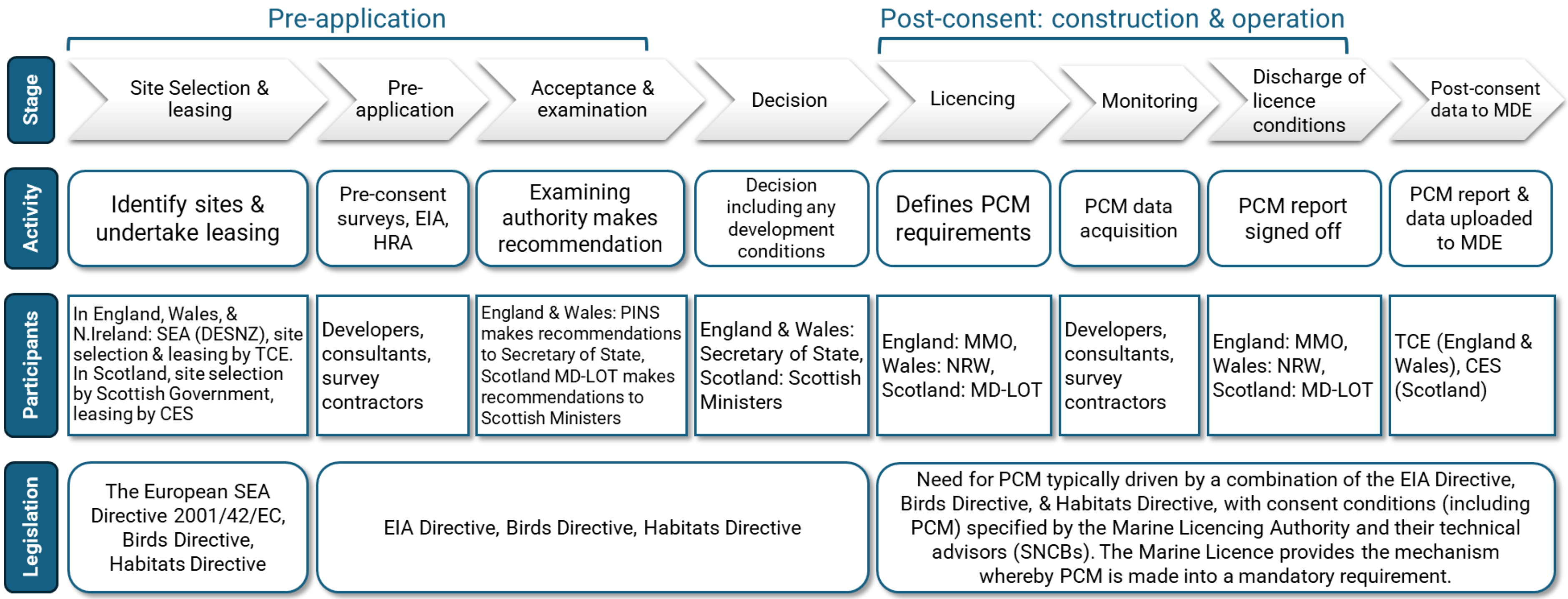

Figure 1. Overview of the current planning process, the participants involved at each stage, and the underpinning legislative drivers for post-consent monitoring.

4.3.1. Site selection and leasing

Once a potential site for an offshore wind farm is identified, the area is leased for development. The Crown Estate (TCE) manages seabed rights in England and Wales, whilst in Scotland this role is undertaken by The Crown Estate for Scotland (CES). For England and Wales, within the site lease, it is stated that all data gathered as part of the project should be uploaded to the Marine Data Exchange (MDE), a digital data management system created in 2013, which enables the offshore industry to share data. This applies to both pre- and post- consent monitoring data. TCE initiated data delivery clauses back in 2003, which specify the requirement to collect and share marine data from offshore projects. Thus, TCE have been collecting marine data for over 20 years. A partnership between TCE and CES began in 2023 and so data from Scotland could be uploaded from 2024 onwards.

4.3.2. Pre-application

The requirement within EIA to characterise the baseline environment means that there typically is a need for surveys to inform this component of EIA. For ornithology, baseline surveys follow a standard format in England, with Digital Aerial Surveys (DAS) conducted monthly over a 24-month period (Parker et al., 2022a). NatureScot guidance is similar, although boat-based surveys are also accepted (as are Vantage Point surveys if within 2km of the coast (NatureScot, 2023). NRW has guidance on how to survey for marine birds, which can be used for any development in the marine environment and is not specific to offshore wind (NRW, 2023). The data gathered within the baseline surveys informs the collision and displacement assessments. More recently, it has become a requirement for developers to submit an In-Principle Monitoring Plan (IPMP) at assessment, which is a key mechanism used by the regulators to ensure monitoring will be controlled and mitigated during construction and operation of the OWF. An IPMP provides a high-level overview of the scope of post-consent monitoring.

4.3.3. Acceptance and Examination

The outputs of baseline surveys are typically included within a Baseline Technical Appendix (BTA) and uploaded to planning portals during the application process. Therefore, they are often easy to find, displaying in standard internet search results. However, although baseline monitoring data is stored on planning portals, it is located in multiple different places depending on the size and location of the project as consenting systems differ across the UK administrations, and is also dependent on the scale of the project (Table 2).

4.3.4. Decision

During the consenting process all relevant legislation is considered alongside the outputs of the environmental assessments, and if there is uncertainty over potential impacts on protected receptors then consent conditions may be attached to the Marine Licence, including the requirement for post-consent monitoring.

4.3.5. Licencing

Although the SNCBs will be consulted to ensure that the work being undertaken will be suitable from a technical perspective, it is the Licencing Authority’s responsibility to write the consent conditions (including in relation to post-consent monitoring) and to ensure that the post-consent monitoring programme is both technically robust whilst also being reasonable and achievable for the developer.

4.3.6. Post-consent monitoring

Once the post-consent monitoring has been completed, the final report is circulated to the Licencing Authority for comment. The Licencing Authority will pass on reports for comment to the SNCBs who act as technical advisors.

The SNCBs are responsible for preparing and maintaining the guidance that is provided to developers. This guidance covers many topics, but typically the focus is on how assessments are conducted, and which tools should be used and how. However, Natural England provides guidance on expectations for PCM, setting out guiding principles and recommendations, which are intended to act as a framework for subsequent discussions at the post-consent phase (Parker et al., 2022d).

However, assessment tools, assessment methods and processes differ across UK administrations. In Scotland, Regional Advisory Groups (RAGs) play an important role in developing post-consent monitoring, and developers are required to participate in RAGs under consent conditions. Monitoring reports are submitted to RAGs for consultation first, and a RAG meeting is held before the final report is submitted to the licencing authority for final sign-off.

4.3.7. Licence Conditions & making data available

Once all comments have been addressed, the report is finalised and discharged as part of the licence conditions. At this point, the report becomes a public document. In England, the MMO (the Licencing Authority) upload the report to their Public Register. However, the SNCBs and the MMO generally do not receive raw data (for example, georeferenced spatial information or ASCII flat files), only the monitoring reports. The Licensing Authority is obliged to ensure that any consent conditions (including PCM) have been discharged, but do not have responsibility (or capacity) to acquire and store raw data. The SNCBs act as technical advisors to the Licensing Authority, and similarly do not have the responsibility to acquire and store data. In Scotland, post-consent monitoring is currently published on Regional Advisory Group websites. Developers have responsibility for uploading data and reports to the Marine Data Exchange (MDE), which is a requirement of the site lease and a process that TCE and CES (for Scotland from 2024 onwards) manage with the developers through regular meetings and engagement. TCE/CES may implement an embargo due for various reasons (e.g. commercial concerns), with release of reporting following an agreed timescale.

4.4. Ornithological monitoring programmes

The section outlines the evolution of PCM and reviews current practice in how PCM is being deployed at different locations across the UK administrations, looking at processes followed and rationale behind particular monitoring choices. The evolution of PCM, and issues raised in this section, are illustrated using site-specific case studies (Sheringham Shoal Offshore Wind Farm and Lincs Offshore Wind Farm).

The need for standardised methods to gather at-sea data on the abundance and distribution of birds to inform UK offshore wind farm (OWF) assessment and subsequent monitoring was recognised at the inception of the industry. In 2004, a review of design of best practice methodologies for both boat-based and aerial surveys was published with an aim to achieving standardised monitoring (Camphuysen et al., 2004). It is notable that some recommendations made within Camphuysen et al. (2004) were not implemented, such as monitoring a wider area six times the size of the wind farm footprint. Thus, from the outset there has been a conflict between what can be practically achieved within the scope of a typical project-level ornithological monitoring programme and what might be considered as desirable coverage from scientific perspective. The focus of the proposed methodologies within the Camphuysen et al. (2004) review was on gathering data '*to understand how such a construction* [an offshore wind farm] *is likely to affect the birds associated with a site*'. Although not explicitly stated, there is the assumption that post-consent monitoring would be a repeat of the baseline surveys. Monitoring was recommended to also include 1-2 reference areas, thereby implying some form of BACI (Before-After-Control-Impact) design was to be used to evaluate the spatio-temporal response of birds to the OWF.

A lack of specific guidance meant that consultations with the regulators and SNCBs determined the relationship between the areas surveyed and even the methods employed during baseline monitoring compared to post-consent monitoring. Continuity across pre- and post- consent monitoring in terms of survey design and data collection aids BACI or BAG (Before-After-Gradient) implementation and analysis, including the ability to detect spatial and temporal changes in seabird distribution and relative abundance. Hindsight indicates a focus of some sites on 'characterisation' surveys geared to EIA and obtaining consent and thus suggestive of a flexible, no-commitment case-specific approach to the nature of post-consent monitoring.

Baseline monitoring was generally intended to be carried out for two years for the purposes of site characterisation and to inform EIA and was thus seen as relatively standard in form. By contrast, post-consent monitoring has always been more variable in terms of duration, depending on the issues raised within EIA. A typical monitoring programme, under a R1/R2 FEPA (Foreign Extortion Protection Act) licence included two years baseline surveys, a year of pre-construction monitoring (typically surveys commenced before construction activities started), 1-2 years of construction monitoring, and 3 years of operational monitoring (this type of monitoring programme was deployed at Thanet (Percival, 2013), Westermost Rough (Percival, 2010) and Gunfleet (Percival, 2013), amongst others). It is not clear whether post-consent pre-construction monitoring was required to provide a baseline prior to construction starting to improve detection of effects, or some survey design parameters may change between the baseline and the post-consent phases of a project. The requirement to monitor for three years once the site became operational was specified within the old FEPA licences. Where construction was delayed, for example, at Sheringham Shoal, monitoring continued with a total of 7 years PCM undertaken. However, the focus of data analysis, especially for birds, has generally been on comparison between pre- and post- construction (i.e. during operation) monitoring.

In some cases, objectives were simply to monitor potential changes in abundance and distribution of birds following wind farm construction, in other cases validation monitoring was required to address issues raised within assessment (Sheringham Shoal). Many early FEPA licences (e.g. Westermost Rough, Thanet) specified that at the end of the monitoring programme, there would be a review to ascertain what future monitoring may be required during the project lifetime. However, there was little guidance around this aspect of PCM and the extent of the developer's responsibility remains unclear.

After the implementation of Round 1 and immediately prior to the launch of Round 3 leasing, Collaborative Offshore Wind Research into the Environment (COWRIE) commissioned a review of monitoring methodologies (Maclean et al., 2009), with the specific objectives of:

1. Assessing whether the earlier recommendations of Camphuysen et al. (2004) had been followed

2. Identifying any differences in interpretation from a review of Environmental Statements for eight Round 1 and 2 sites
3. Testing the use of high-definition cameras during aerial surveys; and
4. Providing more rigorous guidelines on the use of analytical techniques

The use of high-definition cameras rather than visual surveys originally used in surveys in Denmark was subsequently specifically brought to industry attention by Buckland et al. (2012), ultimately leading to what is now commonly known as DAS (Digital Aerial Survey). Maclean et al. (2009) illustrated that the area recommendation for surveys (six times the site footprint) had generally not been followed and by implication that reference areas useful for post-consent monitoring had often not been incorporated. In some cases, this appears to have linked to the practical issues associated with selecting a suitably similar control site (e.g. Ormonde – MMO, 2014), although for others post-consent monitoring included both a BACI and BAG design. In principle, a BAG design lends itself well to the application of density surface modelling techniques (e.g. Mackenzie et al., 2013; Scott-Hayward et al., 2021) to quantify displacement around the site. The site-specific case studies, Sheringham Shoal and Lincs offshore wind farms, which are examples of early monitoring programmes, outline how data and evidence gathered has subsequently been used to inform development of survey and assessment methods.

A key finding of Maclean et al. (2009) was that although the *de facto* recommendation that baseline surveys were to be undertaken over a minimum of two years had been applied, there was considerable variation in survey effort with between 9 and 33 surveys undertaken to support evaluation. Several sites adopted a one-survey-per-month approach, which was subsequently recommended by (Maclean et al., 2009) as an industry standard. Although there is no obvious biological basis underpinning this approach, regular monthly surveys are temporally consistent. Monthly monitoring programmes have largely persisted to the present day (6.2 At-sea survey data).

The concept of covering a much larger area than the site footprint both in pre- and post-consent surveys was effectively incorporated in the current *site and buffer* approach, by which it is assumed that the buffer corresponds to the area over which individuals within a particular species' population demonstrate a response, often implied to be negative, due to the presence of the wind farm. Current Natural England guidance recommends monitoring the site and a 4 km buffer around the array for most species, and a 10 km buffer for divers (Parker et al., 2022a). This differs slightly to NatureScot guidance, which recommends a 6km buffer (for commercial scale developments) on the grounds that this prevents edge effects at 4km when modelling marine bird distribution across a site, but similarly recommends a 10km buffer for divers and sea duck (NatureScot, 2023). NRW guidance is not prescriptive about buffer size but does refer to a 10km buffer for divers (NRW, 2022), loosely based on the response distance demonstrated by red-throated diver *Gavia stellata* (hereafter RTD) in the Greater Wash, Outer Thames Estuary and German North Sea (JNCC, 2022), whereas a 4km buffer has limited empirical support and is included to adopt a precautionary approach (JNCC, 2022).

Although boat-based surveys are no longer typical, bird surveys for offshore wind farms were based on the European Seabirds at Sea methodology. However, improvements in cameras, coupled with plans to build larger sites further offshore led to a change in methods from boat-based surveys to DAS as the principal survey technique. This broadly coincided with improvements in image quality, although some species remain potentially challenging to consistently detect (e.g. storm petrel *Hydrobates pelagicus*) and identify to species level (e.g. terns *Sterninae spp.*). Although NRW and NatureScot guidance still allow for the use of boats, development size, distance from shore, vessel cost and vessel availability now typically constrain their usage. In several cases (at least 5 sites, and possibly more) monitoring methods changed between the pre- and post-consent phases, constraining direct data comparisons of pre- and post-consent monitoring outputs.

A further independent review of PCM was undertaken by the MMO with the intention of reducing burden to industry (MMO, 2014). The MMO issued a formal response to the independent review concluding that PCM for birds had lacked robust monitoring design and rigorous statistical interpretation (MMO, 2020). However, the MMO review was conducted when monitoring programmes for many Round 2 sites were still underway. At the time of the 2014 review, final post-consent monitoring reports were only obtained for 4 sites: North Hoyle, Kentish Flats, Barrow and Lynn and Inner Dowsing.

It is likely that this conclusion was partially prompted by Maclean et al. (2013), a paper which critiqued bird survey methods for offshore wind identifying issues associated with low statistical power and the potential limited ability of monitoring programmes to detect changes in abundance and distribution of highly mobile receptors against high natural levels of variability. Statistical power is increased by increasing survey coverage, frequency and effort, but an increase in coverage also has cost and logistical implications.

The recommendation to carry out power analysis at the design stage has been taken on within guidance in England (Parker et al., 2022a), Scotland and Wales. However, guidance does not specify what level of change the monitoring programme should detect. For abundant species which consistently occur in UK waters all year round, such as common guillemot *Uria aalge*, power to detect change may be reasonable. However, for many other species which occur only during a particular season, or within aggregations, there are acknowledged issues and power to detect change is typically low for particular groups such as gulls. This issue has not been fully resolved, although undertaking regional strategic monitoring provides a means of improving statistical power.

