OFFSHORE RENEWABLES JOINT INDUSTRY PROGRAMME (ORJIP) FOR OFFSHORE WIND

Recommendations and roadmap (WP4)

AssESs: Assessing the extent and significance of uncertainty in offshore wind assessments

December 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 Žilvinas Valantiejus (zilvinas.valantiejus@carbontrust.com) and Ivan Savitsky (ivan.savitsky@carbontrust.com).

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- Royal Society for the Protection of Birds (RSPB)
- Scottish Government Marine Directorate

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Abbreviations

AssESs	Assessing the extent and significance of uncertainty in offshore wind assessments
BBVAS	Boat-based and visual aerial surveys
BRAIDS	ScotMER Bird Responses to Avian Influenza and Developments at Sea
CEF	Cumulative Effects Framework
CES	Crown Estate Scotland
DAERA	Department of Agriculture, Environment and Rural Affairs
DAS	Digital Aerial Survey
Defra	Department of Environment, Fisheries & Rural Affairs
DESNZ	Department for Energy Security and Net Zero
DisNBS	ORJIP Displacement in the Non-Breeding Season
ECOFlow	NERC Ecological Effects of Floating Offshore Wind programme
ECOFLU	NERC Understanding the Ecology of Highly Pathogenic Avian Influenza in Wild Bird Populations
ECOWIND	NERC Ecological Consequences of Offshore Wind
EIA	Environmental Impact Assessment
EU	European Union
GLS	Global Location Sensor (Geolocator)
GPS	Global Positioning System
HPAI	Highly Pathogenic Avian Influenza
HRA	Habitats Regulations Assessment
IBM	Individual Based Model
IEMA	Institute of Environmental Management and Assessment
InTAS	ORJIP Integration of Tracking and At-sea Survey Data
JNCC	Joint Nature Conservation Committee
KE	Knowledge Exchange
MARCIS	Marine Spatial Planning and Cumulative Impacts of Blue Growth on Seabirds
MD	Marine Directorate
MDE	Marine Data Exchange
MD-LOT	Marine Directorate Licencing Operations Team
MetaKitti	ORJIP Modelling of Kittiwake Metapopulation Dynamics

MMO	Marine Management Organisation
NE	Natural England
NERC	Natural Environment Research Council
NRW	Natural Resources Wales
ORJIP	Offshore Renewables Joint Industry Programme for Offshore Wind
OW	Offshore Wind
OWF	Offshore Wind Farm
OWEC	Offshore Wind Evidence and Change Programme
OWEER	Offshore Wind Environmental Evidence Register
OWEKH	Offshore Wind Evidence and Knowledge Hub
OWGRE	OWEER Evidence Gap Analysis and Reprioritisation
OWSAT	Offshore Wind Seabird Assessment Tool
PCM	Post-consent monitoring
POSEIDON	OWEC Planning Offshore Wind Strategic Environmental Impact DecisiONs
PrediCtOr	ORJIP/OWEC Prevalence of Seabird Species and Collision Events in Offshore Wind Farms
PrePARED	OWEC Predators and Prey Around Renewable Energy Developments
ProcBe	OWEC Procellariiform Behaviour and Demographics
PVA	Population Viability Analysis
QuMR	ORJIP Quantification of Mortality Rates associated with Displacement
RESCUE	OWEC Reducing Seabird Collisions Using Evidence
ScotMER	Scottish Marine Energy Research
sCRM	Stochastic Collision Risk Model
SEATRACK	Seabird Tracking
SG	Scottish Government
SNCB	Statutory Nature Conservation Body
SPA	Special Protection Area
SUPERGEN	SUstainable PowER GENeration
TCE	The Crown Estate
TTG	Technical Topic Groups
WP	Work Package

Executive Summary

This report presents the recommendations arising from the Offshore Renewables Joint Industry Programme for Offshore Wind (ORJIP) 'Assessing the extent and significance of uncertainty in offshore wind assessments' (AssESs) project. The key motivations for the project are an **urgent need to quantify current levels of uncertainty** across the **ornithological assessment** process, **sensitivities** of **estimated impacts** to different sources of uncertainty, and a need to **improve** the way in which **information** on **uncertainty** is **translated** into decision-making within the context of a precautionary approach.

This project was delivered through

- a **review** of approaches to the treatment of uncertainty within assessments and the evidence base that informs these approaches,
- a **quantitative** evaluation of how sensitive key impact metrics are to uncertainty in parameter values and model assumptions, and,
- **stakeholder engagement** (via workshops and in-depth semi-structured interviews) to understand how information on **uncertainty** is used in assessments within the context of the **precautionary principle**.

This report integrates this evidence into two sets of recommendations:

Recommendations around priority future research needs to reduce uncertainty are derived primarily from the update to the route map for reducing and quantifying uncertainty in assessments (Searle et al., 2021, 2023), which expanded the original set of 16 priorities to include an additional three emerging priorities, evaluated which priorities are most likely to lead to a reduction in uncertainty, and linked recent and current research activities that address these priorities.

Recommendations around improvements to the evaluation of uncertainty in ornithological offshore wind impact assessments, motivated by the extensive stakeholder engagement within the project:

A1: Develop clearer guidance around technical approaches to the use and propagation of uncertainty within assessment tools

A2: Improve the representation of consultants in the process of commissioning, developing and implementing tools

A3: Develop a more strategic approach to development and maintenance of tools used in assessments

A4: Co-develop ways to address situations in which over-precaution is perceived to occur

A5: Implement more systematic and rapid dissemination and evaluation of new evidence around uncertainty

A6: Facilitate more rapid integration of new evidence into Statutory Nature Conservation Body (SNCB) advice

A7: Ensure an appropriate level of cross-border consistency in approaches to uncertainty

A8: Promote a shared understanding and accessible communication of information around uncertainty

Each **high-level recommendation** contains a set of **specific recommendations**, for which we describe the motivation, roles, responsibilities, constraints, dependencies and timescales required to implement them.

There is a particular focus on highlighting recommendations that have potential to rapidly (e.g. within the next 12 months) deliver benefit. A **Roadmap** for the evaluation of uncertainty in assessments provides a summary of these recommendations for changes to assessments and is intended to be used as a visual tool to promote their uptake and dissemination.

1. Introduction

The Offshore Renewables sector is expanding rapidly, with the growth of the sector motivated by policies to mitigate anthropogenic climate change and increase energy security, driven by ambitious targets including the delivery of 60GW of energy generation at a UK level by 2030. Assessments of the potential ecological impacts of developments must be undertaken to meet the legislative requirements of the EIA (Environmental Impact Assessment) Directive (2011/92/EU), Marine Strategy Framework Directive (EC/2008/56), Habitats Directive (EC/92/43), Birds Directive (EC/79/409) and derived legislation. **Ornithological impacts** are of particular concern, given the global importance of UK seabird populations and the sensitivity of protected seabird species to offshore wind developments.

Assessments of ornithological impacts are complex and typically involve substantial **uncertainty**. Within this context, the legislative framework requires a precautionary approach to decision-making. This approach relies on quantitative and qualitative information around the form and magnitude of uncertainty, and on processes for interpreting this information within the context of the precautionary approach.

The AssESs project (Assessing the extent and significance of uncertainty in offshore wind assessments), funded by the Offshore Renewables Joint Industry Programme for Offshore Wind (ORJIP), aims to **improve the treatment of uncertainty within the assessment process for ornithological impacts**, to reduce risks and delays to the consenting of offshore wind developments.

The key motivations for the project are:

(a) an urgent need to quantify current levels of uncertainty across the assessment process, and sensitivities of estimated impacts to different sources of uncertainty and

(b) a need to improve the way in which information on uncertainty is translated into decision-making within the context of a precautionary approach.

This project is delivered through the following structure (please see 0 for schematic):

- A **review** of existing approaches to the treatment of uncertainty within assessments and of the evidence base that informs these approaches (Work Package (WP) 1).
- These reviews are used to structure a quantitative evaluation of how **sensitive** key impact metrics are to uncertainty in parameter values and model assumptions (WP2).
- Stakeholder engagement (WP3) is used to understand how information on uncertainty in used within assessments, within the context of the **precautionary principle**.
- This final report, from Work Package 4 (WP4) integrates evidence from all work packages into two sets of **recommendations** to address a) the reduction of uncertainty in ornithological assessment methods, and b) the treatment of uncertainty within ornithological offshore wind impact assessments.

We initially focus **recommendations around priority research needs to reduce uncertainty**. The updated route map (within WP1) identified research priorities, and the ongoing research activities that are underway to address these priorities, and we evaluate the extent to which evidence from the sensitivity analysis (WP2) and stakeholder engagement (WP3) modifies or expands these research priorities. We provide a high-level summary of the route map, focusing in particular on those research priorities that have the highest potential to reduce uncertainty. Since we have identified that some research activity is underway to address all 19 of the research priorities identified in the route map, and since existing initiatives (such as the review of the Offshore Wind Environmental Evidence Register (OWEER)) are currently underway to assess the impact of ongoing research projects and to provide a detailed review of their ability to close evidence gaps, it has not been feasible to identify specific new research projects or data collection activities that should be undertaken. However, the updated route map itself, which we have summarised in a more concise form here, will enable the outcomes of these existing initiatives to be translated into a prioritisation of work to reduce uncertainty. We have also (Section 3) focused on recommendations around specific translational research activities (e.g. around the translation of research into advice, the use of tools, and the communication and visualisation of uncertainty) that emerged from the stakeholder engagement in WP3 and that would underpin the use of broader research activities in reducing uncertainty within assessments.