Another key recommendation made by the MMO following the 2014 independent review (MMO, 2020) was to use a Before-After-Gradient (BAG) survey design, adopting density surface modelling approaches to take into account environmental correlates (such as water depth) in order to better evaluate changes in bird densities due to construction and/or operation of the wind farm site, and thereby improving (but again not fully resolving) power to detect change.

4.5. Current practice of post-consent monitoring

Recent Natural England guidance states that PCM for seabirds has moved away from a generic 3-year survey programme towards targeted objective/hypothesis-based monitoring, seeking to address the key uncertainties/evidence gaps identified in the Development Consent Order (DCO) process (Parker et al., 2022d). Although Scotland has its own consenting process (Section 4.5.2), the objective/hypothesis approach to PCM has also been followed in Scotland for R3 sites.

Post-consent monitoring for R3 sites is currently underway, and outputs are not yet available on the MDE. However, IPMPs and Environmental and/or Ornithological Monitoring Programmes were obtained where possible. Since these documents are relatively high-level, the sections below provide a broad indication of current practice.

4.5.1. England

In England, the stated written intention of post-consent ornithological monitoring for offshore wind within guidance is for surveys to adopt standardised DAS-based methods for later comparison with baseline surveys, with the aim being to detect changes in abundance and distribution of target species (Parker et al., 2022d). However, there is now a stated emphasis on setting aims and objectives which will be addressed/tested by the monitoring programme. It is also notable that NE guidance recognises the need for DAS carried out as PCM to encompass areas outside of the buffers used within baseline surveys to detect the limit to the extent of the sea area over which a negative effect on bird density occurs (Parker et al., 2022d).

It also is notable that following updated guidance to allow use of novel techniques, PCM directed towards gathering empirical data on collision impacts is now being requested where relevant, as the lack of empirical data on collision impacts has been long recognised but has been challenging to address within a typical PCM programme (Scottish Renewables 2021; GoBe 2022). Where OWFs have the potential to affect seabird colonies, such as at Hornsea, offshore monitoring to address collision and displacement effects are accompanied by colony monitoring and ringing (GoBe 2022).

Although updates to guidance have been helpful in improving flexibility and enabling future resource to potentially be spent across a more diverse portfolio of monitoring programmes, it is notable that trial of novel technologies (whilst of mutual interest) carries risk, and thus guidance around how that risk is managed by both parties would be advantageous in improving how the delivery phase of PCM works in practice, appreciating the fast moving nature of the regulatory landscape around offshore wind. For example, PCM currently underway at Race Bank (a R2 site) focussed on measuring flight heights using photogrammetry. The efficacy of this method, although originally agreed, has since been questioned, and in this case, adjustments have been made to carry out LiDAR surveys in subsequent years (APEM 2018). However, negotiations have clearly delayed the outputs from PCM, with the current year 1 report taking 4 years and going through 6 versions before becoming available on the MDE.

4.5.2. Scotland

Within Scotland, processes differ, and it was a consent condition for offshore of the section 36 consent and marine licence conditions for wind farm developers to form regional advisory groups. However, this process essentially formalised pre-existing developer groups, which had been collaboratively funding mutually beneficial monitoring in the Moray Firth and the Firth of Forth for around a decade prior to consent.

Within the Firth of Forth, PCM is being deployed strategically between Seagreen, Neart na Gaoithe (NNG), Inchcape, and Berwick Bank in the form of a regional DAS programme, which was undertaken as part of baseline data acquisition, with the same survey design being deployed within the post-consent phase to monitor potential barrier and displacement effects. Tagging is also being jointly funded, as well as a camera and radar study at Neart na Gaoithe. Colony-based monitoring programmes are also supported. Developers have been given common objectives by the Marine Directorate to address within strategic monitoring, but alongside these, developers are also addressing project-specific concerns within their PCM (NNG, 2020; Seagreen Wind Energy, 2019).

In Scotland, the Scottish Marine Energy Research (ScotMER) programme (funded by Scottish Government) strategically addresses evidence gaps relating to marine renewable energy. Thus, ScotMER provides an additional mechanism for answering some of the questions around validation of EIA predictions and realised effects of OWFs which often form the focus of PCM objectives.

4.5.3. Wales

Three Welsh sites were developed in R1/R2 (Gwynt-y-Mor, Ryl Flats and North Hoyle). More recently Awel y Mor, an extension to Gwynt y Mor has been awarded consent, with the focus of PCM directed towards monitoring displacement of red-throated diver (RTD) using buffers reflective of those used within the EIA (Awel y Mor Offshore Wind Farm, 2023).

Although within Round 3, sites were planned within the Bristol Channel and the Irish Sea, development of both zones was abandoned. The Mona and Morgan offshore wind farm sites were leased within Welsh waters during Round 4; however, they are not yet consented and currently plans for PCM are currently unclear.

There are a number of small-scale floating offshore wind farm demonstrator projects planned within Welsh waters, with the aim of providing stepping stones towards large scale commercial deployment of floating offshore wind within the Celtic Sea in Round 5. Of these, only Erebus currently has consent. However, although the Outline Environmental Monitoring plan for Erebus states that monitoring offshore will focus on potential collisions, collision avoidance, flight heights, and attraction to floating platforms, alongside monitoring survival and productivity at local breeding colonies, detail on methods is not included (MarineSpace, 2022).

4.5.4. Summary

Post-consent monitoring for offshore wind farms in the UK now typically involves (where relevant) monitoring at colonies, and monitoring using multiple methods, including use of multisensor systems to gather empirical evidence on collision impacts. There is also a movement towards expanding the scale of DAS programmes within the post-consent phase. There is little information available within the public domain on timescales of PCM programmes in planning, although this should (in principle) be linked to the outputs of power analysis conducted to underpin the design of baseline surveys. The statistical power of a monitoring programme to detect change is based on spatial and temporal coverage. This concept is recognised within Natural England guidance (Parker et al., 2022d), which states: *"The number and spacing of the years in which such surveys should be conducted during the lifetime of a wind farm should be discussed with Natural England and subject to adaptive management as required."* There is a clear need for a more structured process to manage PCM processes, particularly where monitoring conducted over long-timescales may be needed to provide a scientifically robust answer to a particular objective.

4.6. Discharge of PCM outputs and data availability

The Office for Environmental Protection has recently made recommendations to government to take action to ensure that post-decision monitoring evaluations are nationally accessible and for local planning authorities to provide evaluation reports annually (OEP, 2023). Whilst the government have set out measures to strengthen monitoring and evaluation through implementation of the Environmental Outcomes Reports (EOR) regime, which would provide annual consolidated information on how plans are delivering environmental outcomes, they have (at the time of writing) rejected the recommendation to make post-consent monitoring evaluations nationally accessible.

The time taken for projects to obtain consent, and complete operational monitoring is clear from Section 4.4. Understanding that it is the intention for all data to be made available on MDE (from 2024 onwards for Scotland), a search was undertaken to find out how much PCM data were available. Based on the assumption that of sites commissioned pre-2019 (n=26), and assuming 3 years of operational PCM, it was anticipated that up to 78 PCM reports would be uploaded onto the MDE.

From searches carried out 17 June 2024, using searches for 'birds' within the theme, 'post-construction' within the period, and 'wind' within the development type, 20 entries were available from 10 sites suggesting either a lag in uploading to the MDE or PCM has not been discharged for the other 16 sites or a combination of both factors (acknowledging that data are continually being added to the MDE so further records may be available in future; searching with different filters may yield more records; and selecting different filters may changes results.) The outputs of this search (Table 3) appeared incomplete so a further search was undertaken to establish whether additional data could be located by searching for either a year 3 final report and/or 3 years of monitoring data, and also to assess whether raw data had been uploaded or just a report. It is acknowledged that a thorough review of documentation relating to each site would inform a more detailed understanding of the scope of each survey programme and specific conclusions around what deliverables were available and missing – the process undertaken here was to inform where there may be breaks in the chain rather than to make a detailed review of the information available for each site. Figure 2 provides a high-level summary of data available on the MDE for sites commissioned pre-2019 in England.

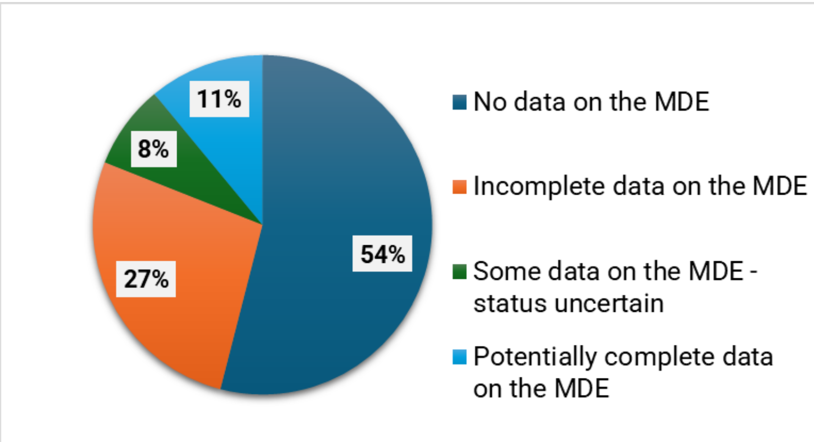

Figure 2. Status of PCM outputs available on MDE for offshore wind farm sites in English waters commissioned before 2019

Table 3. Ornithology PCM data available on MDE based on searches carried out 17 June 2024

Development site	Series Name	Data type(s) available	Status & rationale for classification
Burbo Bank	2008-2009, Centre for Marine and Coastal Studies Ltd., (CMACS), Burbo Bank Offshore Wind Farm, Post-construction (Year 2) Ornithological Monitoring	Report	Incomplete – no year 3 report
Greater Gabbard	2011, ESS Ecology, Greater Gabbard Offshore Wind Farm, Vantage Point Bird Surveys	Maps only (VP surveys)	Incomplete – 1 year only
Gunfleet Sands 1 and 2	2007-2008, RPS, Gunfleet Sands Offshore Wind Farm, Ornithological Monitoring	Report, Raw data (boat-based and aerial survey)	3 years of information uploaded - possibly complete - not clear on survey requirements for original site & extension
Gunfleet Sands 1 and 2	2010-2011, NIRAS Consulting Ltd., Gunfleet Sands Offshore Wind Farm, Year 1 Post-construction Ornithological Monitoring	Raw data (10 x Boat-based surveys), report	As above
Gunfleet Sands 1 and 2	2011-2013, NIRAS Consulting Ltd., Gunfleet Sands 1 and 2, Years 2 and 3 Post-Construction Ornithological Monitoring	Y2 and Y3 report, but only 1 x year of raw data present?	As above
Humber Gateway	2015, Animal and Plant Health Agency (APHA), Humber Gateway, Pink-footed Goose Radar Survey	Report & radar data files	Incomplete – 1 year only
Kentish Flats	2014, Jon Ford Environmental Consulting, Kentish Flats, Bird Survey	6 surveys only - raw data and accompanying summary for each survey	Status uncertain – several years of data and reports uploaded, but unclear if represents whole programme for both original site & extension
Kentish Flats	2008-2009, Ecology Consulting, Kentish Flats, Review of Monitoring of Red Throated Divers	Report only, no raw data	As above
Kentish Flats Extension	2015-2016, Jon Ford Environmental Consultancy, Kentish Flats Extension, Ornithological Survey Annual Report	Year 1 Post-construction report, no raw data	As above
London Array	2012-2013, APEM, London Array, Ornithological Aerial Survey	Report only, no raw data	Incomplete – 1 year only
Lynn and Inner Dowsing	2012, Centrica Energy, Lynn and Inner Dowsing, Environmental Monitoring Report	Raw data from 4 x aerial surveys, report and response to MMO comments.	Incomplete – 1 year only
Ormonde	2014, WWT Consulting, Ormonde Offshore Wind Farm, Weekly Peak Counts of Pink-footed Geese and Whooper Swans at WWT Martin Mere	4 x counts of geese and swans at Martin Mere, data and summary report	Status uncertain – several reports uploaded but unclear on whether complete
Ormonde	2014, Aarhus University, Ormonde Offshore Wind Farm, Ornithological Surveys	Report only, no raw data	See above
Ormonde	2013, WWT Consulting, Ormonde Offshore Wind Farm, Weekly Peak Counts of Pink-footed Geese and Whooper Swans at WWT Martin Mere	Report, 3 surveys of Swan & Goose Counts from Martin Mere, master database	See above
Ormonde	2013, CMACS Ltd., Ormonde Offshore Wind Farm, Boat-based Ornithological Monitoring	Reports and raw data from the ornithological boat-based surveys conducted in May, July, August and September 2013	See above

Development site	Series Name	Data type(s) available	Status & rationale for classification
Scroby Sands	2002-2006, ECON, Scroby Sands Offshore Wind Farm, Ornithological Monitoring, Assessing the potential impact of the proposed wind farm upon Little tern (*Sterna albifrons*)	Final monitoring report and appendices	Final report uploaded
Scroby Sands	2013 Natural England Scroby Sands Little tern use of Scroby Sands Offshore Wind Farm	Report only, no raw data	Final report uploaded
Thanet	2010-2013, Royal Haskoning DHV, Thanet Offshore Wind Farm, Ornithological Monitoring	Year 1, 2 and 3 of post-consent monitoring reports, no raw data	3 years of information uploaded – considered as complete
Thanet	2004-2013, Royal Haskoning, Thanet Offshore Wind Farm, Pre-construction, Construction and Post-Construction Ornithological Monitoring	Year 1 monitoring report, 10 x aerial surveys, 11 x boat-based surveys	3 years of information uploaded – considered as complete
Race Bank	2018, APEM, Race Bank Offshore Wind Farm, Post-Construction Year 1 Ornithological Report	Year 1 monitoring report, no raw data	Incomplete – single year only

Appreciating that more than half of sites appeared not have had data uploaded data to the MDE, and in view of the comparatively small number of Round 2 sites represented within Table 3, a search of the MMO Public Register was undertaken to identify whether most sites commissioned before 2019 had discharged their monitoring conditions.

A search for seven Round 2 sites was undertaken using the MMO Public Register. These sites were chosen because the authors had the casework numbers and information was straightforward to locate. Of these seven sites, the files for five had been closed in 2018, indicating that discharge of consent conditions was complete. One file had been closed earlier, in 2017, and the other in 2021. Therefore, it would be expected that data from virtually all Round 2 sites should be on the MDE, although it is possible that closure of multiple cases in 2018 may have resulted in an MDE backlog, and that this information will be uploaded soon.

In two cases, although files were closed in 2018, recent documents were still being uploaded. For example, at Sheringham Shoal (which became operational in 2011), there is a letter from the MMO dated April 2023 confirming receipt of 2020 benthic monitoring and discharge of the relevant licence condition (the letter dating from after the case was closed). Similarly, at Thanet, the case was closed in 2018, but documents have continued to be uploaded following file closure (the COVID-19 pandemic is also a factor affecting delay during this time). There are many reasons why this may be the case, for example when draft documents have been supplied that satisfy consent conditions, but final documents follow later. Equally there may be a need to conduct monitoring later in the project life cycle as a part of the monitoring plan leading to extended sign-off timescales. When consent conditions are discharged reports officially become public.

To understand the time lag between discharge of consent conditions from the MMO and upload of data to the MDE, an identical MDE search was repeated on Wednesday 26 February 2025 (around 8 months later). An additional nine entries had been added over eight months, all of which related to Round 1 and 2 sites, with end-of-monitoring dates ranging from 2007-2018. (Although it was not possible to establish when all cases were closed from the MMO Public Register, of the four sites where this information could be found, case closure dates ranged from 2014 to 2021). Six entries were additional files relating to sites already represented on the MDE, whilst three entries were related to sites which had not previously had any ornithological PCM data on the MDE.

The new sites were Sheringham Shoal, Lincs, Westermost Rough and West of Duddon Sands. For all sites, upload of data and reporting was incomplete, although Sheringham Shoal had a final monitoring report (according to the criteria set out in Table 3could be considered as 'complete' as information from all years monitoring is included) but raw data files were not present. Lincs had a final monitoring report, but raw data only for one of the three years of survey. Westermost Rough had reporting from all years, but no final monitoring report (which would typically involve data comparisons to test for any potential changes in abundance and distributions of seabirds) and raw data from the last year of monitoring was missing. West of Duddon Sands had only one report from a single year of the three post-consent monitoring years and no raw data.