Our main recommendations focus on **improvements to the evaluation of uncertainty in ornithological offshore wind impact assessments**. Development of these recommendations follows directly from the outcomes of the review of existing tools and evidence used in assessments (WP1), the updated route map (WP1), results of the sensitivity analysis (WP2) and, crucially, the stakeholder engagement (WP3). The recommendations distinguish between scientific and statistical principles and methods for quantifying, propagating and communicating uncertainty within assessments, and the interpretation of this information within the context of specific project-level and cumulative assessments. Recommendations around the former are driven by the outcomes of WPs 1 and 2, and the expertise of the project team, incorporating feedback from all stakeholders. In contrast, recommendations around the latter are driven by the stakeholder engagement within WP3, including both the workshop and follow-up engagement, and recognise (as reflected in the structure of engagement within the semi-structured interviews) that the Statutory Nature Conservation Bodies (SNCBs) ultimately have responsibility for issuing guidance around best practice in assessments. We emphasise throughout that the recommendations produced here need to support, rather than replace, production of such guidance, and the recommendations recognise that "precaution" has a legal, as well as scientific, interpretation in this context. This set of recommendations are therefore closely linked to the stakeholder discussions within WP3 around the use of uncertainty within the context of a precautionary approach.

Recommendations produced by projects are not always translated into practice. The project was structured to **maximise uptake of the recommendations** via a structured, in-depth stakeholder engagement programme. This included use of one-to-one interviews to identify key barriers to adopting new ideas, with the outcomes directly informing the development of recommendations (particularly those related to changes in the assessment process). Stakeholders were also engaged from the start of the project in determining the scenarios, tools and levels of uncertainty to be considered in the sensitivity analysis, which feed into recommendations around future research, ensuring relevance of quantitative results to stakeholder needs. Issues around uncertainty have the potential to become highly technical, so we focused on communicating and discussing ideas, issues and knowledge around uncertainty in a way that is appropriate to a broad audience.

Within this report we propose both a "route map" that sets out future research priorities (Table 1) and a "roadmap" (which provides a summary of recommendations for changes to assessments, and associated timescales). We also offer recommendations for future research and data collection (Section 2), and for changes to the assessment process (Section 3). We conclude with general conclusions (Section 4), in which we focus on project legacy and the uptake of recommendations.

2. Recommendations for future research

Within this project (report: **AssESs – Summary report of uncertainty and approaches to evaluating uncertainty review (WP1)**) we produced an update to the route map of Searle et al. (2021, 2023). The updated route map has identified 19 research priorities (16 priorities from Searle et al., 2023, together with three new emerging priorities) for reducing, and better quantifying uncertainty in relation to the main components of the current assessment process for ornithology (spatial distributions and apportioning, displacement, collision, population viability analysis) and in relation to broader considerations around prey and ecosystem effects. We show these research priorities in Table 1, and, for each of these priorities, summarise the information in the route map to highlight the following key features of each priority:

(a) whether it was evaluated to have high potential for reducing uncertainty;

(b) to which stages of the assessment process it is relevant;

(c) which forms of data collection (if any) are involved in addressing the gap;

(d) the current and recently completed research projects (and other activities) that are underway to address the priority; and,

(e) any key evidence gaps relating to the priority that are not currently being addressed.

The focus for the review of current and recently completed research projects is on UK-based research, since this is most likely to directly align with, and have direct biological relevance to, the requirements of the UK assessment process. Non-UK research can also have relevance to UK assessments, but it was beyond the scope of this project to review all relevant non-UK research.

“Potential for reducing uncertainty” is used here to refer to the direct reduction of uncertainty (e.g. through the inclusion of new evidence arising from data collection). Other activities, such as sensitivity analysis, are indirectly important in reducing uncertainty (e.g. by allowing for the prioritisation of data collection), but “potential for reducing uncertainty” is used here solely to refer to activities that have potential to directly reduce uncertainty.

Other elements of this project have also delivered new evidence pertinent to the research priorities identified in the updated route map. The sensitivity analyses in WP2 have provided new evidence for how uncertainty in key parameters in impact models and inputs, as well as potential correlational bias in parameters, drives changes in key impact metrics. The stakeholder engagement in WP3 has identified areas of future research of particular relevance to stakeholders. The results of the sensitivity analysis and stakeholder engagement have not, however, altered the overall classification of research priorities within the route map. The results of the sensitivity analyses have highlighted the importance of research priorities within the route map around better quantification of avoidance and displacement rates, the importance of dealing with structural uncertainties in population models, and the importance of formulating models such that the effects of external shocks can be captured (e.g., by including relationships between population size and spatial distributions, thereby providing a mechanism to incorporate potential spatial impacts of Highly Pathogenic Avian Influenza (HPAI) on seabird exposure to developments). Stakeholder engagement indicated particular interest from some stakeholders around research to study wider ecosystem effects, but otherwise focused primarily on the delivery of reductions in uncertainty through changes to the interpretation and communication of information around uncertainty, and the development of processes for the translation of new and emerging evidence into updates to SNCB guidance – these topics around translation are addressed directly by the recommendations in Section 3.

It is clear from the updated route map, summarised in Table 1, that much research is already underway to address each of the research priorities, including several multi-million pounds, medium-term collaborative projects (e.g., around ecosystem effects and prey) that involve novel data collection, albeit limited in geographic scope and species coverage. Yet, some key high-priority evidence gaps remain unaddressed, primarily relating to topics that are challenging to study using available data collection technologies (e.g., rates and demographic consequences of displacement for non-adult birds). Other more specific and detailed evidence gaps will exist (particularly in relation to less well-studied species), and there is potential for new research projects to address these gaps, but the identification of these relies upon a detailed investigation of the outputs being produced by current research projects, and an evaluation of the extent to which they will address evidence gaps. Such activities are currently underway, through reviews of the impact of current research projects (for example by the Offshore Wind Evidence and Change Programme (OWEC)) and through re-assessment of key evidence gaps (Offshore Wind Environmental Evidence Register (OWEER) and OWEER Evidence Gap Analysis and Reprioritisation (OWGRE), alongside the Scottish Marine Energy Research Programme (ScotMER)) to identify the extent to which evidence gaps have been, or will be, resolved by current research. Evaluation of the logistics of key forms of data collection were also considered within the **ORJIP Closing the Loop Project**.

The project **Closing the Loop: Feasibility study to determine a feedback approach for post-consent monitoring to reduce consenting risk in future assessments** was undertaken from Apr 24 - Aug 25. Closing the Loop sought to improve the use of post-consent monitoring data (PCM) within the assessment process using a seabirds as a key receptor group. The project produced a set of recommendations, co-developed with stakeholders, to enable PCM data to be used effectively to help reduce uncertainty in the consenting process in the context of both cumulative and future project-based assessments.

It would not be appropriate at the moment, therefore, for this project to provide recommendations around specific new pieces of data collection or underpinning research, because this will duplicate or potentially conflict with these ongoing, overarching activities – led by both OWEC and the Joint Nature Conservation Committee (JNCC). We do, however, provide recommendations around specific pieces of translational research that have emerged as priorities from the process of stakeholder engagement, as part of our recommendations in relation to improvements to the assessment process (Section 3).

Table 1: Summary of route map of research priorities for better estimating and reducing uncertainty in seabird offshore wind farm assessments, moving beyond current tools and methodologies; this is a simplified and summarised version of the updated route map for quantifying and reducing uncertainty that was created in December 2024 for WP1 of this project.

Highlighted cells indicate priorities that were classed as having a "high" contribution to reduction in knowledge uncertainty, as derived by expert judgement – i.e., the authors' assessment for how much each proposed research priority would improve quantification of uncertainty, and reduce knowledge uncertainty, within the context of the UK assessment process.

The stages of the assessment process associated with each research priority are listed in round brackets: S = spatial distributions, A = apportioning, D = displacement, C = collision, P = PVA, E – Ecosystem effects. For recommendations that involve data collection the data collection technologies used in addressing each research priority are listed in square brackets

Research priority (relevance to stages of the assessment process) [forms of data collection involved]	Recent and ongoing projects (since 2023), with notes on any key outstanding gaps (refer to List of Abbreviations for full project names)
1. Data integration from different sources and seasons for better knowledge of **year-round distributions** to quantify and reduce uncertainty (S, A) [Global Positioning System (GPS), Global Location Sensor (Geolocator) (GLS), Digital Aerial Survey (DAS), Boat-based and visual aerial surveys (BBVAS)]	ORJIP InTAS; OWEC PrePARED, Niven et al. 2025
2. Improving uncertainty quantification in movement models (S, A) [GPS, GLS, Motus Wildlife Tracking System (Motus)]	Industry funded work in Forth-Tay; OWEC PrePARED; broader methodological and software developments
3. Better understanding and quantification of year-round distributions and impacts of displacement to quantify and reduce uncertainty (S, A, D) [GLS, DAS, BBVAS, improved GPS technology, Motus]	ScotMER Aukestra; SEATRACK; MARCIS; OWEC POSEIDON; ORJIP DisNBS, **but remains a key gap for many species**
4. Better understanding and quantification of predator-prey interactions, relationship between prey density and prey availability, impacts of offshore wind farms on prey distributions and availability to quantify and reduce uncertainty (S, D, C, E) [DAS, BBVAS and GPS linked to acoustic pelagic prey data]	OWEC PrePARED; NERC ECOWIND programme, **but remains a key gap for many species**

Research priority (relevance to stages of the assessment process) [forms of data collection involved]	Recent and ongoing projects (since 2023), with notes on any key outstanding gaps (refer to List of Abbreviations for full project names)
5. Estimate link between displacement effects and changes in demographic rates (productivity and survival) to better quantify and reduce uncertainty (S, A, D) [GPS linked to other individual-level data on breeding success and survival]	Industry-funded work in Forth Tay, **but remains a key gap for species other than kittiwakes and auks and in other geographical regions**
6. Effects of displacement on different age classes, e.g., immatures and non-breeders to better quantify and reduce knowledge uncertainty (D) [GLS, GPS, Motus]	ORJIP DisNBS; international work around empirical evidence & (e.g. via MARCIS) development of IBMs; **effects of displacement in many species and in non-adult birds remain a key gap**
7. Improve uncertainty quantification within (Individual Based Model) **IBMs** to better characterise and reduce structural and parameter uncertainty (D, C)	OWEC PrePARED
8. Assess sensitivity of collision risk model outputs to variation in input and structural parameters; understand and quantify covariance between parameters used in collision risk models to better quantify and reduce structural and parameter uncertainty (C)	**AssESs – Summary report of sensitivity analysis (WP2)**
9. Improve estimates of flight speed and flight height for species to better characterise and reduce parameter uncertainty, quantify influence of environmental conditions to better characterise natural variability, and understand how variation in flight speed and flight height is related to behaviour (e.g., commuting versus foraging) and Offshore Wind Farm (OWF) characteristics (turbine height and spacing) to reduce knowledge uncertainty (C) [GPS]	ScotMER BRAIDS; OWEC ReSCUE, **but remains a key gap for many species**
10. Improve estimates of avoidance rates and partitioned into micro-, meso- and macro-avoidance to better quantify and reduce structural and parameter uncertainty; improve understanding of the influence of environmental conditions on avoidance to better characterise natural variability; improve understanding of the contribution of model error to predicted collision rates and the implications of this for estimates of avoidance rates (C) [GPS; radar, cameras, turbine monitoring, Motus]	ScotMER BRAIDS; ORJIP/OWEC PrediCtOr; other empirical studies reviewed in Lamb et al., 2024, **but remains a key gap for many species**

Research priority (relevance to stages of the assessment process) [forms of data collection involved]	Recent and ongoing projects (since 2023), with notes on any key outstanding gaps (refer to List of Abbreviations for full project names)
11. Improve estimates for abundance, productivity, adult and immature survival, carryover effects, and inter-colony movements (including uncertainty in rates) to better quantify and reduce parameter uncertainty (P) [ring recovery data; Motus, mark-recapture/resighting, productivity monitoring]	ORJIP MetaKitti; OWEC Remote Tracking of Seabirds at Sea; **Remains a key gap for species other than kittiwake**
12. Empirical estimation of correlation in demographic rates and influence of environmental stochasticity to better characterise natural variability and improve quantification of structural and parameter uncertainty (P, E) [colony counts, productivity data, mark-recapture/resighting]	Horswill et al., 2023, Layton-Matthews et al., 2023; **remains a key gap for many species**
13. Understand relationship between demographic rates and prey availability to better quantify and reduce knowledge uncertainty; improve estimates for interactions between demographic rates and climate and other environmental variables to include in population forecasts to better characterise natural variability and other stressors (P, E)	NERC ECOWIND programme, **but remains a key gap for many species**
14. Integrated population modelling and model fitting methods to better quantify structural and parameter uncertainty by using all available abundance data to inform estimation of demographic rates; improved models of observation error for abundance estimates to support this (P)	OWEC ProcBe
15. Sensitivity analyses for PVAs to help prioritise efforts to reduce structural and parameter uncertainty (P)	**AssESs – Summary report of sensitivity analysis (WP2)**
16. Better understanding and quantification of density dependent processes in populations to reduce knowledge uncertainty (P) [count data, productivity data]	Merrall et al. 2024
Emerging research priorities (since Searle et al., 2023):	
17. Improved quantification of seabird diet outside of chick-rearing, especially during non-breeding season, and ability to switch between different prey species as availability changes; associated variability in demographic rates in relation to diet and prey availability (S, P, E) [diet data, isotopes, eDNA]	ScotMER Aukestra, **but remains a key gap for many species**
18. Impact of external shocks (extreme weather, marine heatwaves, disease outbreaks) on the abundance, distribution, behaviour and demographics of seabirds to better quantify and reduce structural and parameter uncertainty (S, A, D, C, P, E)	ScotMER BRAIDS, NERC ECOWIND , NERC ECOFLU projects, **but remains a key gap for many species**

Research priority (relevance to stages of the assessment process) [forms of data collection involved]	Recent and ongoing projects (since 2023), with notes on any key outstanding gaps (refer to List of Abbreviations for full project names)
19. Quantification of the rates of 'turnover' of seabirds observed at sea, including estimates for foraging site fidelity, to reduce structural and parameter uncertainty (A, D, C) [GPS]	ORJIP QuMR, ScotMER BRAIDS, Industry-funded work in Forth-Tay, **but remains a key gap for many species**

3. Recommendations for changes to assessments

Within this section we propose a set of recommendations around changes to the assessment process to improve the use of information on uncertainty within the process. Within the recommendations we focus primarily on proposing **specific** activities that could rapidly deliver benefit to the outcomes of the assessment process, and that could **feasibly** be implemented within the context of the existing assessment process.

These recommendations are heavily based on the outcomes of the stakeholder engagement activities within WP3, to ensure that they align with the priorities and constraints of relevant stakeholders. To promote uptake of recommendations, we have embedded a transparent process of **co-development** with stakeholders throughout the project lifecycle. This has involved a multi-stage process of stakeholder engagement, to (a) understand current issues with the treatment of uncertainty within assessments, (b) identify potential solutions to these issues and (c) evaluate barriers to the implementation of these solutions. In particular, the formal process of stakeholder engagement used a workshop – which involved a broad audience of relevant stakeholders, and included open discussion, interactive Miro boards, and break-out groups - to identify key barriers and potential solutions. The workshop outcomes were used to structure more detailed follow-up engagement via **semi-structured interviews** with individuals representing a cross-section of organisations actively involved in assessments (including industry, SNCBs, consultants and regulators). Outcomes from these interviews directly fed into the production of draft recommendations, and in identifying the timelines, constraints, dependencies and roles and responsibilities associated with these recommendations. The draft recommendations were refined using outputs from WP1 (review) and WP2 (sensitivity analysis) and using expertise within the project team.

3.1. How to use the recommendations tables

The recommendations are constructed as a **high-level recommendation** in a statement preceded by "A" and a number (A1, A2…) followed by brief text that provides context around the recommendation. A table is presented for a set of **specific recommendations** (A1.1, A1.2…) associated with each high-level recommendation: these specific recommendations provide a set of specific, time-limited, activities that would enable the high-level recommendation to be delivered.

The tables use a colour-coding system to denote timescale over which actions to achieve the recommendation could take place. Timescales are categorised as 'Quick win', 'Tactical', and 'Strategic' and Table 2 shows the definition, explanation, and colour-coding of the categories.

Note that the structure of the recommendations tables is similar to that used in the ORJIP Closing the Loop Project, but the specific definitions of the timescales are different, reflecting the distinct contexts of the two projects.

Table 2: Definition of timescale categories

<table>
<tr><th>Action type</th><th>Timescale</th><th>Constraints and dependencies</th><th>Resourcing</th></tr>
<tr><td>Quick Win</td><td rowspan="2">Has potential to begin immediately and to rapidly (e.g. within 12 months) provide benefit to the operation and outcomes of the assessment process</td><td>No substantive constraints, dependencies or risk that would prevent implementation</td><td>No substantive new resources required</td></tr>
<tr><td>Tactical</td><td>Some dependencies, but does not require major changes to underlying processes</td><td>May require some additional resourcing or redistribution of existing resources</td></tr>
<tr><td>Strategic</td><td>Will deliver longer term benefits – exact timescales will depend on the dependencies</td><td>May be dependent on substantial changes to underlying processes that are outwith the scope of this project</td><td>May require substantial changes to, or increases in, resourcing</td></tr>
</table>

The remaining columns within each specific recommendations table can be interpreted in the context of motivation, roles and responsibilities, and constraints and dependencies:

Motivation: A rationale for the inclusion of a recommendation.

Roles and responsibilities: Organisations or groups of organisations that would be responsible for delivering the recommendation, and their roles within this delivery. Table 3 shows the groupings of organisations that are used in specifying roles and responsibilities.

Constraints and dependencies: Many of the recommendations being made here require resourcing, particularly of staff time, or are subject to other constraints (e.g. around the need for stakeholder agreement on roles and responsibilities). Recommendations may also be dependent on other recommendations being implemented, or on changes within the sector that may occur outwith the scope of this project.

Table 3: Designated groupings by organisation used in the recommendations

Grouping	Organisation included
Regulators	Marine Management Organisation (MMO), Scottish Government (Marine Directorate Licencing Operations Team (MD-LOT), MD-Science), Cyfoeth Naturiol Cymru / Natural Resources Wales (NRW), Department of Agriculture, Environment and Rural Affairs (DAERA), Department of Environment, Fisheries & Rural Affairs (Defra), Offshore Wind Evidence and Knowledge Hub (OWEKH)
SNCBs (Statutory Nature Conservation Bodies)	Joint Nature Conservation Committee (JNCC), Natural England, NatureScot, Cyfoeth Naturiol Cymru / Natural Resources Wales (NRW), Department of Agriculture, Environment and Rural Affairs (DAERA)
Industry	Developers, consultants, sub-contractors, data collection contractors
Researchers	Academia, consultants
Tool owners	Organisations that own tools used within assessments: currently Scottish Government, Natural England, JNCC and NatureScot, but may expand in future to include other organisations.
Tool developers	Organisations (academia, consultants) that have been contracted to develop tools specifically for use within assessments

At the time of publication, the Offshore Wind Evidence and Knowledge Hub (OWEKH) membership was Institute of Environmental Management and Assessment (IEMA), Department for Energy Security and Net Zero (DESNZ), Defra, DAERA, NRW, Welsh Government, Planning Inspectorate, and MMO. OWEKH is expected to receive contributions from Scottish Marine Energy Research (ScotMER), Tethys, Offshore Wind Evidence and Change Programme (OWEC), Ecological Consequences of Offshore Wind (ECOWIND) and Ecological Effects of Floating Offshore Wind programme (ECOFlow), and SUstainable PowER GENeration (SUPERGEN). Within OWEKH knowledge is disseminated through Evidence Notes and a community of practice.

3.2. Recommendation A1: Develop clearer guidance around technical approaches to the use and propagation of uncertainty within assessment tools

Context: Stakeholder engagement in WP3 showed widespread acknowledgement of the challenges of managing uncertainty through the assessment process, but demonstrated a desire for more clarity within SNCB guidance around approaches to propagating uncertainty between tools to streamline the running of assessments and ensure consistency. Specific challenges around the propagation of uncertainty arise from (a) the fact that uncertainty is not always available for the impacts of existing projects used in in-combination assessments, and (b) the Displacement Matrix being implemented to date using a scenario-based approach that differs from the probabilistic approach used within the stochastic collision risk model.