Additional data had been uploaded for London Array, Lynn and Inner Dowsing, and Kentish Flats extension. Data for London Array is still incomplete (2 monitoring reports, no raw data), data for Lynn and Inner Dowsing consisted of two reports only (no raw data), and data for Kentish Flats consisted of two years monitoring reports (including a final report), but only one year of raw data. Whilst it is reassuring that ornithological PCM is being uploaded and becoming available, indicating that there is a significant time lag between sign-off at MMO and upload to MDE, it remains concerning that upload of information is incomplete.

Scottish PCM data are currently stored on RAG websites. A search was undertaken to locate this information. Post-consent monitoring for Robin Rigg (all reports but no raw data) was found on the Marine Directorate Licencing and Operations Team website (Robin Rigg monitoring). Robin Rigg is the only Round 1 site in Scotland, all Round 2 and 3 sites are either in the Moray Firth or the Firth of Forth. Post-consent monitoring data is not yet available for any of the ScotWind or INTOG sites. Post-consent ornithological monitoring (reports only) for sites in the Firth of Forth are uploaded onto the FTRAG website (Forth & Tay Regional Advisory Group (FTRAG) | marine.gov.scot) and for the Moray Firth are uploaded onto the MFRAG website (Moray Firth Regional Advisory Group (MFRAG) | marine.gov.scot). On the MFRAG website it was possible to find ornithological PCM reports for Moray East (pre-construction 2018) and Beatrice (Year 1 and Year 2). On the FTRAG website a pre-consent PCM ornithology report was found for Neart na Gaoithe, and ornithology meeting minutes and reports covering jointly funded GPS tracking were also available.

Although the searches of the licencing and operations website were carried out for Hywind (Hywind Scotland Pilot Park | marine.gov.scot), Kincardine (Index of /datafiles/lot/KOWL), and Aberdeen Bay (https://marine.gov.scot/datafiles/lot/EOWDC/), ornithological post-consent monitoring was not found (However, the Bird Collision Avoidance Study carried out in the post-consent period at Aberdeen Bay is available here: AOWFL-Aberdeen Seabird Study). A further search was undertaken on the LOT website (All application and project documentation | marine.gov.scot) filtering by document type to look for monitoring reports, but no further ornithological monitoring could be found (although various reports for other receptors, environmental management plans and other relevant documentation was available).

4.7. Transferrable learning from other countries

The distinct nature of the impact pathways associated with offshore wind makes it relatively unique compared to other offshore industries (e.g. aggregates, oil and gas) and largely prevents direct transfer of experiences from these industries. The position of the UK, as both a world leader in relation to OW and with many globally important seabird colonies, also constrain the opportunities to transfer experiences from OW in other countries to the UK context. However, the potential to transfer learnings from OW from other countries was addressed by looking for international examples of project case work where the learning derived from PCM had been transferred both back into the project (e.g. to inform mitigation; single loop learning) and into a wider knowledge base of institutional learning (e.g. to improve the assessment process; double loop learning). Monitoring and adaptive management provides a systematic process intended to improve policies and practice through both single and double loop learning (Copping et al., 2019). Adaptive management can be used to monitor impacts and adjust mitigation and compensation at a project scale (single loop learning). If similar types of studies are repeated multiple times, the knowledge base around empirical impacts can be improved and assessment systems can (over time) be updated to be less precautionary (double loop learning). We evaluate the extent to which the approaches adopted in other countries have allowed both forms of learning from PCM to occur, focusing on countries were OW development is most established and where there is greatest potential for transferability to the UK context. In Denmark and Germany, early OWFs (e.g. Horn's Reef and Alpha Ventus), were accompanied by long-term research projects to better understand their environmental effects, with a view to providing information to inform both mitigation and future development. In both countries, site selection is undertaken by government organisations (the Danish Energy Agency (DEA) and the Bundesamt für Seeschifffahrt und Hydrographie (or the Federal Maritime and Hydrographic Agency), through marine spatial planning exercises. Denmark is now moving away from this system to allow developers greater autonomy in deciding when and how to deploy wind turbines and whether to allocate energy as electricity or hydrogen. Denmark is also pioneering the concept of energy islands, which will serve as hubs for multiple offshore wind farms and connect to several countries' electricity grid. Government policy generally drives how marine space is used along with the trade-off between biodiversity conservation and renewable energy development. For example, Germany's inshore waters are a Nature Conservation Area, forming part of the Wadden Sea World Heritage site, which also extends into Dutch and Danish waters. The Wadden Sea Plan states the that no wind turbines shall be erected in the Nature Conservation Area (Common Wadden Sea Secretariat, 2010). Furthermore, the plan also specifies that wind turbines outside the Conservation Area should only be developed if important ecological and landscape values are not negatively affected. For this reason, offshore wind farm development in Germany is typically greater that 40km offshore, with some sites extending 120km offshore. Amongst European countries different approaches are taken in relation to location of wind farms in protected areas, with some being more stringent than others.

At both Alpha Ventus and Horn's Reef, early monitoring programmes were high profile with outputs published and disseminated widely within Europe. At Horn's Reef, visual aerial survey showed displacement of RTDs and common scoter *Melanitta nigra* amongst other species (Petersen et al., 2006; Scott-Hayward et al., 2024). These findings were reinforced through PCM at Horn's Reef 2 (a second extension site) (Petersen et al., 2014). In spite of displacement effects, which were largely viewed as favourable at the time due to reduced collision risk, a third extension was also constructed. Early indications are that there is little to no displacement found at the site of the third extension (larger and more widely spaced turbines than the first and second OWF) and that while site 2 continues to show a displacement effect for diver species, this is much reduced for common scoter (Scott-Hayward et al., 2024).

At Alpha Ventus ornithological monitoring focussed on the migration period (due to its location) and monitored evasive movements of birds using fixed pencil beam radar and assessment of collision risk of migratory birds using the Visual Automatic Recording System (VARS) camera system (BSH & BMU, 2014). This work on migration has been continued by the Dutch Governmental Offshore Wind Ecological (WOZEP) programme, which funds research which targets specific ecological evidence gaps and areas of uncertainty, with a view to filling these prior to the next round of development. Within the Dutch system, each offshore wind farm has a monitoring and adaptive management plan, with the outputs strategically designed to inform institutional learning and decrease constraints for future development rounds. Research carried out under WOZEP at Luchterduinen OWF on migratory birds showed that there was a regular peak of activity during the autumn period, where birds passed through the wind farm, a reasonable proportion of which were at potential collision risk height (Leemans et al., 2022). The results of this work were then used to design a method for detecting this mass migration movement to inform the timing of a temporary shut-down, which functioned as collision mitigation. Similar mitigation is now being applied to other developments in the same region, including projects in construction and in planning, demonstrating how outputs have been fed into double loop learning[5].

[5] See: Dutch offshore wind farms shut down to allow bird migration

Relevant examples of learning from PCM outside the context of European OSW are more limited but do exist. For example, in New et al. (2015), PCM searching for Golden Eagle carcasses ultimately enabled compensatory requirements to be reduced at a US onshore wind farm site.

5. Semi-structured interviews

The interviews serve to understand and conceptualise the problem, and begin to understand the barriers of processes, policy, and data issues that prevent PCM data being properly used within the consenting process.

To understand the procedural barriers to closing the loop, our study adopted a qualitative research approach, seeking depth of insight about internal processes within stakeholder organisations by undertaking semi-structured research interviews with key stakeholder organisations in the UK offshore wind consenting sector. The aim of these interviews was to engage with stakeholders to understand their current processes and practices for using post-consent monitoring data and discuss opportunities for overcoming challenges about the availability of data. Interviews are widely used in social science to enable in-depth discussion around a particular topic, (Knott et al., 2022) and are useful for gaining insight from experts (Döringer, 2021**).** Semi-structured interviews are developed with a set of open questions around key topics, while allowing space for the conversation to develop in different directions, and to ask follow-up questions. The **Closing the Loop – Summary report of stakeholder interviews (D04a)** for this project contains the full details of the approach, results and outcomes from the interviews. Here, we have included a summary of the research approach and executive summary for completeness.

There is a recognised need to 'close the loop' and make better use of post-consent monitoring (PCM) reporting and data to improve assessment processes for offshore windfarm consenting, both in terms of cumulative impact and future project-based assessments. This report presents findings from semi-structured interviews with ten stakeholder organisations (a total of 15 interview participants) undertaken from July-September 2024. The aim of the interviews was to understand some of the **procedural and policy barriers** to closing the loop within organisations involved in the consenting process (in setting requirements for data collection, managing data, and reviewing assessments), and consider ways to overcome those barriers.

The findings of our study are presented in terms of **procedural issues**, which includes issues relating to policy, governance, and organisational practices; and issues more directly relating to **data management and data management frameworks**. Our research identified a range of challenges in accessing PCM reporting and data, and in making use of such data for improving the understanding of the marine environment and improving assessment processes. A key challenge is in the transition from **data to evidence to guidance**, a complex process that involves many layers of expertise and resource need, and draws on multiple evidence sources, not just PCM data. While many of the challenges to using PCM reporting and data (for reasons other than fulfilling licencing or leasing requirements) are long-standing, our study also identified opportunities to improve procedures and practices facilitate better access to such data.

5.1. Overview of methodology

Our research questions focused on the policies and practices about PCM data within regulatory and advisory organisations, and our interviewee sample was identified through a purposive sampling approach in conjunction with the Carbon Trust/ORJIP project steering group. Through this approach, potential interviewees were approached according to their roles and responsibilities within relevant organisations in relation to PCM data. Interviewees included representatives of oversight managers, regulatory bodies, and SNCBs from across the different UK administrations, along with one consultant and one industry representative. In total, ten organisations were represented in the interview sample, with one or two people representing each organisation (fifteen interviewees in total). Questions focused around current policies and processes around post-consent monitoring data within organisations, particularly relating to how PCM data is used to feed back into advice for future environmental assessments.

Interviews were undertaken online using MS Teams from July-September 2024, and lasted around an hour (mean interview length: 62 mins 21 seconds). Recordings were then professionally transcribed, providing a total of 174 pages of transcription data. These data were then analysed thematically using Lumivero's NVivo 12 software package (a qualitative data analysis software package) as a tool to support the analysis. The data were coded using a process of data reduction, coding and analysis (Halperin & Heath, 2020), using a coding frame developed both deductively (analysing the data against pre-determined codes, including 'policies', 'processes', 'data availability' etc) and inductively (where additional topics are identified during the interview analysis, with examples in this study including 'resource need', 'solutions' and 'data-to-evidence gap'). The data were systematically analysed against this coding frame, and then the content of each code was subsequently reviewed for consistency.

6. Seabird case study

6.1. Introduction

Cumulative impact assessment in seabirds has been identified as a key area that is causing delay and uncertainty in the consenting process, and post-consent monitoring data on seabirds are frequently required to be collected as part of license conditions. The case study element allows us to set out in depth the potential for learning from ornithological post-consent monitoring data feed through into the assessment process, and to evaluate the technical challenges associated with doing this.

Post-consent monitoring data have the potential to improve cumulative assessments through the direct estimates of windfarm-related effects at monitored projects. PCM data can also provide information relevant to assessment tool inputs, allowing updated estimates of the likely impact of the monitored projects, and validating assumptions that underpinned the original assessment. Post-consent monitoring data also have potential to improve future project-based assessments through using information that has been synthesised across projects (e.g. as a basis for updating SNCB guidance around assessments). PCM can be used to inform decisions regarding mitigation and compensation of the monitored project within the context of adaptive management as well as to inform and improve assessments. In this project, the latter aim is the focus.

In Sections 6.2-6.5 we summarise the differing forms of PCM data that are collected, or may plausibly be collected in future, the approaches taken to analysing these data, the outputs from analyses of PCM data, and the information that can be obtained from these outputs. Summarising and elaborating on the review, we will consider the nature of data that have been historically or are currently collected as part of PCM data, and opportunities and challenges around the analysis, interpretation and use of these data. We outline the collection, analysis and use of at-sea survey data (both DAS and boat-based surveys, Section

6.2), bird-based telemetry data (Section 6.3) and site-specific case studies (Section 6.4), since these represent key forms of data have been used or are being used in the context of PCM, before briefly considering the potential for alternative forms of data collection (Section 6.5). In Section 6.4, we focus on two specific site-level case studies (Sheringham Shoal and Lincs offshore wind farms). Throughout Sections 6.2-6.5 we identify key statistical, technical and scientific challenges, including the need for meta/pooled analyses to combine information across projects; use of data integration to account for differing survey methodologies; requirement for transferability to be evaluated across time, space, and species; and the requirement to link any proposed solutions to these challenges with the processes for developing SNCB guidance. In Section 6.6 we outline the potential for post-consent monitoring data, collected as part of licensing requirements and analysed using the approaches described above, to be better used to inform cumulative assessments and future project-level assessments, and the mechanisms required to overcome barriers to delivering this. Potential challenges around the use of PCM data to inform assessments include accounting for inherent variability (especially inter-annual) and external shocks, lack of direct information on mortality of birds observed within the surveys, and the fact that avoidance rates used in collision risk models can also be used to account for model mis-specification, and we will consider the scientific and statistical potential for resolving these challenges.

6.2. At-sea survey data

Visual boat/aerial and digital aerial surveys (whichever we collectively refer to as 'at-sea survey data') have long been used to gain an understanding of at-sea distributions of seabirds. At-sea survey data can provide information on the form, magnitude and spatial scale of redistribution. This has potential to provide information on rates and spatial scales of displacement and avoidance, and thereby on displacement and collision mortality. In this section we review the scientific and statistical opportunities and challenges associated with collecting and analysing at-sea survey data.

Prior to consent, these surveys enable the characterisation of baseline spatial distributions via estimation of the overall species-specific abundance and geo-referenced estimates of their locations. In addition, with regular surveying it is possible to understand how variable these distributions are over time, and how the underlying abundances might have changed. At-sea surveys are frequently required for PCM (Section 4.4). These surveys, combined with correction for imperfect detection (e.g. declining detection with distance on visual surveys), can then be subject to (spatial model based) analysis methods which deliver evidence-based estimates of spatial distributions with uncertainty, and estimates of changes in these distributions over time (e.g., for example, between pre-construction and post-construction periods). Frequentist and Bayesian are two inferential approaches that differ in how they interpret uncertainty and probability. Therefore, methods that are used for spatial analysis are either frequentist Generalised Additive Model (GAM) based (e.g. implemented using `R` packages such as `MRSea`/`mgcv`/`dsm`) or Bayesian and GAM based, which allows for non-linear relationships between the response and covariates (e.g. implemented using `R` packages `inlabru`/`mgcv`) (MacKenzie et al., 2013; Scott-Hayward et al., 2021; Wood, 2017; Bachl et al., 2019). The `mgcv` package is capable of both frequentist and Bayesian outputs depending on the implementation. Typically, the methods chosen for analysis need to account for, or accommodate, characteristics routinely seen in data of this kind (e.g. overdispersion, zero inflation or spatial and temporal residual correlation) and be equipped to reflect the uncertainty in the geo-referenced estimates and propagate these uncertainties through the various stages of analysis (e.g. combining distance and spatial modelling analyses). The `R` packages mentioned above can all accommodate these data characteristics given appropriate implementation and inspection of relevant diagnostics.

The `MRSea` R package (Mackenzie et al., 2013; Scott-Hayward et al., 2021) was explicitly designed to infer spatial redistribution as a result of OWFs via spatial modelling, and has been used in the consenting process for a number of UK based OWFs (e.g. Lincs, Lyn and Inner Dowsing, Burbobank, Hornsea 3 and 4, Humber Gateway, Robin Rigg, Liverpool Bay and Moray West) and in the assessment of long-term impacts of five Danish OWFs (e.g. Petersen et al., 2018).