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A1.1. [Quick Win]. More specific information within SNCB guidance around the approaches to take to propagation of uncertainty between tools in situations where uncertainty is only partially quantified	This situation presents specific technical challenges because stochastic and deterministic outputs need to be combined. The issue arises, for example, in relation to treatment of uncertainty within in-combination and cumulative assessments, where information on uncertainty in estimated impacts is typically available for some projects but not others	**SNCBs** to update guidance, following consultation with **researchers (academics and consultants)**	**See Section 3.10 for a more detailed discussion around implementation of this recommendation.** Need to adopt an approach that is both consistent (e.g. across different situations, and ideally across different UK administrations) and defensible. Would be expedited by addressing constraints around SNCB resourcing (A6.2)

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A1.2. [Tactical]. Transition to quantifying uncertainty in the Displacement Matrix probabilistically (via simulation)	This approach would ensure that uncertainty in the Displacement Matrix was implemented in comparable ways to that used in stochastic collision risk modelling, and in ways that would allow propagation of uncertainty from the Displacement Matrix into Population Viability Analysis (PVA). In practice, this would involve simulating displacement and displacement mortality rates, and using simulated density values (as are e.g. already used in the Stochastic Collision Risk Model (sCRM)), and thereby generating a set of simulated displacement mortality values	**SNCBs** to update guidance, following consultation with **consultants** and **academics.** Possible link to the **Cumulative Effects Framework (CEF)**, which developed functionality (R code) around this	Need for agreement around distributional assumptions to make for displacement rate and displacement mortality rate, and consequent updates to SNCB guidance around ranges of rates to use. Need for a consequent change to the interpretation of displacement-related mortality, from a scenario-based approach to a focus on more statistical approach to the quantification of uncertainty in outputs

3.3. Recommendation A2: Improve the representation of consultants in the process of commissioning, developing and implementing tools

Context: Stakeholder engagement highlighted the crucial role of consultants, but noted that research projects and project steering groups, whilst involving developer representation, rarely include consultants, who are the group most likely to use tools or methods developed through those research projects. There is therefore a need to improve consultant representation within the processes of commissioning, developing and implementing new tools and methods, and to facilitate the use of existing tools by consultants.

Specific action	Motivation	Roles and responsibilities	Constraints and dependencies
A2.1. [Quick Win]. Improve mechanisms to support consultants in using tools, e.g. via the establishment of user forums for individual tools	There are currently no formal mechanisms in place to provide support to consultants in using tools, so this recommendation aims to address this	**Tool owners and SNCBs:** strategic oversight; **Tool developers:** contribute to support; **Consultants:** engage	Need clarity around respective roles of SNCBs and tool developers. Would ideally be structured in such a way as not to impose additional demands on SNCB staff, or require uncosted inputs from tool developers
A2.2. [Quick Win]. Develop opportunities for knowledge exchange and shadowing, to allow greater understanding of consultant/end user experience by tool developers and SNCBs	Shadowing, and other related knowledge exchange (KE) activities, may allow tool developers and SNCBs to gain greater understanding of the challenges faced by consultants in using tools and methods	**Consultants:** to liaise with **tool developers** and **SNCBs**	Short, informal placements (e.g. a few days) may be possible to organise on a bilateral basis. Longer or more formal placements are likely to need budget and SNCB coordination
A2.3. [Tactical]. Include consultant representatives in project steering groups and in the commissioning of research projects that will involve development of tools	Involvement of consultants in the development of methods and tools from the outset may help to identify and mitigate challenges to the use of these methods and tools within assessments	**Funders**, especially of projects involving tool development: to invite consultancies; **Consultants:** engage	Funding of staff time may be needed to allow consultancies to be represented. Could potentially begin immediately but benefit will emerge as research projects complete

3.4. Recommendation A3: Develop a more strategic approach to the development and maintenance of tools used within assessments

Context: Quantitative tools are used throughout the assessment process, and are central to SNCB advice, but stakeholder engagement highlighted challenges in working with current tools (particularly in relation to lack of available training), and a desire for greater clarity around the process of establishing when new tools need to be developed or refinements to existing tools are required.

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A3.1. [Quick Win]. Greater provision of training in relation to assessment tools	The need for training in tools was identified by stakeholders as a key priority	**Tool developers**: create training workshops; **Tool owners:** oversight (and where relevant commissioning) of training; **Consultants**: attend training	Training should be co-designed between tool owners and tool developers. Funding or charging mechanism to enable co-development of training should be agreed
A3.2. [Tactical]. Develop a mechanism to provide strategic overview of the quantitative tools used within the assessment process: e.g. to agree refinements to tools, and identify requirements for development of new tools	There is a need for a mechanism to streamline the process of aligning tool refinements and development with evidence gaps, and of aligning tool versions between UK administrations	To be decided, but **SNCBs and regulators** (both as tool owners, and as developers of guidance) will have a key role. Link to existing prioritisation mechanisms: **OWEKH, ScotMER**	To streamline processes, and avoid duplication, use link to existing prioritisation mechanisms, but with focus on the specific features and versions of individual tools. User forums (A2.1) may support delivery of this recommendation

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A3.3. [Tactical]. Ongoing funding or internal resource for the maintenance and development of tools routinely used within assessments	There is no formal ongoing process of maintenance in place for existing tools, which can lead to delays in resolving issues identified by tool users	Coordinated and funded by **tool owners**, explore potential for funding by **The Crown Estate (TCE) / Crown Estate Scotland (CES)**	Dependent upon setting up a viable funding mechanism and would be expedited by addressing constraints around SNCB resourcing (A6.2). Exact scope of "maintenance" would require clear definition

3.5. Recommendation A4: Co-develop ways to address situations in which over-precaution is perceived to occur

Context: There is widespread perception from industry stakeholders of "over-precaution" within the calculations involved in assessments, particularly in relation to a concern that precaution may accumulate through the different stages of the assessment process. Although this position is not necessarily shared by all stakeholders, there are specific challenges around the interpretation of uncertainty in relation to precaution. This recommendation focuses upon identifying practical ways in which specific forms of perceived over-precaution could be addressed in ways that would be acceptable to a range of stakeholders.

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A4.1. [Tactical]. An agreed set of criteria to ensure that quantified levels of impact are biologically plausible, especially where they directly form the basis for determining the magnitude of compensation required	Industry stakeholders highlighted situations in which they felt that quantified levels of impact were implausibly high. There would be value in stakeholder discussions (outwith the context of casework) to agree general criteria for assessing biological plausibility of quantified levels of impact	**SNCBs** work in consultation with **developers**, **consultants** and **researchers**. **SNCBs**: to update guidance. A mechanism will be needed to develop consensus around appropriate criteria for evaluating "biological plausibility": workshops may be an appropriate way to achieve this outcome. Some expert elicitations have already been conducted around expected mortality associated with displacement effects in a range of species in both breeding and non-breeding seasons (ORJIP QuMR project)	Challenges in formulating clear and transparent criteria for sense-checking of biological plausibility that are accepted by a range of stakeholders. Need to integrate agreed criteria into SNCB guidance

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A4.2. [Tactical]. Reach agreement around standardised working definition(s) of precaution that are used within the sector	Stakeholder engagement yielded limited information regarding legal definitions of precaution, and the outcomes of the engagement tentatively suggested that legal definitions were not regarded as a primary barrier to the adoption of alternative approaches to the treatment of uncertainty and precaution within assessments. However, there is a need for clarity around the way in which precaution is defined in practice within the context of offshore wind assessments, since ambiguity around this can create confusion and create challenges around the evaluation of uncertainty in relation to precaution	**SNCBs, regulators, developers, consultants** and **researchers:** to discuss, potentially via a workshop or short research project (e.g. involving experts in environmental law)	A starting part will be to identify legal definitions that are used, but the key aspect of this recommendation is to understand, and reach consensus around, working definitions that are used in applying these legal definitions within the specific context of offshore wind assessments. Differences between UK administrations will need to be considered
A4.3. [Strategic]. Develop alternative approaches to quantifying baseline abundance within the Displacement Matrix, to replace the current seasonal mean peak density approach	Industry stakeholders highlighted issues with the use of the mean peak density (based on 2 years of at sea survey data), on the grounds that it may not provide a representative or reliable measure of baseline abundance within the windfarm. There is value is considering alternative approaches to quantifying levels of baseline abundance to use when quantifying displacement mortality	**SNCBs, consultants** and **academics:** to work together to develop alternative approaches. potentially via a short research project; **SNCBs**: to update guidance	Challenges in gaining consensus around an appropriate alternative approach to use. For example, use of the mean density (based on 2 years of at sea survey data) has been put forward as a potential alternative, but there does not appear to be consensus around this. Work to explore alternatives could begin rapidly but benefit would only arise once this work was completed

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A4.4. [Strategic]. Move to the evaluation of precaution in relation to uncertainty in outputs rather than uncertainty in inputs	Industry stakeholders expressed concern around the accumulation of precaution (the possibility of "precaution on precaution") when precaution is applied to individual model inputs at different stages of modelling. They highlighted the interpretation of precaution in relation to outputs as a potential alternative. Work in WP2 highlighted ways in which uncertainty in outputs may be more completely captured, via propagation of uncertainty between tools, making the interpretation of uncertainty in outputs rather than inputs more statistically defensible	**SNCBs, regulators, developers, consultants** and **researchers:** to discuss and evaluate potential alternatives, potentially within the context of workshops or a research project; **SNCBs:** to subsequently update guidance	**See Section 3.10 for a more detailed discussion around implementation of this recommendation.** Challenges in gaining consensus around an appropriate alternative approach to use. Approaches such as the use of mean values throughout are simple but do not explicitly capture uncertainties in outputs. Simulation-based approaches to propagation of uncertainty between tools allow uncertainty in outputs to be captured, but depend on changes to the use of the Displacement Matrix (A1.2) and require careful interpretation in relation to qualitative forms of uncertainty. Consequent shift in interpretation, and the way scenarios are used, would require substantive changes to SNCB guidance

3.6. Recommendation A5: Implement more systematic and rapid dissemination and evaluation of new evidence around uncertainty

Context: Research plays an integral role in the growth of the offshore wind industry, as scientific evidence is used to inform policy decisions and increase understanding about the environmental implications of offshore wind farms. Evidence around uncertainty is a critical element of this but can be particularly challenging to evaluate, given the different ways in which information on uncertainty is calculated, reported and summarised.

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A5.1. [Quick Win]. Research projects advised to include lay (plain English) summaries to help stakeholders assess relevance and transferability of findings and associated uncertainties by clearly communicating assumptions, limitations and confidence levels	Information around the uncertainty, limitations and caveats associated with the findings of research projects is not always currently reported in a way that is consistent or accessible to all stakeholders	**Funders:** to request or require this; **researchers:** to produce summaries; mechanisms (e.g. **OWEKH Technical Topic Groups**, **ScotMER**): needed to ensure dissemination	Clear guidance on the appropriate format and structure of such summaries, particularly in relation to reporting of information on uncertainty, would be needed (links to A8.1). Dissemination mechanism needed (see A5.2). Work could begin rapidly, would deliver benefit as research projects complete. Links to Recommendation F2 of ORJIP Closing the Loop Project

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A5.2. [Tactical]. Develop mechanisms to promote awareness of new evidence (around uncertainty) methods and tools amongst stakeholders	More rapid uptake of new methods and tools depends upon an awareness of these methods/tools amongst stakeholders, including consultants, SNCBs and researchers	Avoid duplication by exploiting existing mechanisms of **OWEKH, ScotMER:** to coordinate; **all stakeholders**: to engage	Both OWEKH and ScotMER need to be involved as SG not part of OWEKH. Links to Recommendations F3 & F5 of ORJIP Closing the Loop Project. An additional constraint to rapid uptake of new methods is ensuring that tools are user ready and have good associated documentation – inclusion of consultants in the process of tool development (A2.3) and better mechanisms for ongoing maintenance (A3.3) will help with this. Not all evidence emerging from research can be directly used in assessments, so synthesis or adaptation may be needed (see A5.3)

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A5.3. [Tactical]. Develop mechanisms to systematically evaluate the relevance of emerging evidence to the models and parameters considered within SNCB advice, accounting for the uncertainty associated with this evidence	When determining the appropriate parameter values to use within assessment tools, and the uncertainty associated with this, it will typically be necessary to evaluate multiple sources of evidence. These may differ in the approaches used for data collection and analysis, in the resulting caveats and limitations, and in the potential for transferability. Structured processes to synthesise and evaluate this evidence in a transparent way would support the process of updating SNCB advice. Possible mechanisms for debating and analysing emerging evidence on a regular (e.g. annual basis) could include Evidence Bridges or topic-specific workshops	Coordination, collaboration and dissemination via **OWEKH Technical Topic Groups (TTG), ScotMER and SNCBs**	Linked to recommendations for the evaluation of evidence from post-consent monitoring data being developed within the ORJIP Closing the Loop Project. Links to Recommendation F1& F3, and J (evidence bridges) of ORJIP Closing the Loop Project. As new tools are developed, they need, where feasible, to be futureproofed to be able to accept evidence updates

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A5.4. [Tactical]. Identify ways of reducing the complexity, and increasing the biological realism, of tools and methods used within assessments	Stakeholder engagement raised concerns around (a) the complexity of current tools and methods and (b) areas in which tools and methods lack biological realism. Model complexity can increase as additional realism is included in models, but it is also possible for complexity to increase in ways that are either redundant or infeasible to parameterise. This recommendation proposes work to identify, via biological judgement and statistical considerations, those situations in which (a) complexity could be reduced without loss of accuracy and realism, and (b) situations in which additional realism is required	**SNCBs, regulators, developers, consultants, researchers:** via a short research project, whose main focus would be workshops to bring together a range of relevant experts and stakeholders, followed by work to develop specific ways of reducing complexity and/or increasing realism	Would need to build on the exploratory work around this topic undertaken within WP2 of this project, and, in the context of displacement, on work undertaken within the ORJIP QuMR project. A key challenge for this work will be in developing consensus around the evaluation of accuracy, given the challenges involved in empirically validating many of the models and tools used in offshore wind assessments

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A5.5. [Strategic]. Increased involvement of SNCBs and developers in joint evidence gathering (e.g. data collection) to address key evidence gaps	The involvement of key stakeholders in the design and implementation of research projects helps to ensure that the outputs from those projects directly address key evidence gaps, and use approaches that are regarded as defensible by stakeholders, maximising the potential for the outcomes of these projects to be rapidly integrated into the evidence basis that underpins SNCB guidance	Via joint funding mechanisms (such as **ORJIP**), or, where not feasible, through active involvement of relevant stakeholders in project steering groups and expert panels; **OWEKH Technical Topic groups** and **ScotMER:** could agree evidence suitability for closing evidence gaps & approving new technology for data collection	A high level of active involvement in design and planning of the research may be necessary to ensure that there is agreement around the design and methods. Would be expedited by addressing constraints around SNCB resourcing (A6.2). Links to Recommendations F5, H1 and H5 of ORJIP Closing the Loop Project

3.7. Recommendation A6: Facilitate more rapid integration of new evidence into SNCB advice

Context: It is important that as new evidence, becomes available that it is rapidly translated into SNCB guidance. This recommendation focuses around the specific challenges in doing this in relation to new tools and quantitative methods. This is complementary to recommendations within the ORJIP Closing the Loop project around the integration of evidence from post-consent monitoring data into SNCB guidance. There is a specific need to consider the implications of the WP1 review for SNCB guidance.

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A6.1. [Strategic]. Improve resourcing for SNCBs and key public sector actors to enable (a) more rapid incorporation of evidence into SNCB advice, (b) effective participation of SNCBs in steering groups for cross-sector research projects	The role of SNCBs and regulators is key, but there are major constraints on resourcing of these organisations. The other recommendations that we have proposed are designed to not be completely reliant on additional resourcing for SNCBs and public bodies, but additional, targeted, funding would expedite implementation of many of these recommendations	**All stakeholders:** to advocate for additional, targeted, funding, and to identify potential funding mechanisms; **SNCBs, regulators:** to ensure that if additional funding is provided then it is targeted to actions that would maximise benefit	Constraints on overall public spending, and, in some cases, on recruitment. Benefits of increased resourcing may not be immediate (given, e.g., time required to recruit and train staff). Links to Recommendation G1 of ORJIP Closing the Loop Project

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A6.2. [Tactical]. Regularly update SNCB guidance in relation to new statistical approaches and tools	Active research programmes around the ecological impacts of offshore wind (such as OWEC, ORJIP, ECOWIND and ECOFLOW) mean that new methods and tools are rapidly being developed, and there is a need to ensure that updates to SNCB advice account for these developments. Advice in relation to new methods and tools can be particularly challenging to update regularly, since the specific caveats and limitations of methods/tools in relation to their use in assessments may be challenging to assess. Evidence emerging from academic research (e.g., NERC) may not always be designed to link directly into impact assessment frameworks, requiring translation prior to use	**SNCBs:** to update guidance; **developers** and **consultants:** liaise	Would benefit from a structured process of evaluating evidence, via Evidence Bridges or other approaches (A5.3). Depends on awareness and understanding of new approaches and tools, so links to A5.1 and A3.1. Would be expedited by addressing constraints around SNCB resourcing (A6.2)

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A6.3. [Quick win]. Evaluate the implications for SNCB guidance of the review of parameter values and associated uncertainty undertaken within WP1 of this project	The review of parameter values and associated uncertainty within WP1 of this project provided a comprehensive review of the empirical evidence around the values of key parameters used within assessments, including flight speeds, flight heights, levels of nocturnal flight activity, avoidance rates and displacement rates. The review makes a number of specific criticisms around the use of this body of evidence within current SNCB guidance (e.g. around the use of evidence based on air rather than ground speeds in specifying guidance on flight speed, and around the use of evidence for terrestrial windfarms in specifying guidance on avoidance rates). There is a need for these criticisms to be considered, and, where appropriate, for SNCB guidance to be rapidly updated	**SNCBs:** to review current guidance in light of the outcomes of the WP1 review, consulting relevant stakeholders where appropriate	Needs to align with existing processes for review of SNCB guidance, and for alignment of guidance across UK administrations

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A6.4. [Tactical]. Clearer documentation around the criteria that are used in determining how specific sources of empirical evidence are used within the development and updating of SNCB guidance	The use of empirical evidence in updating SNCB guidance will depend on evaluation of a range of criteria, around data quality, relevance and transferability. More information around the criteria used for this evaluation, and how these translate into decisions around the extent to which a particular piece of evidence is used or not in updating guidance, is key to improving transparency, and would be of value in ensuring that research projects maximise their impact	**SNCBs:** to consider ways in which this information could be provided	Would be expedited by addressing constraints around SNCB resourcing (A6.2) and by developing mechanisms to systematically evaluate the relevance of emerging evidence to the models and parameters considered within SNCB advice (A5.3)

3.8. Recommendation A7: Ensure an appropriate level of cross-border consistency in approaches to uncertainty

Context: Stakeholders expressed a desire for greater consistency in approaches to uncertainty across the different UK SNCBs. However, it was also appreciated there is a need to consider local circumstances within any drive for greater consistency, whether in relation to ecological, environmental or biophysical variation or to differing policy drivers between different UK administrations. As such, there will be situations where it is appropriate for differences to remain.