The outputs of the spatial distribution models (including uncertainty) may also be post-processed to provide additional information, for example, to quantify distributional persistence, scenario planning and power analyses. Post-processing is the method of taking modelling outputs (e.g. predictions and bootstrap predictions) and manipulating them to make comparisons between units of interest or infer future scenarios. For example, let us say you have 20 surveys, 10 before construction and 10 after construction, and each survey is modelled separately. We may wish to know the mean distribution in the two phases and assess any differences. This can be achieved by grouping the predictions (and bootstraps) for each phase and combining associated uncertainty.

Distributional persistence allows the reader to get a measure of intra/inter-annual variability across multiple surveys. For example, there may be areas of consistent usage, despite survey-to-survey variability, which can provide context to the ability to detect post-construction changes (e.g. Petersen et al., 2022, Scott-Hayward et al., 2024).

In contrast, scenario planning is the process of imposing a known change to the baseline distribution (e.g. a 50% decline in abundance in a proposed footprint with linear return to normal over 5km) to determine number of birds potentially displaced if the distribution were to remain stable (e.g. Petersen et al., 2022). The details of the scenarios need to be considered carefully but are typically based on existing literature on observed displacement rates for individual species. These scenarios then provide information which helps determine if mitigation or compensation might be required and if so, what the levels of mitigation/compensation might need to be.

Spatially explicit power analysis takes the scenario planning phase a step further and quantifies, subject to specific (and verifiable) assumptions, whether current or future surveying regimes have the power to detect the change imposed. Or, alternatively, if a change does exist, the nature and magnitude of any changes which are able to be detected (e.g. changes in abundance and/or distribution) given a particular survey design. The `R` package `MRSeaPower` was developed to implement such a process where the key component is simulating data with the same characteristics as the original (Mackenzie et al., 2017).

Post-consent/post-construction surveys can be analysed using the same software as for baseline surveys. Once the spatial models are estimated, like before, post processing of the outputs enables the estimation of spatially explicit change by grouping data into phases (e.g. baseline, post-consent but pre-construction, during construction, post-construction). This modelling approach and assessment of spatially explicit differences allows the assessment of displacement/barrier effects (spatially and in reference to distance from footprint) even in the presence of interannual variation. With no wind-farm specific terms in the model, the post-modelling outputs are agnostic to wind farm location allowing non-uniform displacement effects to be detected (Petersen et al., 2014, 2018). An alternative that is commonly used is to include a variety of wind farm related terms in the model (e.g. distance to footprint, in/out wind farm zone etc) and assess significance/relationships for these terms (e.g. Peschko et al., 2020a; Garthe et al., 2023). However, these terms assume a consistency to the effect: that the 'impact' is the same in all directions from the footprint, which might be unrealistic. For instance, it is plausible that if the wind farm acts as a barrier for a species, its abundance may increase on one side and decrease on the other leading to a 'flattening' of this relationship and a non-significant distance to footprint term. It is therefore wise to ensure that effects are considered both as a univariate function (e.g. a function of abundance changes relative to distance from footprint) and spatially (e.g. a map of spatially explicit differences) (Peschko et al., 2020a; Petersen et al., 2014; Scott-Hayward et al., 2024). Scott-Hayward et al. (2024) showed evidence that the displacement of common scoter, when assessed in concentric rings from the footprint of the Horn's Reef II windfarm, was approximately 4.5-6 km. However, when assessed in three sectors (north-east, south-east and west) the displacement ranges varied between 2-5km in the north-east and 6-7km in the west. In contrast, analysis of Diver species in the same area shows a more consistent effect, which was very similar in all directions (Section 4.4). Trinder et al. (2024) recently developed a method for quantifying assessing the distribution of seabirds at different distances from turbine locations. This method also accounts for the large interannual variation shown in seabird distribution and abundance using a gradient-based approach to aggregate counts of seabirds that are separated by behaviour. Simulations are based on randomising the location of individual turbines, and data are analysed in a BACI design. In this study, survey transects were placed over turbines and along corridors between turbine arrays. Therefore, this survey design requires data where transects fly directly over a sufficient number of turbines.

Comparisons between periods (e.g. post-construction and baseline) can give an indication of the form, magnitude and spatial scale of displacement and avoidance. This potentially provides evidence around the effectiveness of mitigation and compensation measures that may inform adaptive management at the same wind farm but can also provide evidence that can feed back into future wind farm assessments.

The survey area around each potential development footprint is also crucial since it needs to be sufficiently large to detect effects as well as ensuring that there are enough non-wind farm related areas to reflect background conditions (i.e. non-wind farm related changes in abundance). To capture this the survey area needs to contain the footprint, the surrounding "buffer" around the footprint from which displacement is also assumed to occur, and areas beyond this. Additionally, if the survey area covered is large enough to encompass areas of future wind farm construction, the outputs may also be used to empirically estimate the cumulative effects of multiple wind farms (Scott-Hayward et al., 2024; Peschko et al., 2020a; Garthe et al., 2023). In contrast, surveys with limited spatial extent are one of the challenges of project-based surveying schemes, since these can make it difficult to encompass displacement/barrier effects and to assess cumulative impacts from multiple wind farms (Ryan et al., 2019; Lamb et al., 2024; Garthe et al., 2023).

In addition to good spatial coverage, temporal coverage is also a key consideration. In some development areas, there may be non-PCM surveys (e.g. surveys conducted as part of research projects or publicly funded long-term monitoring programmes) undertaken at a different temporal resolution to PCM (e.g. annually rather than twice monthly for two years), which may limit assessment to a particular season (e.g. breeding vs non-breeding) but provide valuable information, nonetheless (e.g. because they cover a wider spatial area), so there is value in integrating information from PCM with that from other spatial surveys within analyses. In contrast, longer temporal periods for surveying enables inter annual (yearly) and intra-annual (within year, including breeding or migration) variation to be understood and external shocks accommodated. However, care is needed when analysing data collected across the annual cycle: a recent study by Lamb et al. (2024) showed that studies based on analysing data pooled across the annual cycle were less likely to detect changes than studies focusing on either breeding or non-breeding seasons. Additionally, Peschko et al., (2020a) were able to show species specific effects of wind farms between breeding and non-breeding seasons.

Survey periods which cover a longer time series post consent may allow longer-term habituation to be identified (e.g. Petersen et al., 2014, 2018; Scott-Hayward et al., 2024). For example, there may be a short-term negative impact but longer-term habituation or return to 'normal' usage of the wind farm area. Furthermore, in the very long term (e.g. an operational window of approximately 20 years), these sites will undergo additional changes from decommissioning or re-powering. For example, the Horn's Reef I wind farm site in Denmark, which has been surveyed repeatedly over the last 24 years, is now approaching the end of operation and with continued surveying it may be possible to assess impacts from the next stage; decommissioning or re-powering.

External shocks are factors or stressors on the population that are not wind farm related but may affect the abundance and distribution of birds. For example, the recent avian flu outbreak, which dramatically, but temporarily, increased the mortality rate for many marine birds (e.g. Tremlett et al., 2024 or marine heatwaves which can increase mortality directly (heat stress) or indirectly with the disruption of food webs leading to changing distribution patterns or mortality (Piatt et al., 2024). These shocks are part of the interannual variability seen in seabird abundance and distribution so it is important to understand their effect on populations so that they may be separated from wind farm related effects. If the response to shocks is decreasing abundances, then to tease apart effects of shocks and windfarms increasing spatial and temporal coverage are likely to be required. Fortunately, power analysis can be used to assess if large scale decreases alongside finer scale wind farm associated distributional changes can be detected using existing survey regimes, under a set of specified conditions (Nowacek et al., 2024). It is also likely that information on changing distributions of food sources (e.g. benthic or fish surveys) might help explain some changes in bird distribution and therefore help to separate shock effects and wind farm effects , which is the core research theme of the OWEC Predators and Prey Around Renewable Energy Developments (PrePARED) project.

It is important to note that the effect of wind farms on different species is not necessarily consistent across all wind farms which leads to uncertainty in parameters relating to the magnitude and spatial scale of displacement (Lamb et al., 2024). This could be due to environmental conditions or population level differences however it is also possible that it is due to differences in wind farm characteristics. Newer wind farms tend to have fewer turbines with larger spacings over larger footprints and geographically in deeper waters and further offshore. For example, Scott-Hayward et al. (2024) found significant impacts of the construction of the Horn's Reef II wind farm but there was no significant detectable change post construction of the Horn's Reef III wind farm, which has much larger and wider, more irregularly spaced turbines. This highlights the importance of considering windfarm characteristics (e.g. spacing and size) when results are being transferred to an area with different windfarm characteristics.

In addition to the potential for variable responses to different wind farm characteristics, Lamb et al. (2024) also found that there was a confounding effect of the advancement of wind technology (e.g. increasing turbine numbers, wider spacings, further offshore) with improvements in survey design (e.g. larger survey areas). So, it is unclear whether effects detected more recently are due to larger survey areas and/or more distant control sites, which tended to contribute to a higher likelihood of detecting distributional changes, or changes in wind farm characteristics.

Distribution maps from at-sea survey data are typically used to quantify displacement and avoidance within the assessment process. However, driven by sector requirements to inform plan-level assessment and sectoral marine plans within the marine planning process, maps are also used as a starting point for IBMs, either as utilisation or distribution maps, and a key input to sensitivity/risk mapping (e.g. Bradbury et al., 2014; Certain et al., 2015). Other data types such as GPS tracking data may be used to inform/support space use/utilisation over different time frames and therefore reduce uncertainty arising from seasonality or snapshots.

6.3. Bird-borne telemetry data

6.3.1. Overview

Bird-borne telemetry data are increasingly used in the scientific literature to examine exposure to, and impacts from offshore wind farms (OWFs), considering alterations to seabird movements, behaviour and distributions. This information is particularly insightful because it provides high resolution data on the movement, behaviour and space use of individual birds. As potential impacts of OWFs on seabirds can occur through sub-lethal effects (aside from collision impacts), it is the accumulation of these changes to individual behaviour, movement and space use in the presence of operational OWFs that ultimately drive population level consequences in protected species. Importantly, behavioural responses, which are the ultimate determinant of animal fitness via their effects on energetics and demography, cannot be studied in and around OWFs by methods relying on visual or digital surveys (Peschko et al., 2020b). In addition, observations deriving from aerial or ship-based data from current post-construction monitoring have low statistical power with which to detect potential changes in spatial patterns attributed to OWFs (Pollock et al., 2024), in part because potential effects from OWFs vary across local environmental conditions and seasonal periods (Peschko et al., 2020b; Heinanen et al., 2020; Thaxter et al., 2024). Of all the post-construction surveying methods, telemetry data for individuals provides the most relevant information at an appropriate spatio-temporal resolution to elucidate the driving mechanisms through which environmental variation and seasonal period influence general behavioural responses, and therefore potential impacts. These data therefore provide a powerful method for quantifying fine- and large-scale behaviour and habitat use (Peschko et al., 2020b, 2021; Thaxter et al., 2024), providing the potential for both more accurate empirical estimation of impacts following construction and for more predictive capacity to assess potential OWF impacts of future projects, across variable marine environments, prior to consent. However, a number of studies illustrate that tag attachment/loading and/or handling of birds to fit tags may influence their behaviour and thus temporal and spatial habitat use, and have potential to negatively impact reproductive rates and survival. Wherever possible, tagging studies should therefore incorporate rigorous study to determine that any negative effects are mitigated and data quality is not fundamentally compromised.

6.3.2. Principles of tagging

Bird-borne telemetry, specifically in the form of a tag to archive or relay data back to the observer (i.e. tagging or biologging), was first used in the context of OWF studies in the early 2000s (Perrow et al., 2006). Technological advances in tag type and miniaturisation, attachment methods, locational accuracy, the addition of further sensors and remote download have since considerably expanded the use of tagging studies, primarily using GPS tags, at all stages of wind farm development especially to elucidate connectivity of seabirds from protected colonies with OWFs and estimate seabird responses to OWFs post-construction (see Thaxter & Perrow, 2019). The latter review highlights the ever-increasing scope and value of bird-borne telemetry, while also stressing the need to increase sample size to account for individual variation and the need to ensure that handling and tag attachment and subsequent loading does not modify foraging behaviour or spatial usage or negatively impact upon individual condition, productivity or survival; noting that detection of any ‘tag effect’ itself requires careful study.

In general, the prospect of comparing the temporal and spatial distribution of tagged birds with untagged ‘controls’ is limited as the methods available to measure the latter are also extremely limited. A rare example is the study of Seward et al. (2021) on Arctic terns (*Sterna paradisaea*) where the utilisation distributions of tagged birds and those followed from the colony with a fast boat using the technique known as visual tracking (see 6.4.1 below) showed good agreement, although the area occupied by tagged birds was larger. Whether this was indicative of a tag effect or an occasional inability to follow far ranging birds remained unclear. The larger foraging range of tagged birds was also associated with, although could not be attributed to, the observed reduced nest attendance and chick provisioning rates of tagged birds vs unhandled/untagged 'control' individuals. However, similar negative effects were noted amongst handled but untagged birds, suggesting handling rather than tag attachment/loading was the more important factor.

Evidence of handling and tag deployment effects on chick provisioning rates were found also in Atlantic puffins (*Fratercula arctica*), with reduced feeding rates by both ringed only and GPS-tagged and ringed individuals compared to the expected values if pair members shared chick provisioning duties equally, as is typical for this species (Bogdanova et al. 2020, 2021, 2022, 2024). In general, where there can be no control comparison with untagged birds, any possible effect may have to be inferred from other data on nest attendance, provisioning rates, productivity and survival. In this context, Langlois Lopez et al. (2023) note reduced breeding success of tagged great black-backed gull (*Larus marinus*) and Thaxter et al. (2016, 2024) record reduced return rates and thereby likely reduced survival of both great skua (*Stercorarius skua*) and Sandwich tern (*Thalasseus sandvicensis*) respectively, with all these studies using harness-type attachment methods. In contrast, lesser black-backed gull (*Larus fuscus*) tagged in a similar way exhibited no detectable negative response (Thaxter et al. 2016).

Studies using tape attachment to back or tail feathers have generally not shown adverse effects on demographic rates although there is evidence that such tag deployments can negatively affect behaviour and physiology. For example, Heggøy et al. (2015) reported elevated levels of stress hormones, reduced nest attendance and longer foraging trips in black-legged kittiwakes (*Rissa tridactyla*). Similarly, Chivers et al. (2016) found that tagged black-legged kittiwakes spent less time flying compared to control birds. Gillies et al. (2020) showed that Manx shearwaters (*Puffinus puffinus*) carrying GPS devices spent more time away from the nest, had reduced foraging gains and spent less time flying compared to control individuals. All these studies, however, used relatively heavy devices (>3.7% of the body mass of the birds).

In contrast, lightweight tags (4g, c.1% body mass) attached with tape to the tail feathers of Black-legged kittiwake breeding on the Isle of May (Bogdanova et al. 2020, 2022, 2024) showed no negative device effects on parent changeover rates indicative of foraging trip duration (and thus possibly behaviour), chick condition or breeding success. However, small but measurable negative effects on parent changeover rates, chick attendance and breeding success were found when using larger (9g, c.2.4% body mass) tags with a different attachment method (glued to back feathers) and longer deployment duration (Bogdanova et al. 2020, 2022).

Overall, careful consideration of known or likely species' sensitivity to handling and tagging as well as the adoption of best-practice methods and procedures throughout all aspects of the study are demanded to deliver the highest quality outputs. Key considerations in this respect are the choice of device (dimensions, weight, shape), optimal placement on the bird and attachment method, as well as minimising handling-related disturbance, with particular attention required with loggers attached using harnesses or glued to feathers (Vandenabeele et al. 2012, 2014; Thaxter et al. 2014, 2017).

6.3.3. Current evidence

In recent years, there has been a considerable increase in the use of telemetry data, primarily GPS tracking, to estimate seabird responses to OWFs post-construction. Below, we review the most recent, relevant studies for species considered at risk from collision and displacement in the UK context. The focus here is on reviewing studies that have used telemetry data, whether or not this was collected as part of a PCM requirement.

A range of studies on northern gannet *Morus bassanus* have used tracking data to demonstrate that this species tends to avoid OWF areas, which can cause displacement and potentially lead to habitat loss (Vanerman et al., 2015b; Dierschke et al., 2016; Garthe et al., 2017). GPS tracking of breeding northern gannets has demonstrated that birds from the Helgoland colony in the southern North Sea predominantly avoided OWFs over a two-year period (89% of tracked individuals; Peschko et al., 2021). However, the tracking data also revealed important variation between responses of individuals, with 11% of tracked gannets frequently entering OWF areas when foraging, or when commuting between the colony and foraging areas (Peschko et al., 2021). These individuals foraged intensively within the OWFs, indicating a potential increase in foraging conditions around turbine bases due to a ‘reef effect’, although the study did not have concurrent data on prey with which to validate this assumption (Peschko et al., 2021). The same study estimated a reduction in the usage of OWF areas by gannets of 21% and 37% over the two-year period (Peschko et al., 2021). The use of detailed tracking data in this study provided estimates for avoidance of OWF areas (relevant to estimates of displacement and barrier effects), increased flight distances (relevant to estimates of displacement and barrier effects) and flight heights and flight speeds (relevant to estimates of collision effects, and also displacement/barrier effects within Individual Based Models). Importantly, the high resolution of the tracking data used in this study also identified differences in flight heights inside and outside OWFs with some individuals flying at higher altitudes inside OWFs, which could increase their collision risk (Peschko et al., 2021), a finding not possible to identify without the use of post-construction data.

Similarly, tracking of common guillemots in the breeding season has evidenced avoidance of OWFs, particularly when turbines were rotating. This study estimated proportional changes to usage of OWF areas by breeding guillemots, documenting a 63% reduction in selection of OWF areas in comparison to surrounding areas, increasing to a 75% reduction when turbines were in operation (Peschko et al., 2020b). Other behavioural patterns were also identified, including very limited approaches to OWF areas by commuting birds (Peschko et al., 2020b).

A recent multi-year GPS tracking project on Sandwich terns (*Sterna Sandvicensis*) also demonstrated post-construction responses in this species, including shifts in both the foraging and commuting areas used by the population during the breeding season. Birds continued to use OWF areas for foraging, but appeared to avoid them during commuting, resulting in a ‘funnelling’ effect to key foraging locations. Foraging trip characteristics for this population of Sandwich terns also altered depending on the phase of OWF construction in the area, with both trip duration and foraging ranges decreasing in construction years, suggesting an alteration of wider movement patterns in response to potential disturbance. The study also identified a marked reduction in the usage of two OWFs between the first and second years of operation, again suggesting altered space use patterns in response to operation. Avoidance of OWFs in this population was also shown to be greater for those developments with higher turbine densities, suggesting within OWF characteristics also influence space use and avoidance of OWF areas in this species. Importantly, the tracking data from this population revealed that avoidance of OWF areas created a ‘shadowing’ effect between two developments, whereby the gap between the two OWFs was largely unused by commuting and foraging birds, demonstrating an important cumulative impact. This highlights the use of individual tracking data for understanding potentially significant non-additive, cumulative impacts from multiple OWFs on breeding seabirds.

GPS tracking of black-legged kittiwakes at a breeding colony in north-eastern Scotland has demonstrated variation in avoidance/attraction depending on OWF location and the spatial scale of analysis (Pollock et al., 2024). Analysis was directed at both macro- (i.e. whole footprint) and meso-scales (i.e. around individual turbines). The study demonstrated that breeding black-legged kittiwakes tended to avoid OWFs at macro-scales of 3-4km, but to show 'attraction' at macro-scales of 0-1km (from the OWF boundary; Although, the authors note that this apparent 'attraction' in the area immediately surrounding the OWF footprint could in fact result from aggregation caused by displacement from the area inside the OWF boundary. At the meso-scale, black-legged kittiwakes avoided turbines up to 120m. Together, these findings were interpreted as evidence for slight attraction to, or aggregation due to displacement, in the immediate vicinity of an operational OWF, and avoidance of areas around individual turbines. A further analysis of the same dataset revealed considerable individual level variation in the time spent within operational OWFs, ranging from 10 minutes to four hours (O'Hanlon et al., 2024).

Similar methods to those described above for black-legged kittiwakes have also been used to investigate responses of lesser black-backed gulls to operational OWFs. Analysis of GPS tracking data from a breeding colony in north-western England revealed that these birds exhibited attraction to nearby OWFs at scales within 4km of development boundaries, but with considerable variation in this relationship over different distances up to the boundary (Johnston et al*.,* 2022). Birds showed significant macro-avoidance between 3km and 4km, which weakened as distance bands approached wind farm boundaries indicating that the majority of birds did not alter flight routes to avoid OWFs. Rather, lesser black-backed gulls in this study appeared to enter OWFs and avoid turbines at a meso-scale. In contrast to black-legged kittiwakes, the lesser black-backed gull study indicated that birds exhibited apparent attraction to individual turbines within 70m when at flight heights below the rotor height range (potentially utilising turbine structures as roosting opportunities), although they showed avoidance at distances approaching turbines when flying within rotor height range. This highlights the importance of fine-scale movement data, coupled with flight height information, in elucidating collision risk in seabird species and potential adaptive behaviours to minimise this risk. Earlier work utilising GPS tracking data in this species, again in northwest England, has also highlighted a likely meso-avoidance behaviour around operational turbines (Thaxter et al*.,* 2018).

Finally, telemetry of red-throated divers has demonstrated strong displacement from operational OWFs, with a gradual lessening of the displacement effect out to 15km from development boundaries (Heinanen et al*.,* 2020). Density (usage) of these birds within and up to 5km surrounding footprints decreased by up to 90% compared to densities more than 20km away from wind farm boundaries (Heinanen et al*.,* 2020). Particular insight from the use of telemetry data in this study revealed that displacement distances decreased with reduced visibility and were shorter during daytime periods than during the night, potentially due to accentuated disturbance from lights (Heinanen et al*.,* 2020).

In summary, telemetry-derived evidence for post-construction impacts of OWFs on seabirds is accumulating rapidly, providing considerable opportunities for improving current assessment methods, and for delivering estimates of realised impacts on seabird behaviour, movement, energetics and demography (Table 4).

6.3.4. Telemetry data in the non-breeding season

At a plan level (e.g., marine spatial planning), light-based geolocators (GLS) tags have been used to identify potential concentrations of seabird marine habitat space use in the non-breeding season, although only in a few species (e.g., Buckingham et al., 2022). These geolocators measure light levels, saltwater immersion and sea surface temperature (SST), from which daily locations can be estimated. GLS loggers can remain operational for up to 5 years, which makes them well suited for studying year-round distribution (Buckingham et al., 2022). However, GLS loggers have large uncertainty in location estimates, meaning they are primarily of relevance to plan-level, large-scale spatial planning, rather than project level assessment methods.

For instance, Buckingham et al. (2022) showed that coastal Scottish waters and the southern North Sea, both identified as key areas for development of OW, are commonly used by UK auk populations (common guillemot and razorbill *Alca torda*) during the non-breeding period, including the post-breeding moult, when individuals are less able to move freely, and in mid-winter, when environmental conditions are often most harsh. This information is very relevant to future siting and marine planning for OW, and is starting to be used within Individual-Based Modelling frameworks to consider potential impacts from OW on some seabird species during the non-breeding season (e.g., Layton-Matthews et al., 2023). It is, however, currently unlikely that post-construction GLS derived space use estimates will be of sufficient resolution to robustly identify changes in space use due to OW construction and operation.

6.3.5. Summary of analytical methods

Here, we briefly summarise the main analytical methods that have been used to derive OW relevant inference from seabird telemetry data collected post-construction.

- **Point process models** (e.g., Peschko et al., 2020b, 2021, Heinanen et al., 2020): quantifying if resource selection of an OWF area and environs is reduced in comparison with other areas away from the OWF (often coupled with Generalised Additive Mixed Models (GAMMs) or Generalised Linear Mixed Models (GLMMs) to assess if differences are correlated with OWF presence, or phase of operation)
- **Behavioural classification models** (many alternative methods, although Hidden Markov Models (HMMs) are commonly implemented, e.g., Langrock et al., 2012, Thaxter et al., 2024)
- **Kernel density estimation** (e.g., Thaxter et al., 2024): estimation of utilisation distributions
- **Avoidance/Attraction Index (AAI)** (e.g., Johnston et al., 2022, Pollock et al., 2024): assessment of changes in space use (increases and decreases interpreted as avoidance versus attraction) in distance bands around OWF footprints or individual turbines, calculated as the scaled difference in expected proportions of location fixes from simulated tracks (observed trips rotated randomly around the colony) versus the observed proportion of location fixes from observed tracks
- **Bhattacharyya's affinity index** (e.g., Thaxter et al., 2024): quantification of similarity in area use by a population between years
- **Generalised Linear Mixed Models (GLMMs)** (e.g., Thaxter et al., 2024): quantifying if differences in foraging trip characteristics and proportion of time spent in OWF areas are associated with OWF status (pre-construction, construction, operational)

Table 4. Summary of relevant outcomes for OW assessments arising from use of post-construction telemetry data.

Outcomes from post-construction telemetry data	Component of EIA/HRA of relevance
Changes to the spatial use of areas inside and adjacent to OWFs (e.g., Peschko et al., 2020b, 2021; Johnston et al., 2022; Pollock et al., 2024; Thaxter et al., 2024)	**Displacement risk and effects** – habitat loss, barrier effects **Collision risk and effects** – avoidance
Behaviourally-dependent avoidance or usage of OWF areas and turbine surrounds (e.g., Peschko et al., 2020b, 2021; O'Hanlon et al., 2024; Thaxter et al., 2024)	**Displacement risk and effects** – habitat loss, barrier effects **Collision risk and effects** – avoidance
Changes to foraging trip characteristics in relation to phases of OWF (pre-construction, construction, operational) both within and around OWFs (e.g., Thaxter et al., 2024)	**Displacement risk and effects** – habitat loss, barrier effects **Collision risk and effects** – avoidance
Individual variation in responses to OWFs (e.g., Peschko et al., 2021; O'Hanlon et al., 2024)	**Displacement risk and effects** – habitat loss, barrier effects **Collision risk and effects** – avoidance
Flight height information for use in collision risk assessments	**Collision risk and impacts** – impact modelling (CRM)
Flight speed information for use in collision risk assessments and Individual Based Modelling (IBM) approaches for displacement and barrier risk assessments	**Displacement risk and impacts** – impact modelling **Collision risk and impacts** – impact modelling (CRM)
Effects of environmental conditions on avoidance of OWFs or areas around turbines (Heinanen et al., 2020)	**Collision risk and effects** – impact modelling (CRM)
Information to estimate and predict apportioning of seabirds observed at sea to colonies	**HRA**
Information on foraging within and around OWFs linked to potential reef effects and Nature Positive outcomes	**EIAs and Marine Net Gain**

Outcomes from post-construction telemetry data	Component of EIA/HRA of relevance
Linking sub-lethal responses of seabirds to OWFs to subsequent demographic consequences (when coupled with individual-based studies on individual breeding success and survival; Bogdanova et al., 2022)	**Displacement risk and impacts** – validation of predicted demographic impacts Assessments of requirements for **Compensatory measures and Marine Net Gain**

6.4. Site-specific case studies

At R1 and R2 sites, PCM was typically focussed on monitoring the array site. At earlier sites, boat-based surveys were used as standard, later replaced with DAS. The Sheringham Shoal Case study presents information on what was a relatively typical boat-based survey programme at the time.

In addition to standard boat-based surveys, a novel technique (visual tracking) was undertaken to address licence objectives to verify collision risk predictions for Sandwich tern made within the EIA. This technique allowed collection of data around the movement and behaviour of individual birds. In this section we provide two case studies that outline the use of visual tracking data in the context of PCM and use these case studies to highlight key opportunities and challenges around the use of PCM data. The case study on Lincs offshore wind farm demonstrates some of the issues that have arisen in PCM, which encompass both technical and policy considerations. These case studies were chosen because monitoring has been completed, reports discharged, and sufficient time has elapsed to allow outputs to be reviewed and incorporated into existing guidance.

6.4.1. Sheringham Shoal offshore wind farm

Ornithological PCM of the Round 2 Sheringham Shoal OWF required under the conditions of Marine Licence L/2011/00153/8 (updating the previous Food and Environment Protection Act Licence) had two objectives:

- Determine if there is any change in bird distribution, use and passage, measured by species' abundance and behaviour, at the wind farm site, 1 km and 2–4 km buffer zones and the reference (control) site.
- Validate the collision risk modelling to identify avoidance rates of the Sheringham Shoal Wind farm site with reference to tern species in the breeding season.

These objectives accord to the validation of predicted effects or the detection of any unforeseen effects/impacts, two of the principles for PCM later set out by MMO (2014) and Parker et al. (2022a, b, c, d).

For the first objective, the nine sensitive receptors recognised in EIA and post-consent discussions, a mixture of both breeding and passage/wintering seabird species of relevance to many UK and North Sea wind farms, were the focus of interest. In approximate order of sensitivity these were Sandwich tern, common tern *Sterna hirundo*, little gull *Hydrocoelus minutus*, razorbill, northern gannet, lesser black-backed gull, common guillemot, black-legged kittiwake *Rissa tridactyla* and great black-backed gull *Larus marinus*.

For the second objective, the focal tern species was Sandwich tern, a qualifying breeding species of the North Norfolk Coast SPA originating from the Blakeney Point colony nearby to Sheringham Shoal, but also possibly from the more distant SPA colony at Scolt Head, that is also within foraging range (Perrow et al., 2010, 2017). Although birds may breed at both colonies simultaneously, historically, this has tended to be in unequal numbers so that one or other colony predominates in any one year, with this pattern switching every few years for reasons that remain unclear.

Objective 1 Changes in seabird spatio-temporal abundance

Any changes in spatio-temporal abundance of sensitive receptors were determined through a boat-based monitoring programme comprising 180 surveys utilising characterisation (2004–2006) and post-consent (2009–2016) periods thereby providing three years of baseline (*n*=51 surveys), three years of construction (*n*=63 surveys) and three years of operation (*n*=66 surveys) in a before-after-control-impact (BACI) analysis of the wind farm site and control areas (not including any buffer areas that were added for PCM). The survey 'year' was from March to February inclusive with between 1–3 surveys in any one month biased towards the breeding season (May–July) as determined by the occurrence of breeding terns, the most sensitive receptors and following discussion with the statutory nature conservation body, Natural England (NE). Characterisation data was, however, only included in analysis to strengthen the initial PCM design of a single year of baseline as required under licence conditions, after completion of the PCM programme and submission of draft final reporting and the ensuing discussion with representatives from NE and MMO. The initial analyses of post-consent data only (2009–2016) using both BACI (with one year of baseline) and before-after gradient (BAG) designs, with the latter over a larger area including the site and extending 0–2 km and 2–4 km buffer zones added for PCM, were seen as complementary and as an aid to interpretation.

The analytical framework adopted comprised Generalised Additive Mixed Models (GAMMs) using *site* and *phase* alongside an interaction coefficient that indicates potential attraction where positive and avoidance were negative (see Vanermen et al*.,* 2015a, 2016). Significance was tested using ANOVA with model accuracy tested using Pearson correlation coefficients (r) and Spearman rank correlation coefficients (ρ). In addition, to try and understand any specific effects of construction almost entirely undertaken during the summer (April–September) months, non-parametric Kruskal-Wallis tests were used to assess any differences in bird abundance within the wind farm and 0-2 km buffer combined, between pre-construction (including characterisation), construction and operation. Further Kruskal-Wallis tests were also conducted to investigate any specific effects of pile-driving by grouping surveys from the same summer periods according to pre-piling, piling or post-piling periods. The duration of piling during installation of each monopile is 30–40 minutes.

In all analyses, the abundance of each species was represented by density as individuals.km^{-2}, combining: i) the density of birds on the water within transect incorporating `distance` analysis to account for imperfect detection where applicable, ii) density of birds in flight from radial snapshots every 500 m and iii) a derived density of any birds perched on structures (typically navigation buoys) encountered within transect.