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A7.1. [Quick Win]. Continue efforts to streamline the production and updating of cross-UK guidance	SNCB representatives indicated that discussions are already ongoing about where greater consistency might be achievable	**SNCBs** with coordination from **JNCC**	Work is already underway - continues efforts that have already begun, and should rapidly deliver benefit
A7.2. [Tactical]. Provide specific guidance around approaches to take for quantifying impacts and associated uncertainty for projects that cut across different administrations	Differences in guidance and approaches between administrations present specific challenges for projects that cut across different administrations - e.g. where a project within the waters of one administration may impact on a Special Protection Area (SPA), or and/or be part of a cumulative effects assessment, within another administration	**SNCBs** with coordination from JNCC; liaising with **regulators** and **industry**	Challenges in formulating general advice that covers all relevant situations. Dependent on wider initiatives to develop cross-UK guidance (A7.1). Would be expedited by addressing constraints around SNCB resourcing (A6.2)
A7.3. [Strategic]. Investigate the potential to achieve greater cross-border consistency via integration of OWSAT (Offshore Wind Seabird Assessment Tool) and the CEF, particularly in relation to aligning the input datasets used by both tools	OWSAT and the CEF both aim to make assessments more standardised and transparent. There are technical challenges in fully unifying OWSAT and the CEF, as they have differing objectives and use differing approaches, but there would be value in unifying features (especially input data) that are common to both, and in identifying ways in which the two tools could perform complementary roles	**Natural England (NE)** and **Marine Directorate (MD)**: lead; **tool developers** and **data providers**: advise; **SNCBs**: update guidance	Differing timelines for the development of OWSAT and the CEF. Technical challenges around reconciling the use of different data sources (e.g. on colony counts). Would be expedited by addressing constraints around SNCB resourcing (A6.2)

3.9. Recommendation A8: Promote a shared understanding and accessible communication of information around uncertainty

Context: Stakeholders recognised the need for a shared understanding across organisations and emphasised a requirement for more accessible information around uncertainty to help inform decisions in the context of OW assessments. Translating technical understanding of uncertainty and related concepts into clear wording and visualisations that better meet the communication needs of all stakeholders involved, will underpin more effective dialogue and decision making.

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A8.1. [Tactical]. Promote accessible communication and visualisation of information about uncertainty within the context of OW assessments	Stakeholder engagement indicated consensus around the importance of improved communication of information on uncertainty, particularly to the stakeholders who will ultimately make decisions (e.g. ministers)	**OWEKH, ScotMER:** to coordinate**; All stakeholders:** to input, **academics with experience on communication and visualisation:** to advise on best practice. A research project or workshop may be a suitable vehicle to deliver this	The appropriate approaches to use for communication and visualisation are likely to vary between audiences. Communication to the ultimate decision makers (e.g. ministers) will be key

Specific recommendation	Motivation	Roles and responsibilities	Constraints and dependencies
A8.2. [Strategic]. Identify key skill shortages and training needs within the sector in relation to uncertainty, and identify and develop mechanisms for addressing these needs	There are challenges in ensuring that organisations cover the range of skills needed to deal effectively with uncertainty, so there is value in identifying skills gaps, and potential mechanisms for addressing these	**All stakeholders**: there is a need to identify an appropriate organisation to lead on this activity	Need to link to wider initiatives for identifying skill gaps within the sector. Even where skills gaps are identified there may be challenges in addressing these. Could begin relatively rapidly but the benefits of identifying and closing skills gaps are likely to be long term

3.10. Evaluation of precaution in relation to uncertainty in outputs

Overview

We are proposing (Recommendation A4.4) to "*Move to the evaluation of precaution in relation to uncertainty in outputs rather than uncertainty in inputs*". This recommendation arises from engagement in the stakeholder workshop and semi-structured interviews (WP3). Industry stakeholders raised concern around the compounding effect of precaution, where precaution is applied to individual model inputs at different stages of modelling, potentially leading to 'precaution on precaution', and highlighted that interpreting precaution in relation to model outputs could offer a more as a more appropriate approach. Within the stakeholder engagement process, statisticians also emphasised the benefit of moving to the evaluation of precaution in relation to uncertainty in outputs rather than inputs when uncertainty is being propagated between tools.

One of the key advantages of evaluating precaution in relation to uncertainty in outputs, rather than inputs, is that it enables a more explicit and transparent understanding of the overall level of precaution being applied. When precaution is applied across individual inputs at different modelling stages, it becomes inherently difficult to assess its overall impact. Moving the focus to outputs may offer a more consistent and transparent framework for applying precaution.

A rudimentary approach to applying precaution in relation to outputs is to use fixed non-precautionary values for inputs (e.g. using best estimates of parameters, rather than 95% quantiles or upper limits). Precaution could then, since it is not being applied to inputs, be applied to outputs. However, a drawback is that using fixed input values (without uncertainty) means that uncertainty in outputs would be unquantified, making it difficult to determine or justify an appropriate level of precaution to apply to outputs. A potential solution is to propagate uncertainty from underlying data that are used in models, and also propagate uncertainty between models using sets of interlinked tools, so that the uncertainties in outputs are quantified. Precaution could be evaluated in an explicit, probabilistic way (e.g. by selecting an appropriate quantile from the distribution of outputs). The choice of the level of overall precaution to apply would remain a judgement, involving legal as well as scientific considerations, but would be specified directly rather than indirectly, improving transparency and enabling more explicit discussion around the approach level of precaution to apply.

Motivating case study

We use an extremely simple illustrative case study in a simulated system to compare three different approaches:

1. interpretation of precaution in relation to uncertainty in inputs;
2. interpretation of precaution in relation to uncertainty in outputs, without propagation of uncertainty;
3. interpretation of precaution in relation to uncertainty in outputs, with propagation of uncertainty.

In practice, the treatment of precaution in relation to uncertainty involves a range of context-dependent non-quantitative elements (e.g. around adjustments for model mis-specification – where models fail to capture true underlying relationships in the data, the consideration of multiple scenarios, and qualitative considerations around transferability of evidence), but for the purposes of this illustrative case study we ignore these elements and assume that uncertainties can be fully quantified, and that precaution can therefore be evaluated in an entirely quantitative way. These simplifications allow us to consider questions around the link between uncertainty and precaution, so that, within the context of this simple system, it is possible to apply an approach in which uncertainty is fully quantified and propagated, and in which precaution is applied in a transparent way to outputs.

The methods and results used in the illustrative case study are given in Appendix 2: Illustrative case study around evaluation of precaution in relation to uncertainty. The results of this illustrative example indicate that, within the context of this simplified system, (a) an approach based on applying precaution to inputs, rather than outputs is over-precautionary, and in some cases highly over-precautionary whilst (b) an approach based on applying precaution to outputs without propagating uncertainty can be either over- or under-precautionary, depending on context (since the lack of information on uncertainty in outputs does not allow an appropriate level of precaution to be applied).

There are, however, important limitations and caveats when interpreting the results of this, or other, simplified case studies in relation to the actual assessment process. The actual assessment process is substantially more complex and diverse than the simple system considered in the case study, and the implications of these results for assessments are dependent on a number of key caveats and assumptions:

1. within this system uncertainty has been captured using a very large number of simulations (100,000): this will not always be feasible for the tools used in actual assessments (e.g. for computational reasons), and the use of smaller numbers of simulations will introduce a degree of approximation error (i.e. precision may be affected) even when uncertainty is propagated;
2. the models considered in the illustrative case study are exceptionally simple and the propagation of uncertainty through them is straightforward;
3. the illustrative case study makes simple assumptions around the distribution of model input (assuming that they are either uniformly or normally distributed), but in reality the distribution of inputs may be substantially more complicated that this (e.g. skewed, bimodal);
4. within this simple system we make the assumption that the model is correctly specified, that uncertainty in the inputs has been fully quantified, and that no other sources of uncertainty exist;
5. within this system we assume that precaution is evaluated entirely in relation to quantified uncertainties, and interpreted in a probabilistic way.

Assumptions (1), (2) and (3) mean that the detailed quantitative results (especially in relation to the appropriate adjustment factor to use for Approach 2) are unlikely to be generalisable, but the key qualitative conclusions follow from general statistical principles and are not likely to be dependent upon these assumptions.

Assumptions (4) and (5) are crucial, however, and mean that the results of the case study should be interpreted cautiously. In practice, as outlined in Searle et al. (2023) structural uncertainties mean that it cannot be assumed that all models used in assessments are correct (i.e. that there is no model mis-specification) and that uncertainties in all inputs are fully quantified, so the interpretation of precaution will need to account for these unquantified elements of uncertainty, and this will presents challenges whether precaution is evaluated in relation to uncertainty in inputs or outputs. It was also clear from stakeholder engagement in WP3 that SNCBs take a nuanced and diverse approach to the interpretation of precaution in relation to uncertainty in inputs, so the simplistic approach around "evaluation of precaution in relation to inputs" considered within the case study does not fully capture the approach that is currently used in practice.

Despite these caveats, the case study illustrates the potential benefits of moving to an evaluation of precaution in relation to outputs rather than inputs, and the potential drawbacks of approaches based on evaluation of precaution in relation to inputs. However, the caveats highlight that the evaluation of precaution in relation to outputs within assessments would still involve careful interpretation and judgement, especially around the interpretation of unquantified uncertainties when evaluating precaution.

Implementation of Recommendation A4.4.

A transition to the evaluation of precaution in relation to uncertainty in outputs rather than inputs (Recommendation A4.4.), would allow precaution to be treated in a more explicit and transparent way, and for this reason we regard the recommendation to move towards this is an important outcome of this project. However, realising the benefits of this change largely depends on uncertainty in outputs being as defensibly and consistently quantified as possible so that precaution can be explicitly evaluated in relation to the magnitude of uncertainty in the outputs. Quantification of uncertainty in outputs depends, in turn, upon the propagation of uncertainty throughout the assessment process. Current barriers to the interpretation of precaution in relation to uncertainty in outputs are:

a) that the Displacement Matrix is not currently regarded as a probabilistic, simulation-based approach, making it difficult to explicitly quantify uncertainties in outputs whenever displacement risk is considered. However, there is no substantive technical barrier to treating quantifying uncertainty in the Displacement Matrix (by simulating values of the displacement and displacement mortality rates from distributions that capture uncertainties associated with them). Using the Displacement Matrix in this way (Recommendation A1.2.) would be an important step in moving to a greater focus around quantification of uncertainty in the outputs of the assessment process, thereby enabling precaution to be interpreted in relation to those uncertainties.

b) the need to propagate uncertainty throughout the assessment process. However, the technical capacity to do this already largely exists within individual tools (see Appendix 3: Propagation of uncertainty through the assessment process for details), so there is no specific substantive technical barrier to this occurring.

c) The fact that there is considerable variation in the extent to which, and the way in which, uncertainty is quantified within the assessment process (e.g. Searle et al., 2021, 2023, and **AssESs – Summary report of uncertainty and approaches to evaluating uncertainty review (WP1)**). Propagation of uncertainty within this context is addressed via Recommendation A1.1.