A key finding was that non-breeding auks, both razorbill and common guillemot, were displaced with this beginning in construction and continuing into operation. For razorbill, piling appeared to have a particularly strong effect that was not clearly shown by guillemot. The displacement of auks at Sheringham is in line with the general conclusions of the later literature review by Vanermen & Stienen (2019) which revisited and updated the earlier review of Dierschke et al. (2016). As noted by the authors Robin Rigg was one of the few sites reviewed where common guillemot did not show an avoidance response (Vallejo et al., 2017). Similarly, Trinder et al. (2024) found no evidence of displacement of breeding common guillemot from the Beatrice wind farm during digital aerial surveys. In contrast, however, tagged common guillemots breeding at Helgoland were reported to show strong avoidance of a cluster of wind farms in the south-eastern North Sea (Peschko et al., 2020b); although the study was conducted after the wind farms were already operational and it was not clear if the area occupied by them was used beforehand.

Although the factors underpinning the displacement of auks could not be established, the displacement of their prey species, especially the clupeids Atlantic herring *Clupea harengus* and European sprat *Sprattus sprattus*, known to be important prey for seabirds in the area, was suggested to be the most likely root cause through varying mechanisms in the different phases of development. In theory, noisy pile driving during construction cannot be tolerated at close distance by hearing-sensitive clupeids without injury (in a similar way to cetaceans), thereby leading to displacement at least in the short term. Moreover, at Scroby Sands OWF a longer-term effect on the local adult stock and thus recruitment of young fish taken by little terns was linked to piling during the sensitive winter spawning period (Perrow et al., 2011a). More generally in the operational phase however, pelagic forage fishes like clupeids are predicted to be disfavoured by the shift to demersal and larger predatory fish associated with the changing habitats within OWFs known as the 'reef-effect' (Dannheim et al., 2019, Gill & Wilhelmsson, 2019). At Sheringham Shoal, this was thought likely to have continued the trend of lowered abundance of pelagic prey compared to the pre-construction baseline. Evidence of a reduction in such forage fish was provided by the continued significant decline in foraging rates of tracked Sandwich terns (see below) within, compared to outwith, the wind farm after construction and into operation.

An alternative possibility that the displacement of auks was caused directly by an increase in vessel traffic during and post-construction was discounted following an evaluation of the response of auks to the relatively large survey vessel as an indicative proxy. For example, no observable response was recorded beyond 200 m from the vessel, with <5% of razorbills (c.1% of guillemots) flushing into flight at closer distances. Even at 50 m or less from the vessel, most birds showed little response with around 20% simply diving to then resurface behind the vessel (Berridge et al., 2019a, Perrow et al., 2024).

In contrast to auks, northern gannet was only displaced following construction. Such was the strength of the response that a 'polo' effect was noted with virtually no birds recorded within the operational site. Again, the mechanism underpinning the response could not be determined, although this was thought to be linked to a 'fear' of moving structures driven by the relatively low flight manoeuvrability of northern gannet and the potential risk of collision, rather than any response to prey distribution given that the response was only apparent in the operational site and northern gannet has a wide prey base and thus potentially able to exploit the changing fish community linked to the reef-effect.

The displacement of northern gannet from operational sites was seemingly first recorded by Krigsveld et al. (2011) at Egmond aan Zee in the Netherlands and at similar time at Robin Rigg in Scotland (Nelson et al., 2015) in UK. The pattern has subsequently been repeated at other sites, which has led to Natural England commissioning an investigation of macro-avoidance by northern gannet (Pavat et al., 2023) with the idea that collision risk would be reduced should birds not enter operational sites. The intention was that this prospect may then be reflected in EIA predictions.

Little gull also appeared to be displaced during operation though this result was treated with caution as a result of high variability in abundance and thus large confidence intervals in model predictions. Similarly, the lack of observations for common tern confounded interpretation of results. In contrast, the lack of significant results for breeding lesser black-backed gull and non-breeding black-legged kittiwake and great black-backed gull was thought to be a genuine reflection of a lack of a clear response perhaps complicated by mixed avoidance and attraction responses in different phases. While great black-backed gull appeared to be attracted to the operational site, this was conflated by an increase in the wider population in the area.

No response by Sandwich tern was detected as a result of higher abundance in the control area throughout. This in turn was also confused by the attraction of terns to the eight navigation buoys located around, and within 400m of the wind farm prior to construction (see Berridge et al., 2019b). Higher use of terns, for the purpose of resting and socialising, was noted in early breeding season with up to 29 individuals recorded per buoy.

Objective 2 Avoidance and collision risk of Sandwich tern

Objective 2 was addressed using the (then) novel technique of visual tracking aboard a rigid-hulled inflatable boat (Perrow et al., 2011b) of Sandwich terns heading toward the wind farm from within the 4 km buffer during outbound and inbound foraging flights from/to nearby SPA breeding colonies, principally Blakeney Point. Flightlines were strongly biased to northeast and southwest according to inbound/outbound from the Blakeney Point colony. Data was collected over a seven-year period and was partitioned into pre-construction (2009 & part 2010), protracted construction of monopiles and then assembly (part 2010–2012) and operation (2013–2015). Before and after tracking measuring relative change proved invaluable to evaluate and compare the importance of the different components of the overall avoidance rate – macro-, meso- (both lateral and vertical) and micro-avoidance – according to the following:

Avoidance rate (AR) = 1–((1-macro)*(1-meso lateral)*(1-meso vertical)*(1-micro))

where:

- macro = entering the site,
- meso-lateral = flying within 50 m of turbine base (the ‘risk cylinder’ reached by blades depending on orientation),
- meso-vertical = flying at risk height (>25 m to 130 m),
- micro = passing through the plane of an operational turbine.

A total of 1,858 individual tracks (total length of 22,843 km) were available for analysis. Close observation of every aspect of behaviour (e.g. height and speed of flight, foraging and prey consumption, interactions with other species) provided unique insight into the behavioural response of Sandwich terns to a wind farm and associated infrastructure. As well as the unexpected attraction to navigation buoys, terns also avoided areas of construction activity including installed monopiles with no blades that offered (virtually) no risk of collision (Harwood et al., 2017). During the pre-construction baseline, 97.3% of tracks entered the future wind farm with flightlines according to destination assumed to be potential foraging grounds or the colony.

A decline in the proportion of birds entering the site (34.5% fewer), indicative of macro-avoidance, began in the final construction phase. A broadly similar rate of macro-avoidance was maintained during operation (32.2–43.5% fewer in the different years). Individual tracks provided clear evidence of a range of responses including diversion before entering the site, typically across a ‘corner’ throughout construction and operation, diversion around the entire site generally (but not exclusively) during operation, and flights increasing in height to pass entirely above the height of all structures (>130 m).

Of those that did enter the wind farm <1% flew through the turbine rotor radius (a concept incorporating all potential orientation of the blades according to wind direction) compared to 51% that flew through the same area prior to turbine installation.

The observed avoidance rate was 100%, whereby none of the tracked birds (n=639) entering the operational site passed through the rotor plane of a rotating turbine. However, seven birds did enter the 'risk cylinder' with two birds doing so twice. Of the nine 'risk' events, four birds passed by the rotor in a different plane, two were lower than the rotor sweep and three passed through a stationary turbine. However, a greater sample size may be expected to yield a sample of birds passing through an operational turbine and thus allowing calculation of micro-avoidance rate and thereby an overall avoidance rate. To allow the calculation of an estimated precautionary rate, Harwood et al. (2018) initially included the sample of two birds below risk height as though they were at risk height. In contrast, Perrow et al. (2024) suggested the inclusion of the three birds passing through a stationary turbine as it is debateable if the vision characteristics of terns allow ready discrimination of moving vs stationary turbines at very close range especially considering the scale of the structures involved.

The resultant calculation of micro-avoidance rate allowed an overall estimated AR of 98.86% and the relative contribution of the different components to be calculated. This showed the large contribution of meso-lateral avoidance (61.4%) that led to birds being obviously concentrated midway between turbines in 'flight corridors'. Macro-avoidance (22.6%) was also of moderate importance followed by micro-avoidance of 10.9%. Meso-vertical avoidance made little contribution (4.1%) illustrating that terns did not routinely change height in the presence of turbines. In fact, there was evidence that in some years, terns flew at greater height than in baseline conditions, bringing them into 'risk height'. Observations suggested that such birds may have increased flight height to better assess the position of turbines either through visual or sensory (perhaps by feeling increased turbulence) cues to effectively locate themselves midway between turbine rows.

Following calculation of an estimated avoidance rate, Harwood et al. (2018) used boat-based density estimates in different months combined with mean distance travelled and flight speed in order to estimate the number of passages (flux) across the wind farm in different operational years (n=196,993–292,085) combined with the proportion of birds entering the turbine rotor radius at risk height, the estimated probability of entering a swept area, the collision risk factor from the Band model (Band, 2012) and the proportion of time the turbines are operational. This provided an average estimate of 12 collisions per annum; a value in close agreement with the estimate of 13 from standard collision risk modelling attributed to Sheringham Shoal in the combined Appropriate Assessment of additional sites in the Greater Wash, namely Race Bank, Docking Shoal and Dudgeon (DECC, 2012).

Although the licence conditions were discharged, the approach was novel yet had not been validated by the wider scientific community or updated with collision risk modelling that had developed substantively since using relevant bird and turbine parameters and actual bird densities for reporting. Accordingly, Perrow et al. (2024) further estimated collision risk using the deterministic model in the sCRM tool (https://dmpstats.shinyapps.io/sCRM/m combined buffer areas (i.e. not already subject to avoidance). They used the derived estimate of avoidance rate of 98.86% and the generic avoidance rate of 99.02% for gulls and terns (TCE & JNCC, 2024). Estimated collision rates were 1.37–1.95 at 98.86% and 1.18–1.68 annum at 99.02% indicative of the high degree of avoidance behaviour observed.

Finally, observations during tracking showed a significant decline in foraging rate within, compared to outside the wind farm during final construction and throughout operation, from being indistinguishable in the pre-construction and initial construction phases. This provides some circumstantial support for a change in forage fish spatio-temporal abundance offered as a mechanism to account for the displacement of auks (see above) and emphasises the need for better understanding of the potential impact of wind farms on forage fish and the wider ecosystem, relative to other factors.

Important findings may be summarised as follows:

- Boat-based surveys may provide an excellent platform to assess changes in spatio-temporal abundance of birds in relation to wind farms (Vanermen et al., 2015a, 2016), especially over small areas when conducted with a high degree of coverage and at high frequency. Specific advantages over DAS include the collection of detailed information on seabird behaviour and flight while typically encompassing any diurnal and tidal patterns of seabird activity as a result of the relatively slow speed of the platform and survey being undertaken throughout all daylight hours height (Webb & Nehls, 2019). Nevertheless, DAS is currently actively preferred in statutory guidance (Parker et al., 2022a, b, c, d).

- 'Before' data in PCM is intuitively beneficial to the interpretation of results (Webb & Nehls, 2019), especially if its quantity and duration can be increased by incorporating the characterisation phase, as this may increase the power of subsequent analyses to detect change (Maclean et al., 2013). Increased duration moves towards the goal of longer-term PCM monitoring (intervals up to 15 years) suggested by Jackson & Whitfield (2011). If characterisation data is to be successfully incorporated this also points to careful premeditation of survey design, perhaps linked to specific sensitive receptors, so as to be 'fit for purpose' for *both* EIA and PCM.

- The consistent use of the same methods throughout PCM and including characterisation studies as required, also intuitively aids interpretation and the passage of any publication through peer-review, but data collected via different survey methods still have value and can be jointly analysed using statistical approaches such as data integration (Section 6.6.4).

- The displacement of auks *beginning in construction* does not appear to have been shown in any other studies, largely because most studies rely on comparisons before and after construction (i.e. baseline and operation), as boat-based surveys have often been curtailed during construction activity on the grounds of H&S risks. However, at Sheringham Shoal, rigorous planning and effective communication between site managers and construction and survey vessels removed any limitations.

- Recognition that non-breeding auks *may* (as at Sheringham Shoal) begin to be displaced from construction should be recognised by the industry and incorporated in guidance by SNCBs. The Joint SNCB Interim Displacement Advice Note (2022) classifies sensitivity to displacement using 'Disturbance Sensitivity' and 'Habitat Specialization' scores from Bradbury et al. (2014) (expanded from Furness et al. 2013). 'Disturbance Susceptibility' scores in Bradbury et al. (2014) are used to give a possible indication of potential displacement levels (% of birds likely to be displaced) that may be exhibited by each species. Although both the JNCC note and NE guidance (Parker et al., 2022c) acknowledge construction effects within accompanying text, displacement from construction and operational phases are not dealt with separately within assessment. At this stage it is not known if this may also apply to breeding auks undertaking central place foraging as these may be more constrained in their choice of habitats and thus be more tolerant of wind farms (Vanermen & Stienen, 2019). More generally, the likelihood and strength of any response will likely depend on the root cause of displacement. If this is linked to a change in the spatio-temporal abundance of prey species (as data available on foraging rates of Sandwich tern inside and outside wind farms would seem to imply) then local environmental factors determining prey availability over the wider area would seem likely to play a critical role in the choices available to the birds and ultimately the effects upon them.

- The displacement of non-breeding northern gannet from operational wind farms and its effect on reducing potential collision risk is now recognised by the industry manifested by the calculation of a high macro-avoidance rate (Pavat et al., 2023). The potential for this may have occurred earlier in the UK if the results from Sheringham Shoal had been used to reinforce the findings at Robin Rigg at around the same time (Nelson et al., 2015). In fact, the study of Pavat et al. (2023) still did not include information from Sheringham Shoal, despite the fact that the minutes of the workshop held (Appendix B) recorded an action by an NE staff member to "*point HiDef in the direction of further reports from grey literature*". It is of note that all three NE staff attending the workshop were directly engaged with Sheringham Shoal.
- The detailed derivation of the different components of avoidance for Sandwich Tern enabled by 'before' data and relatively large sample size appears to remain more or less unique in the study of the interaction between a breeding seabird and a wind farm. Other valuable studies of breeding seabirds such as Thaxter et al. (2018) and Vanermen et al. (2019) where birds were fitted with tags, focussed on the effect of wind farms during operation in isolation and could only imply the relative influence of macro vs meso-avoidance for example. In contrast, previous impactful studies upon migrant non-breeding waterfowl by Desholm & Kahlert (2005) and Plonczkier & Simms (2012), both using radar benefitted from some form of before vs after comparison, but without the specific breakdown of the various components of avoidance. Data from Sheringham Shoal thus provides crucial evidence of the potential for a high degree of avoidance behaviour to virtually eliminate the risk of collision, even if at least some of the individuals involved continue to pass through the operational site.
- In contrast with telemetry through tagging birds, where, in the absence of additional sensors to Global Positioning System (GPS) such as Time Domain Reflectometry (TDR) or accelerometery, specific behaviours typically have to be inferred from flight patterns, the technique of visual tracking allows direct observation of every aspect of bird behaviour. Visual tracking is also non-invasive and does not risk an adverse reaction that may otherwise jeopardise data quality (see the review of Thaxter & Perrow, 2019). The technique also provides the scope to readily acquire a large sample size of independent observations as a consequence of tracking different individuals. Thus, Perrow et al., (2011b) concluded that "*because birds can be readily tracked over relatively short distances, visual tracking may be particularly useful for studying the potential impacts of OWFs, for example, to establish behavioural responses and avoidance rates*". In terms of applicability, Perrow et al. (2010) suggested the technique would lend itself to use on a variety of terns and gulls (*Laridae*) as well as skuas (*Stercorariidae*), whereas petrels, shearwaters and sulids (e.g. northern gannet) were thought to be unsuitable subjects, largely as they may typically fly too quickly and may prevail in environments that are too far offshore to access readily.

6.4.2. Lincs offshore wind farm

Background information: 75 turbines, 250MW, 8km offshore of Lincolnshire, commissioned in 2012 with operational monitoring undertaken 2013-2016. The Greater Wash SPA was classified in 2018 for the protection of red-throated diver.