Implementation of Recommendation A1.1.

Implementation of Recommendation A4.4. will, in most cases, be dependent upon propagating uncertainty through the assessment process in contexts where the quantification of uncertainty within individual elements of assessments (e.g. tools, input data) is incomplete, and, in some cases, completely missing. The issue is particularly acute within in-combination and cumulative assessments, where information on uncertainty in estimated impacts is typically available for some projects but not others. However, it will also arise in project-level assessments, since uncertainty is currently either unquantified, or only quantified in a partial way, within other key elements of assessments (particularly in relation to apportioning). Structural uncertainties are also largely unquantified throughout the assessment process. Stakeholders indicated the need for more specific information within SNCB guidance around the approaches to take to propagation of uncertainty between tools in situations where uncertainty is only partially quantified (Recommendation A1.1.). Guidance would need to clarified in relation to two elements:

1. The technical approach by which uncertainty can be propagated through assessment tools in situations where uncertainty is quantified in some cases and not in others: where, for example, stochastic and deterministic outputs need to be combined. Within a simulation-based approach to the propagation of uncertainty (described in more detail in Appendix 3: Propagation of uncertainty through the assessment process, and reflecting the approach that is currently used within assessments where propagation does occur) there is no inherent difficulty in combining outputs in these situations, since all outputs can be regarded as simulations, and resampling can, if necessary, be used to ensure that a common number of simulations is used across all inputs or tools that are being combined. Deterministic outputs are a special case of this in which the number of simulations can be regarded as one: the deterministic value can simply be repeated in order to have the same length as the stochastic outputs they are being combined with. As such, we would recommend that SNCB guidance be updated to clarify that uncertainty can be propagated even in situations where it is only feasible to partially quantify uncertainty through the use of a simulation-based approach in which resampling is used, where necessary, to ensure a consistent number of simulations.
2. Limitations on the ability of quantify uncertainty within specific elements of assessments will impose important limitations on the extent to which uncertainty in key outputs from assessments (e.g. PVA metrics) can be fully quantified. These limitations would need to be considered when interpreting uncertainty of outputs in relation to precaution, since they mean that quantitative measures of uncertainty in outputs will not necessarily capture all uncertainties, and SNCB guidance would need to reflect this. The interpretation is likely to be context-specific (depending on the elements of uncertainty that have not been feasible to quantify) and to require judgement around the likely impact upon the magnitude of uncertainty in outputs of being unable to quantify some sources of uncertainty.

3.11. Moving to a plan-level approach

Within the context of addressing issues around uncertainty and precaution, there was broad support across the sector for moving to a **plan-level approach**, particularly in relation to cumulative and in-combination impacts of offshore wind developments. This could provide a **strategic overview**, reduce inconsistent interpretation of guidance across projects, and help address mitigation and compensation at scale rather than through piecemeal efforts by individual developers.

Examples of existing plan-level work include:

- **The Crown Estate's plan-level (Habitats Regulations Assessment)** HRA for Leasing Round 4 in England and Wales, which gave an early indication of potential adverse effects of developments on kittiwake. However, impacts were mitigated at a project level (including compensation).

Despite limitations, the approach was helpful in enabling SNCBs to give advice e.g. on individual project designs.

- Scotland adopts a **National Marine Plan** (currently undergoing review) and has a **Sectoral Marine Plan** for offshore wind energy. Sectoral marine planning can use submitted application assessments, but timing often prevents overlap with all expected projects in each review cycle. Consequently, plans are regularly reviewed and revised as offshore wind rounds progress.

Although there were differing opinions on what a plan-led approach should look like, there are key aspects that a plan-level approach could address:

Benefits of a plan-level approach include:

- Increasingly complex project-level assessment could be alleviated by implementing a plan-level approach, and strategic assessments can help position individual applications within a broader framework.
- While **EIA legislation remains unchanged**, unnecessary complexity in project-level assessments could be reduced.
- Plan-level approaches can **integrate post-consent monitoring** data and individual assessments could access information from the plan-level (all scenarios) for consideration.
- **Improve knowledge about potential adverse impacts on key habitats and species**, and at an earlier stage, thereby enabling more strategic level approaches to compensation plans to be implemented (including requirements for species and regions) and lowering the risks on individual projects. Such knowledge would lead to early-stage agreement to identify critical bird species at a project level, enabling stakeholders to work together to resolve concerns.
- Improve marine spatial planning through identifying **unsuitable areas for leasing.**
- Allow for uncertainty in relation to compensation to be dealt with in a more strategic way: Support the propagation of cumulative and in-combination uncertainty, using 'as-built' numbers rather than estimated impact from previous applications
- Potentially enable SNCB staff resources to be focused more comprehensively on providing advice on other parts of the assessment processes.
- Ensure **consistency across projects** by assessing impacts at a larger scale.
- Plan-level assessments can be **scientific, transparent, and accommodate full uncertainty**.
- Encourage consensus on terms like **"realistic worst-case scenario."**
- Drive risk-based communication and bring transparency on assumptions and risks.
- Resources can be applied directly to conservation actions.
- A **centralised, developer-funded EIA model** (as in some EU countries) could reduce inconsistency across applications.

Challenges and considerations:

- Plan-level work requires robust **baseline data** (e.g. such as from the OWEC POSEIDON project or Round 5 in Celtic Sea surveys).
- Project-level assessments and compensation responsibilities would remain necessary.
- There is a risk of duplicating effort unless project-level requirements are adjusted.
- Implementation would require **cross-sector acceptance**, with clarity from regulators and SNCBs on respective roles, responsibilities, and the implications of a change in approach at the project level, including identification of any risks in changing to a new approach.
- Overall, while legislative changes may not be necessary, broad **stakeholder alignment** and clear governance will be essential for success.
- Could streamline project-level requirements, though **site-specific issues may still need detailed consideration**.
- **Compensation obligations must still be assigned at project-level** for clarity around financial responsibility.

Stakeholders showed support to adopt a change in scientific focus to a more strategic, **ecosystem approach** to more effectively manage environmental risks. This was seen as essential for identifying key areas of concern and managing environmental risks more effectively. Given the rapid pace of offshore energy development and the ongoing process of consenting projects, timely integration of best available and most recent evidence was viewed as critical. Industry representatives raised the importance of whole ecosystem understanding rather than relying only on time-bound or project-specific HRAs and EIAs. The need for a 'health of the ecosystem' assessment was raised so that there could be a better **understanding of environmental impacts of offshore wind at an ecosystem level**, and it was posed that academic work could propose **research and monitoring approaches** to do this. Such efforts could provide a more robust evidence base for environmental decisions, reduce uncertainty, and potentially **lower the substantial costs of compensatory measures**. Proposals for long-term, large-scale monitoring were seen as valuable to **de-risk the marine environment** through assessing the cumulative effects of windfarms and for understanding broader offshore stressors such as climate change and species' responses.

Roadmap for the evaluation of uncertainty in assessments

AssESs - Roadmap for the evaluation of uncertainty in assessments

Quick win | Tactical | Strategic

A1: Develop clearer guidance around technical approaches to the use and propagation of uncertainty within assessment tools	A1.1. More specific information within SNCB guidance around the approaches to take to propagation of uncertainty between tools in situations where uncertainty is only partially quantified	A1.2. Transition to quantifying uncertainty in the Displacement Matrix probabilistically (via simulation)			
A2: Improve the representation of consultants in the process of commissioning, developing and implementing tools	A2.1. Improve mechanisms to support consultants in using tools, e.g. via the establishment of user forums for individual tools	A2.2. Develop opportunities for knowledge exchange and shadowing, to allow greater understanding of consultant/end user experience by tool developers and SNCBs	A2.3. Include consultant representatives in project steering groups and in the commissioning of research projects that will involve development of tools		
A3: Develop a more strategic approach to the development and maintenance of tools used within assessments	A3.1. Greater provision of training in relation to assessment tools	A3.2. Develop a mechanism to provide strategic overview of the quantitative tools used within the assessment process: e.g. to agree refinements to tools, and identify requirements for development of new tools	A3.3. Ongoing funding or internal resource for the maintenance and development of tools routinely used within assessments		
A4: Co-develop ways to address situations in which over-precaution is perceived to occur	A4.1. An agreed set of criteria to ensure that quantified levels of impact are biologically plausible, especially where they directly form the basis for determining the magnitude of compensation required	A4.2. Reach agreement around standardised working definition(s) of precaution that are used within the sector	A4.3. Develop alternative approaches to quantifying baseline abundance within the Displacement Matrix, to replace the current seasonal mean peak density approach	A4.4. Move to the evaluation of precaution in relation to uncertainty in outputs rather than uncertainty in inputs	
A5: Implement more systematic and rapid dissemination and evaluation of new evidence around uncertainty	A5.1. Research projects advised to include lay (plain English) summaries to help stakeholders assess relevance and transferability of findings and associated uncertainties by clearly communicating assumptions, limitations and confidence levels	A5.2. Develop mechanisms to promote awareness of new evidence (around uncertainty) methods and tools amongst stakeholders	A5.3. Develop mechanisms to systematically evaluate the relevance of emerging evidence to the models and parameters considered within SNCB advice, accounting for the uncertainty associated with this evidence	A5.4. Identify ways of reducing the complexity, and increasing the biological realism, of tools and methods used within assessments	A5.5. Increased involvement of SNCBs and developers in joint evidence gathering (e.g. data collection) to address key evidence gaps
A6: Facilitate more rapid integration of new evidence into SNCB advice	A6.1. Improve resourcing for SNCBs and key public sector actors to enable (a) more rapid incorporation of evidence into SNCB advice, (b) effective participation of SNCBs in steering groups for cross-sector research projects	A6.2. Regularly update SNCB guidance in relation to new statistical approaches and tools	A6.3. Evaluate the implications for SNCB guidance of the review of parameter values and associated uncertainty undertaken within WP1 of this project	A6.4. Clearer documentation around the criteria that are used in determining how specific sources of empirical evidence are used within the development and updating of SNCB guidance	
A7: Ensure an appropriate level of cross-border consistency in approaches to uncertainty	A7.1. Continue efforts to streamline the production and updating of cross-UK guidance	A7.2. Provide specific guidance around approaches to take for quantifying impacts and associated uncertainty for projects that cut across different administrations	A7.3. Investigate the potential to achieve greater cross-border consistency via integration of OWSAT (Offshore Wind Seabird Assessment Tool) and the CEF, particularly in relation to aligning the input datasets used by both tools		
A8: Promote a shared understanding and accessible communication of information around uncertainty	A8.1. Promote accessible communication and visualisation of information about uncertainty within the context of OW assessments	A8.2. Identify key skill shortages and training needs within the sector in relation to uncertainty, and identify and develop mechanisms for addressing these needs			
Moving to a plan-level approach					

4. Conclusions

Given the importance of offshore renewable energy in the provision of energy security and in addressing the climate crisis there is a critical need for cross-sector collaboration to enable the rapid development of the industry whilst minimising environmental impacts, with stakeholders across the sector showing a willingness to work together towards this objective. However, there are substantial uncertainties around ecological impacts of developments in the marine environment, and the focus of this project has been upon identifying ways in which the treatment of uncertainty within Offshore Wind (OW) assessments can be improved. We have proposed recommendations around improving the treatment of uncertainty within assessments via (a) future research and data collection and (b) changes to the assessment process. These recommendations directly arise from work undertaken within the project – in particular, recommendations around changes to the assessment process have been derived through a multi-stage process of engagement that included a workshop and a series of semi-structured interviews involving a range of relevant stakeholders.