Red-throated divers: The vulnerability of RTDs to displacement impacts was identified at Kentish Flats, Gunfleet, and London Array, all located within TCE's R2 Outer Thames Estuary development area. The baseline monitoring conducted for the OSW development revealed a far higher usage of the Outer Thames Estuary by RTDs than had previously been understood, resulting in designation of the Outer Thames Estuary in 2010. The PCM carried out at Kentish Flats and Gunfleet (as well as in Liverpool Bay) showed displacement of RTDs from OWFs. As a result London Array was granted consent in 2006 for a staged build (2 phases), with a Grampian condition requiring the developer to demonstrate that any change caused by additional turbines to the habitat of RTD would not compromise the conservation objectives of Outer Thames Estuary SPA (see: Phase Two – London Array). This is an unusual use of a Grampian condition, which is typically attached to a decision notice, preventing the start of a development until off-site works have been completed on land not controlled by the applicant. However, the Grampian condition applied to Phase 1 of London Array (built 2009-2012) meant that the second phase was never progressed.

RTDs in the Greater Wash: During the baseline monitoring for Lincs, conducted between 2004-2006, only relatively small numbers of red-throated divers were observed. Monitoring conducted later during the operational phase of the development between 2013-2016 revealed higher numbers of RTDs, but outside of the wind farm in the wider study area, leading to concerns that RTDs were being displaced from the site. Although monitoring methods differed between the baseline and the operational phase, it was nonetheless concluded that the distribution of RTDs within the Greater Wash had changed significantly between the baseline and operational monitoring periods (Webb & Nehls, 2019).

The consent condition to conduct ornithological monitoring was re-opened by Natural England, due to concerns over the effect of the wind farm on what was a provisional Special Protected Area (pSPA), and the developer was asked to conduct further survey work to establish whether displacement effects on RTDs persisted beyond the three years of operational monitoring already undertaken.

1. A shadow Appropriate Assessment (AA) commissioned by the developer concluded that Lincs was built on sub-optimal habitat for RTDs (a point made within the original ES Chapter) and that the areas of optimal habitat in the wider local, Wash Approaches, were secure and able to support the small numbers of displaced birds from the turbine array footprint (Marine Space, 2017). The monitoring was discharged in 2018 (6 years after the site was built), but it is clear from the large volume of documentation associated with the site on the MMO Public Register that the process was far from simple.

2. The management of large SPAs for highly mobile receptors alongside large-scale offshore wind continues to pose issues both in the consenting and post-consent phases of developments. This case study is included to demonstrate the complexity of issues that can arise during the operational phase of a project and the need for clearer guidance to better support decision-making.

3. The extent of developer responsibility is unclear, specifically:

a) It is unclear whether the developer is or is not responsible for potential effects on protected species at their wind farm site over the whole project life.

b) There is no agreed process for dealing with ecological change, and no process for dealing with issues which were not raised at assessment, but which have become more relevant during the project life.

c) There is no agreed process for dealing with future designations and possible requirements to monitor protected species in the future once PCM has been discharged. (In this case Lincs was not located within the SPA boundary, so concern was associated with potential for pressures occurring outside of the SPA boundary to spill into the SPA and effect receptors within the SPA).

d) There is no clarity or guidance around when the consent condition to monitor birds should/should not be re-opened.

6.5. Other data types

We have summarised three key broad types of data that have been collected, or are currently being collected, within the context of PCM: at-sea surveys (including boat-based surveys and DAS), bird-based telemetry data and visual tracking data. These are key data sources in providing information about abundance, space use, movement and behaviour. However, the review has highlighted additional types of data that may provide additional information relevant to assessments, and that have either been collected as part of PCM, or else have been considered for collection, which are turbine-based radar and video data can be used to assess meso- and micro-avoidance and to estimate collision-related mortality (Skov et al., 2018) and rangefinders (e.g. Petterson, 2005) which can be used to estimate flight heights. A third type, colony-level monitoring of abundance and productivity can be used to understand overall trends in demography and abundance for protected populations. In general, trends in colony-level data may be difficult to attribute to OWF impacts, but when linked at an individual-level to data on OWF exposure (e.g. telemetry data) they can potentially be used to directly estimate demographic consequences of OWF interactions. Even where they cannot be directly linked to OWF exposure, colony-level data may provide important context for interpretation of other PCM data, by, for example, providing an indication of overall population health and variability. Colony-level monitoring and abundance is already undertaken within long-term monitoring programmes outside of the context of PCM, but not all colonies are monitored in all years and there is potential in some circumstances for PCM to fund additional, targeted, colony-level monitoring that can supplement these wider monitoring programmes and provide data on those populations that are most directly at risk for OWF impacts.

6.6. Application of learning from PCM to cumulative assessment and future project-based assessments

We outline the ways in which post-consent monitoring data collected as part of licensing requirements and analysed using the approaches described above, can be better used to inform cumulative assessments and future project-level assessments, and the mechanisms required to overcome barriers to delivering this.

6.6.1. Review of assessment tools

Assessments of OWF impacts on seabirds, in the context of HRA and EIA, currently exploit a range of quantitative tools. ORJIP AssESs WP1 (**AssESs – Summary report of uncertainty and approaches to evaluating uncertainty review (D01))** has reviewed the methods and tools that are commonly used in the context of assessments, and the SNCB guidance around the use of these approaches. Tools to assess collision risk from OWF are typically based on the Band Model (Band, 2012), or on the associated stochastic collision risk model (sCRM) that extends this model to include stochasticity in input parameters (Caneco et al., 2022). Displacement risk is quantified using either a simple visual approach known as the Displacement Matrix (JNCC, 2022) or, in the breeding season for certain species, using an individual-based model (SeabORD, Searle et al. 2018). Tools are also used to apportion OWF effects to protected populations, with approaches varying between the breeding and non-breeding seasons, and to evaluate longer-term consequences of annual effects via population viability analysis (PVA; e.g. via the NE/JNCC PVA tool, Searle et al. 2019). Assessments quantify annual mortality from protected populations as a result of collision and/or displacement, and the resulting impacts in relation to metrics such as change in population growth rate over a 30-year period. Cumulative (in-combination) effects are typically quantified by assessing the project-level effect and then adding this to mortality estimates for OWFs that have already been consented. The Cumulative Effects Framework (CEF) integrates existing assessment tools, and the data used in running them, and is designed to provide a transparent approach to the assessment of project-level and in-combination effects. This tool is not yet in the public domain.

The tools used within assessments contain input parameters, and SNCBs provide guidance around the values of the parameters, and around the treatment of uncertainty regarding these values. ORJIP AssESs WP1 review ed this guidance, and the underpinning scientific literature. A relatively small set of parameters within these models directly control the magnitude and form of spatial interaction between OWFs and birds:

- Within collision risk models the avoidance rate determines the proportion of individuals that avoid exposure to collision risk;
- Within the displacement matrix and SeabORD the *displacement* rate determines the proportion of individuals that are susceptible to displacement;
- Within the displacement matrix and SeabORD the *buffer* area, represented as a distance around the OWF footprint, determines the spatial scale over which displacement occurs;
- Within SeabORD the *displacement zone* determines the size of the area, beyond the footprint plus buffer, into which birds are displaced;
- Within the Displacement Matrix, the demographic consequences of OWF-bird interactions are directly controlled by a parameter, the Displacement Mortality Rate, whilst the Band Model / sCRM and SeabORD derived estimates of demographic consequences through mechanistic approaches and so do not contain parameters that directly control the magnitude of these consequences;
- Collision risk models also contain a range of additional parameters that, although not directly related to OWF-bird interactions, are related to the magnitude of collision-related mortality and are assumed to relate to the period of OWF impacts. These include flight height, flight speed, proportion of nocturnal activity and proportion of upwind flights.

6.6.2. Information arising from PCM that is potentially relevant to assessments

Post-consent monitoring data provide a range of information that is of relevance to assessments. PCM data have the potential to provide direct information on OWF-related mortality, information on the quantitative values of the inputs used to quantify mortality within assessment tools (Cook et al., 2018) and on the plausibility of the assumptions that underpin the representation of processes. Where the data indicate that the assumptions that underpin current assessment tools and methods are implausible, they may also be able to help in identifying ways in which these assumptions could be modified to improve plausibility. Key input parameters that can be informed by PCM include those that directly control the magnitude and scale of spatial interactions between birds and OWFs in relation to avoidance and displacement (Table 5), but PCM data also have value in informing the values of other key parameters that relate to the period of OWF impacts (e.g. flight height, which is a key determinant of collision risk).

Table 5. Key inputs/outputs for current seabird assessment tools with potential to be informed by post-consent monitoring data

Input to assessment process	Relevant to impact type	Assessment tools the input feeds into	Potential types of monitoring data that may provide information relevant to this input
Displacement Rate	Displacement	Displacement Matrix and SeabORD	- At-sea survey data (aerial and boat-based) - Individual-based tracking data (e.g. GPS)
Buffer width			
Displacement zone		SeabORD	
Barrier Rate		SeabORD	- Individual-based tracking data (e.g. GPS)
Displacement Mortality Rate		Displacement Matrix, SeabORD	- Individual-based tracking data (e.g. GPS) and linked behaviour, energetics, demographic data
Avoidance rate	Collision	Band Model / sCRM	- GPS tracking data - Turbine-based video/radar data
Flight height			- GPS tracking data
Flight speed			- GPS tracking data
Collision-related mortality		Cumulative assessments	- Turbine-based video/radar data

6.6.3. Feedback from PCM into cumulative assessments

One potential use of PCM is in informing cumulative (in-combination) assessments. The potential magnitude of cumulative impacts is a key concern in relation to consent risk, with high levels of uncertainty regarding cumulative impacts leading to a precautionary approach. PCM could provide improved estimates of OWF effects for monitored windfarms, which should reduce uncertainty regarding cumulative impacts, thereby reducing the need for precaution. This should, in turn, lead to increased headroom.

PCM data have historically been unable to provide direct, purely empirical estimates of OWF-related mortality, although direct data on collision mortality (e.g. turbine-based video) are now starting to be collected as part of PCM. Displacement-related mortality arises from sub-lethal effects, so is inherently challenging to estimate empirically, since the attribution of mortality to the consequences of displacement is only possible with additional assumptions.

The key value of PCM data within the context of cumulative assessments, at present, will therefore be in providing improved estimates of the input parameters used in assessment tools, allowing these tools to be re-run for monitored projects, to produce improved estimates of mortality. The most obvious relevance of PCM data will be in producing empirical estimates of spatial OWF-bird interactions that can be used to provide updated estimates of the magnitude and spatial scale of displacement and avoidance for the monitored OWF, which can then be used to produce updated estimates of mortality for this OWF for use in cumulative assessments. Crucially, the empirical evidence derived from PCM data relates directly, within this context, to the OWF for which mortality is being quantified, so there is no need to make assumptions of spatial transferability between OWFs. However, there are still a range of scientific and statistical challenges that need to be taken into account when using PCM data to produce updated estimates of parameters relating to displacement and avoidance:

1. Challenges in abundance will not arise solely from OWF effects, so the effects of external shocks (e.g. disease, extreme events), a shifting baseline (e.g. as a result of climate change) and temporal variability all need to be accounted for when translating spatial changes in abundance into estimates of displacement or avoidance;
2. Habituation may lead the magnitude, form and scale of OWF-bird interactions to change systematically over time;
3. The spatial extent of surveys must be sufficient to be able to detect displacement/avoidance across the scales at which these processes occur;
4. Parameters within assessment tools may have a complex interpretation, and by difficult to relate to empirical evidence – the avoidance rates used in collision risk models, for example, include a correction to account for model mis-specification, and so are not straightforward to relate to empirical evidence on avoidance (**AssESs – Summary report of uncertainty and approaches to evaluating uncertainty review (D01)**);
5. Assessment tools typically make strong simplifying assumptions (e.g. that the magnitude of displacement is not dependent on direction) that may conflict with the empirical evidence derived from PCM.

A complex set of judgements are therefore required when using PCM data to produce revised estimates of displacement and avoidance-related parameters, and advanced statistical approaches may also be needed. PCM data can also be used to provide revised estimates of other CRM parameters, such as flight height and flight speed.

6.6.4. Feedback from PCM into future project-level assessments

PCM can also be used to improve future project-level assessments by producing updated estimates of parameters within assessment tools, allowing updated estimates of mortality. The key distinction in this case, is that information from PCM data at consented OWFs is being used in producing estimates of mortality for OWFs that have not yet been consented. This involves the same challenges and considerations as though involved in using PCM data in cumulative assessments, but also involves additional challenges around spatial transferability. Crucially, PCM data must be available from a sufficiently diverse and representative set of OWFs that empirical information derived from these OWFs can, defensibly, be extrapolated out to other OWFs. This depends upon judgement, and empirical evidence, as to how OWF impacts vary in relation to (a) spatial location, (b) environmental conditions and (c) OWF characteristics. Assumptions around transferability relate to assumptions about the underlying biological mechanisms, especially predator-prey dynamics, so research projects such OWEC PrePARED are investigating the potential for transferability of evidence from PCM-type data between sites.

There may be situations in which PCM can be used to directly extrapolate from one wind farm to another. The empirical flux Collision Model of Kleyheeg-Hartman et al. (2018), for example, provides a mechanism for translation of absolute estimates of collision mortality at one site into predictions of collision-related mortality at another site, circumventing some of the challenges associated with estimating collision risk using a mechanistic collision risk model. This model effectively assumes that even though collision risk depends on a large number of factors, only some of these will differ (or differ substantively) between OWFs, with the result that relative differences in collision-related mortality between two sites will depend on a much smaller set of parameters than the absolutely level of mortality at a single site. This thereby provides a mechanism for empirical estimates of collision-related mortality at one site to be used to provide an estimate of collision-related mortality at another site.

As noted earlier, current PCM data do not include direct monitoring of collision-related mortality, and displacement-related mortality is inherently challenging to directly observe. A more general use of PCM is therefore likely to be in informing SNCB guidance on the parameter values that should be used within assessment tools, including advice around region-specific parameter values (e.g. where evidence from PCM can be transferred to nearby projects with similar environmental conditions). SNCB guidance represents a synthesis of the available evidence, so other relevant sources of data (e.g. from long-term monitoring programmes and research projects) will be considered alongside PCM when this guidance is reviewed and updated, and where PCM data from multiple OWFs are available there will be advantages in synthesising information across these datasets. Data integration, aggregation, and synthesis are commonly used terms when considering analyses that combine data in some way. Meta-analyses use multiple independent studies to calculate statistics, generally from aggregate data, accounting for effects or sample sizes. This type of analysis, when applied to PCM data, is likely to be most useful when considering parameters estimates for assessment tools such as displacement or collision risk (e.g., Lamb et al., 2024). Pooled analyses, where 'raw' data from multiple OWFs would be combined offer greater potential for a better understanding of transferability, and hence would be of great benefit to informing new guidance. A recent paper by Blackwell & Matthiopoulos (2024) estimates utilisation maps by jointly modelling survey data and tracking data, allowing multiple types of data to be used and uncertainty to be propagated through the modelling process. Explicit spatio-temporal hierarchical modelling approaches such as `inlabru` (Bachl et al., 2019) also have the capability to integrate multiple data types and OWFs to analyse pooled data. However, pooled analysis requires data that are overlapping in time, space, and species. Therefore, it is not only important that baseline and post-construction are well characterised in terms of spatial and temporal extent, but that data collection also covers pre-construction and construction. Given that environmental conditions are rapidly changing, and some areas are experiencing shocks to the system such a HPAI and marine heatwaves, it is essential that we can characterise and understand the impacts of the changing baseline on seabirds and the ecosystem (NatureScot, 2023; Piatt et al., 2024).

6.6.5. Feedback from PCM into assessment approaches

As well as providing improved estimations of parameter values, PCM can also provide a range of broader, more qualitative, information around the plausibility of the assumptions that underpin current assessment methods and tools. If PCM consistently indicate that the magnitude of displacement or avoidance is related to specific, quantifiable OWF-related or environmental characteristics, for example, then this would suggest that assessment approaches should be modified so that the values of these parameters are specified in relation to these characteristics. Judgement is required, however, as to whether there are sufficient, and sufficiently representative, PCM data to defensibly revise the approach to assessment. The process for arriving at such judgements needs to be consistent and transparent.

6.7. Conclusions

PCM has typically involved at sea surveys but is beginning to also involve the collection of tracking data and other forms of data collection (e.g. turbine-based radar/video). There is potential for PCM to reduce uncertainty, and thereby precaution, within assessments. This will currently be via the use of PCM to produce improved estimates of input parameters used within assessment tools, and to improve the tools themselves (e.g. by identifying situations in which the assumptions that underpin the tools are violated), although there may be potential in future for PCM to also provide direct estimates of mortality (e.g. if turbine-based radar/video data are used).

PCM can feed into both cumulative assessments and future project-level assessments. In both cases, complex judgements are typically required to translate evidence from PCM into estimates of assessment-related parameters. The key distinction between the two contexts is that the application of PCM to future project-level assessments relies on assumptions around spatial transferability and is therefore dependent upon synthesis of information across multiple OWFs, making pooled analyses and meta-analyses particularly important. It is important that existing PCM data are exploited as far as possible, to extract insights relevant to the assessment process, and throughout this section we have highlighting analytical approaches that can enable this to happen - for example through the use of data integration methods to analyse data across multiple survey platforms. In Sections 6 and 7 we focus on the potential for PCM to feed into updates to SNCB guidance, bringing together the statistical and scientific considerations discussed in this section with the outcomes of Sections 4 and 5 in relation to policy and processes.

7. Interactive app

7.1. Introduction

We have identified barriers to 'closing the loop', alongside potential solutions, in relation to policy, process, and data availability (Sections 4 and 5) and to scientific and statistical considerations (Section 6). Some of these issues required additional discussion with the stakeholders to develop an understanding of how and when they relate to the evidence base and guidance. We focused on key points which are:

- Establishment of best practice in relation to the collection and analysis of PCM;
- Aligning outputs from the analysis of PCM with the inputs required for cumulative assessments and future project-based assessments;
- The statistical power of PCM to empirically detect OWF effects, and to the capacity of PCM to reduce uncertainty in assessments;
- Combining information obtained from PCM at multiple sites (e.g. through aggregation, pooled analysis, data integration and meta-analysis);
- Accounting for spatial variation and transferability, particularly in context of using PCM to inform assessments for future projects;
- Accounting for external shocks and temporal variation – in particular in order to understand the extent to which temporal change in abundance arises from OWF effects, and the extent to which it may arise from other factors;

- The balance of evidence needed to justify changes to guidance.

Each point represents a complex set of underlying issues and will necessarily be linked with barriers relating to policies and processes that guide the use of scientific and statistical evidence from PCM within assessments. A second round of stakeholder engagement for the project was a focused group workshop (Section 8). This was designed to engage participants from the semi-structured interviews to explore in detail the ways in which these scientific and statistical barriers are addressed via current policy and processes, and the potential for improvements that would increase the use of PCM data within assessments.

7.2. Interactive app

Since many of these themes involve complex issues and trade-offs, we used a facilitation device for the focused group workshop to help to structure discussions by encapsulating the issues through use of quantitative examples to highlight key trade-offs. A web-based interactive app, developed in Shiny, has been developed which allows stakeholders to explore, quantitatively, how pre- and post-consent monitoring data can be used to provide evidence that will help to inform guidance around cumulative assessments and future project-level assessments, and to assist in identifying and resolving specific barriers to achieving this. The app investigates how scientific and statistical barriers to 'closing the loop' are addressed within policy and processes by allowing stakeholders to:

1. Explore the ability to detect effects of windfarm under difference scenarios.
2. Explore the impact of variability and external shocks on the ability to detect effects of the windfarms.
3. Explore how information from post-consenting monitoring data be used to review recommendations and guidelines, and the opportunities and challenges associated with doing this.

This exploratory quantitative approach was used to facilitate a focused feedback workshop. The app is user-driven, allowing stakeholders to explore a range of scenarios relevant to their own institutional processes, and a comparison of scenarios can be helpful in identifying and understanding trade-offs. Crucially, the tool is not designed to either provide definitive quantitative outputs (which would depend on an extensive analysis of existing monitoring data, beyond the scope of this project) or to propose or advocate for an approach to the analysis of PCM data, but is, rather, designed to provide a mechanism to enable and structure discussions between stakeholders.

The tool uses relatively simple statistical methods (generalised linear models), and assumes these methods are applied to aggregate project-level data (e.g. total annual abundance per project), which may either represent aggregate raw data or may represent data that have been processed and analysed prior to aggregation (e.g. to adjust for detection). The use of relatively simple methods, applied to aggregate data, enables the interactive tool to run quickly, making it an effective device for facilitation, but is also designed to reflect the types of data and analysis that might readily be available and implementable in practice. In particular, the tool is designed to capture the type of information that might be obtained from the main forms of data currently and historically used in PCM (e.g. DAS and boat-based at-sea surveys). The tool is not designed to present or propose best practice in relation to the collection or analysis of PCM, or to capture all of the potential for using PCM (especially in the context of alternative types of PCM data, such as telemetry and radar/video data), but is rather designed to capture a sufficiently plausible approach to the analysis of existing and current PCM data that it provides an effective basis for promoting and structuring discussion.

The tool focuses on a comparison of abundance between *post-impact* versus *pre-impact* periods. Since the tool is relatively generic and so may have relevance in multiple contexts, we do not define exactly which periods this comparison relates to but instead leave this for users to determine and discuss. Post-impact and pre-impact could, for example, relate to *post-construction* and *pre-construction*, but could also relate to *during construction* and *pre-construction* periods. The focus is, however, on a comparison of abundance between periods that are hypothesised to be biologically distinct (e.g. post-construction, pre-construction) rather than on periods that differ in relation to the status of the data being used (e.g. baseline, post-consent). As such, the app, although relevant to PCM, is not necessarily focused solely on data collected as part of post-consent monitoring requirements.

The tool uses a simulation-based approach, in which the true windfarm effect and other parameters (e.g. mean abundance, levels of variability) are assumed to be known. Data are simulated using these known parameters, but each simulated dataset is then analysed as if the true parameters were unknown. This process is repeated many times, and, by summarising across simulations, we can evaluate the performance of the analysis approach (e.g. the statistical power of that approach to detect a windfarm effect, and the bias and uncertainty associated with the approach). This simulation-based approach is widely used in statistics, including for power analysis. Different scenarios are captured by using different parameters within the simulations, and by controlling the form of data that are available within the analyses (e.g. some of the scenarios that we consider involve the simulations containing features that are controlled by data that we will assume are unavailable for analysis).

7.2.1. Explore the ability to detect effects of windfarm under difference scenarios

To assess how different levels of impact (defined as percentage change in abundance as a result of offshore windfarms effect and ranging from 0 to approximately −50%) can be detected with varying amounts of data explore, multiple scenarios were simulated with different projects collecting data at different points in time based on the users' inputs. Within the app, the users can select a timeframe for the analysis and the number of projects with data available within the geographic region of interest (e.g. 5 years period in East Scotland). Additionally, the users can specify how many years of pre-impact and post impact data were collected per project and the mean baseline abundance (abundance during pre-impact). The objective of this part was to stimulate discussions around bringing data into evidence across multiple projects, focused on opportunities and challenges relating to pooled analyses and data anonymisation. During the workshop, we demonstrated a scenario with data from a single offshore wind farm and progressively increase the number of projects and consequentially the amount of data. Note that the focus is upon the number of projects with *available* data, so although the scenarios in this section have relevance to discussions around future data collection requirements, they are also relevant to discussions around barriers to data availability. The scenarios assume that, at minimum, total annual counts are available for each project that is included in the analysis.

For each scenario, a power analysis was then carried out, by simulating and analysing 100 datasets and calculating the proportion of simulations for which the difference between pre- and post-impact abundance is significantly different from zero. Each dataset was simulated from a Poisson distribution with different mean in pre- and post-impact periods. Aggregated ecological count data will often be overdispersed (e.g. have higher levels of variability than we would expect from a Poisson distribution), so we account for this by simulating noise (variability) in the mean, on the log scale, from a normal distribution with mean of zero. To analyse each dataset, a generalised linear regression with a quasi-Poisson distribution (e.g. Poisson distribution, with standard errors adjusted to account for the effects of overdispersion) was run, with abundance as response variable and a binary variable representing period (pre- or post-impact period) as explanatory variable. As such, the models are used for simulation and for the analysis of simulated data are very similar (but account for overdispersion in subtly different ways).

Statistical power is designed to capture the extent to which there is evidence that an effect (in this case the wind farm effect) is different from zero. Whilst power is an important and widely used metric, there are key considerations that are not captured by focusing on power alone, including the uncertainty in estimated effects and any systematic bias associated with the estimation of effects. Within the app the mean estimated level of impact and associated uncertainty were therefore also calculated and visually compared with the true level of the impact used in the simulations. The app therefore presents multiple forms of information to users.

7.2.2. Explore the effect of natural variability on the ability to detect effects of the windfarms

Seabirds use different marine environments depending on food availability, breeding sites, and other ecological factors, which can vary both spatially and temporally. This natural variation can significantly influence ability to detect the impacts of windfarms. To illustrate how natural variability affect the ability to detect windfarm impacts, we simulated a highly simplified scenario where the geographical area of interest is divided into two different habitats: habitat 1 and habitat 2. For this exercise, we assume that the environmental conditions of the two habitats are different, and therefore the baseline abundance of seabirds and the magnitude of the windfarm effect both vary spatially between these habitats.

In this part of the app, in addition to the inputs mentioned above, the users can also specify the percentage of projects in habitat 1. User inputs were used to simulate a scenario with different developments collecting data at different points in time and in different habitats.

The data were simulated from a Poisson distribution, where the mean of the distribution varied across different time periods (pre- and post-impact) and across different habitats. Additionally, an interaction term between the period and habitat was included, so that the mean counts due to the impact differ across the habitats. As before, the data was analysed using a generalised linear regression with a quasi-Poisson distribution. However, here two different models were run 1) one with habitat type as explanatory covariate, in addition to pre- or post-impact period, and an interaction between the two terms and 2) one without habitat information but allowing abundance to differ between projects (by including project ID within the model, to capture some of the spatial variability between projects). A power analysis was carried out as described above and the mean estimates of impact and uncertainty compared with the true level of impact used in the model.

The aim of this section was to simulate questions about transferability of data, especially around the information required, challenges and potential solutions. During the workshop, we run three scenarios, one where projects were equally split between the habitats, one where the projects with data were biased towards habitat 1 and one where the projects with data were biased towards habitat 2. The assumption underpinning these scenarios is that we are ultimately interested in understanding the average windfarm effect across habitats 1 and 2, but that the data available may be skewed towards one or other of the habitats to investigate the impact of this skew. The objective was to demonstrate what could potentially happen when the available data are either spatially or temporally biased and such bias is not accounted for in the analysis (e.g. by including additional covariates), and how this might influence transferability.

7.2.3. Explore how can post-consenting monitoring data be used to review recommendations and guidelines

There are valuable opportunities to use evidence derived from post-consenting monitoring data to review, and where relevant update recommendations and guidelines. This process involves a detailed analysis and evaluation of the data to assess whether the available information warrants changes in the recommendations. Thus, here we focused on using the app to stimulate discussions the decision-making processes, especially around the weight of evidence required to adjust recommendations.

In addition to the inputs mentioned in previous sections, the users now have the option to select how frequently the data is reviewed, thus mimicking the process of evaluating how the power to detect varying levels of impact, as well as the uncertainty estimates, evolve over time as new data becomes available. This approach enables us to track how the growing body of evidence impacts the reliability of the conclusions drawn from the data.

The data were simulated and analysed as described above. However, instead of running one power analysis for the entire period, here we analyse the data in increments, starting from the second year after post-impact data is available, with the frequency of increments specified by the user (e.g. every 1 year, every 2 years, etc.). This allows for a dynamic understanding of how the power to detect impacts and the uncertainty in estimates change as more evidence accumulates.

7.2.4. External shocks

External shocks, events leading to changes in the number of seabirds, such as avian flu outbreaks, marine heatwaves, storms, or other extreme events, introduce a source of variability and uncertainty into the data. As these become more frequent, it is critical to consider how to best integrate them into the guidance and assessment processes. This calls for a careful consideration of how such shocks can best be handled when reviewing evidence and updating guidance. Thus, here we allowed for the inclusion of such external shocks in the simulated dataset to understand how they influence our ability to detect the effects of offshore windfarms, and the potential for external shocks to lead natural changes to wrongly be attributed as OWF impacts. To simulate the effect of an external shock, we reduce the number of seabirds in a single year. Data were then, as before, analysed using a quasi-Poisson generalised linear model with a covariate for period (post-impact vs pre-impact), habitat and an interaction between the two terms. Crucially, the model that is used to analyse the simulated data does not explicitly include the external shock, so that there is potential for the effect of the external shock to be wrongly estimated as part of the OWF impact. This is designed to reflect the reality that it will often be difficult to disentangle the effects of OWFs from those of external shocks, especially when shocks have just occurred.

The aim of this section was to stimulate discussion around the processes that would enable evidence from PCM to feed into the evidence base and into guidance in the future, as the amount of data increases, well as the thresholds of evidence required for updating guidance, and the ways that external shocks are accounted for within these processes. During the workshop we run a scenario without external shocks with data being reviewed every year once we had at least two years of post-impact data. The same scenario was then run with the presence of external shocks and the results from the power analysis and the estimates with associated uncertainty compared.

7.2.5. Conclusions

We have developed an interactive app that is designed to facilitate stakeholder discussion with the focused group workshop around issues relating to (a) statistical power to empirically detect OWF effects from PCM, (b) data availability, and levels of data collection, in relation to pooled analyses, (c) transferability and the use of auxiliary data (e.g. around environmental characteristics), (d) impacts of external shocks, and (e) incorporation of evidence from PCM into SNCB guidance around assessments.

8. Focused group workshop

A second stakeholder engagement event was held in December 2024 and most of the participants had taken part in the semi-structured interviews. A full workshop report is published as part of the project in the **Closing the Loop – Summary report of focused group workshop (D04b)**. A summary of the workshop is as follows:

The focused group workshop (similar to a focus group; Nyumba et al*.,* 2018) was conducted to:

1. Provide feedback about the outcomes of the synthesis of evidence approach we developed, which incorporates results from stakeholder interviews (undertaken Jul-Sep 2024) and develop consensus about how some of the potential solutions could be implemented in practice.
2. Discuss factors to be considered to incorporate data and evidence arising from post-consent monitoring data within assessments.
3. Contribute to the subsequent development of recommendations recognising stakeholder needs and constraints that account for existing barriers to uptake in the use of post-construction monitoring data.

The workshop was carried out in line with the ESRC's research ethics guidance for social research and reviewed by the JHI's Research Ethics Committee. The nature of workshops meany that confidentiality within the participant group was impossible, and it was made clear to participants that 'Chatham House Rules' apply (i.e. the topics of discussion can be discussed externally, but not the identities of participants). Informed consent was formally sought from each participant.

The workshop took place online over 3 hours. The first part focussed on a feedback discussion of the synthesis of evidence approach put forward by the project team, as a result of earlier activities from the project: a literature review of current policy and processes, semi-structured interviews, and seabird case study. These have been synthesised to identify barriers and potential solutions to resolve issues in using post-consent monitoring data. High-level feedback was sought on the barriers that had been identified, primarily on whether anything has been misrepresented or omitted. Feedback on the potential solutions was captured using a Miro board, designed to gauge information around how feasible the participants thought the solutions were to implement in practice.

After a short break, the second session adopted a participatory approach using the interactive app developed within the project to frame qualitative discussion. The interactive app allowed workshop participants to explore how pre- and post-consenting monitoring data can be used to inform their decision making. This enabled participants to explore the potential for such data to inform updates to their current recommendations, and to assist in identifying and resolving specific barriers to achieving this. This exploratory approach, delivered via a simple, user-friendly interactive tool, will be demonstrated, and a range of scenarios relevant decision-making processes were presented, with outcomes synthesised into recommendations relating to implementation and uptake of the strategic approach. The interactive app was presented in three parts (Sections 7.2.1-7.2.4), and after each part a relevant discussion was facilitated, which were:

1. The level of data that needs to made available so that they can brought into evidence, across multiple projects (e.g. data anonymisation, pooled analyses)
2. How transferability (e.g. across time, space, species) is accounted for when reviewing evidence
3. How and when data and evidence are incorporated into guidance, and evidence thresholds and criteria

The focused workshop was the intermediary step switching between understanding the parameters and constraints of the current processes to ‘closing the loop’ and looking forwards for viable solutions. The outcomes informed the development of draft recommendations for the project.

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