4.1. Recommended future research and data collection

Searle et al. (2021, 2023) provided a route map that outlined 16 research priorities that would reduce, or improve, quantification of uncertainty within the assessment process. This route map has been updated within this project (Table 1) to include an additional three emerging priorities, and to capture recent and ongoing research activities to address each of these priorities. The outcomes of the sensitivity analysis aligned with the research priorities identified in the updated route map, and the outcomes of the stakeholder engagement activities were consistent with these priorities (but focused primarily on the transition and interpretation of research into evidence, rather than on research itself).

The review of recent and ongoing research demonstrated that work is underway to at least partially address all 19 of the priorities, and that in many cases there are multiple strands of active research underway in relation to the priority. A range of initiatives to identify the extent to which evidence gaps have, or will be, addressed by these research activities are also currently underway (e.g. via a review of the extent to which evidence gaps in OWEER have been addressed). In order to avoid duplication with these activities, and since a detailed assessment of the outputs being produced by each of the ongoing research projects is beyond the scope of this project, we have not attempted to identify specific remaining evidence gaps in relation to the priorities identified in the route map. The route map itself, however, is of value in determining key areas of focus for future research, and we have explicitly highlighted those research priorities that have high potential to reduce uncertainty.

4.2. Recommended changes to the assessment process

We have proposed eight specific high-level recommendations for improvements to the assessment process in relation to the treatment of uncertainty, with each of these high-level recommendations then being broken down into a set of specific, time limited, recommendations. We have outlined the timescales, roles, responsibilities, constraints and dependencies associated with each of these specific recommendations. The recommendations have, in almost all cases, been derived directly from the stakeholder engagement activities, and so seek to reflect the constraints that stakeholders operate within, in order to maximise the potential for uptake.

There was a clear consensus amongst stakeholders that rapid changes to the assessment process are needed, given the pace of development, urgency required to mitigate climate change, and energy motivations for the expansion of the sector. We have therefore proposed a series of "quick win" and "tactical" recommendations, that capture incremental changes that could be made within the current assessment process and that would rapidly deliver benefit to the assessment process. We define both "quick win" and "tactical" activities as those that have potential to deliver improvements to the outcomes of the assessment process within around 12 months: we differentiate between them by defining "quick wins" as those that could be achieved without substantial additional resources or structural changes and defining "tactical" activities as those that are dependent on either additional resourcing or on structural changes.

Many of the recommendations that we have proposed align with recommendations that are arising, or have arisen, from other research projects. In particular, our high-level recommendations around the evaluation of evidence (A5) and around the incorporation of new evidence into SNCB guidance (A6) reflect broader discussions within the sector around these topics, and complement recommendations made within the ORJIP Closing the Loop Project which was undertaken at the same time as this project and which focused on increasing and improving the use of post-consent monitoring data.

Other recommendations are more specific to the remit of this project, and, although motivated by the outcomes of the stakeholder engagement, have been outlined in a particularly high level of detail because they relate specifically to expertise within the project team. In particular:

- moving to the evaluation of precaution in relation to uncertainty in outputs rather than uncertainty in input, building on work in WP2 which highlighted ways in which improved propagation of uncertainty between tools can make the interpretation of uncertainty in outputs rather than inputs more statistically defensible (A4.4.);
- improving communication of information on uncertainty in formats that are relevant to a range of audiences, including ministers (A8.1.). We propose that a workshop, or short research project, involving experts on visualisation and the communication of quantitative information, would provide a mechanism to rapidly deliver this;
- ongoing funding or internal resource for the maintenance and development of tools routinely used within assessments (A3.3.);
- investigating the potential to achieve greater cross-border consistency via integration of OWSAT (Offshore Wind Seabird Assessment Tool) and the CEF (A7.3.).

Resourcing, particularly of SNCBs and other public bodies, was highlighted in the stakeholder engagement as a key issue, and we have explicitly captured this within our recommendations (e.g. in specific recommendation A6.2.). However, we also recognise the importance of progressing actions immediately on this topic, and our recommendations are formulated in such a way that they avoid, wherever possible, being fully dependent on additional resourcing. To minimise the needs for additional resourcing, and to avoid duplication, we have tried to link our recommendations to existing mechanisms and initiatives. In particular, a number of our recommendations highlight and exploit the key roles of OWEKH and ScotMER in the dissemination and evaluation of evidence, and emphasise the benefits of building and maintaining closer links between these two mechanisms.

In addition to the eight high-level recommendations, we have also outlined the potential for broader changes to the assessment process to lead to improvements to the treatment of uncertainty. There was broad support amongst stakeholders for major changes to the way assessments are undertaken, particularly in relation to a move towards plan-based and ecosystem-level approaches. We have outlined the potential advantages of those changes, in relation to the treatment of uncertainty, and the key characteristics that a new approach would need to have in order to provide a more effective mechanism for dealing with uncertainty. However, major changes to the assessment process also carry risks, and the importance of understanding and mitigating these risks was highlighted. In relation to timelines, the greatest opportunity for change comes in relation to the adoption of new processes for future leasing rounds, since this minimises risks to projects currently in the assessment process. The timing of any changes would be key, noting that marine planning should be undertaken ahead of leasing rounds, prior to leases being issued and applications being submitted. Any substantive change in approach would need to be trialled alongside existing systems before being fully implemented, in order to evaluate the potential benefits and risks of the change.

Within this project we have focused specifically on the ornithological assessment process, and on the data, methods and tools associated with this receptor. Our stakeholder engagement has also been specifically targeted at individuals working on ornithological impact assessments. All the high-level recommendations that we have proposed potentially have relevance beyond ornithology, although the specific recommendations, and associated details around roles, responsibilities, constraints and dependencies, would likely need to vary when considering receptors other than seabirds. We would highlight the high-level recommendation around improved communication and visualisation of uncertainty (A8) as being a key recommendation that has wider relevance and that would be directly applicable to other receptors. Evidence bridges have also been identified here (A5.5) as a general mechanism for rapidly assimilating and evaluating new evidence that would help to underpin other recommendations (e.g. around the updating of SNCB guidance, A6.2) – this approach has the potential to be used across multiple receptors, and the ORJIP Closing the Loop project has investigated the application of this approach in the context of marine mammals. Evidence Bridges can provide an appropriate approach to ensure that science can be translated into decision making. The approach is a defined process to tackle challenges or specific questions through a practical method of systematically reviewing evidence. The process follows four steps (ask, assemble, appraise, apply) which can apply to any taxa or domain. These ideas draw elements from expert elicitation, which is a well-established and widely applied statistical approach to condense human judgments to support decision making, whilst minimising the inherent biases and heuristics that arise in such instances, across all domains (Sutherland, 2022).

4.3. Defining and interpreting precaution

Stakeholder engagement (**AssESs – Summary report of stakeholder engagement (WP3)**) indicated that different stakeholders interpret the term "precaution" in different ways, and regard different degrees of precaution as appropriate, with industry representatives outlining concerns around how precaution is currently applied within assessments. This highlights a need for greater clarity around both the definition of precaution, and the application and implementation of precaution within the assessment process.

Stakeholder engagement provided a substantial amount of valuable information regarding the current interpretation of uncertainty in relation to precaution, and highlighted a range of viewpoints on this topic. There was particular focus around the interpretation of precaution in relation to (a) quantification of the magnitude of impacts used to specify compensation requirements and (b) the selection of project-level scenarios to consider when quantifying the magnitude of impacts to use in in-combination assessments. The interpretation of precaution in relation to uncertainty is particularly challenging in both of these contexts, since a single number (rather than, for example, a range or confidence interval) is typically required in both cases: in the context of in-combination assessments for logistical reasons, and in the context of determining compensation requirements, because the level of impact will directly determine the level of compensation that the developer is required to deliver. Within Recommendation A4 we have formulated some specific recommendations that aim to build consensus around specific approaches to refining the interpretation of uncertainty in relation to precaution, through the use of statistical methods and through the introduction of a more explicit criteria for biological sense-checking.

Stakeholder engagement yielded much more limited information regarding legal definitions of precaution, and tentatively suggested that legal definitions were not regarded as a primary barrier to the adoption of alternative approaches to the treatment of uncertainty and precaution within assessments. We have therefore not presented specific recommendations around this topic, although we note that there would be value in collating further information around the legal definitions of precaution, so that these could help to inform future discussions around the links between precaution and uncertainty.

4.4. Pathways to impact

Recommendations are only successful if they are implemented. We have aimed to promote uptake of the recommendations, and to ensure a legacy of the project, by:

- Using a **transparent** process to **co-develop** recommendations via stakeholder engagement that included in-depth semi-structured interviews with a range of key stakeholders (including consultants and developers, as well as SNCBs and regulators), and broad engagement (via workshops) with a wider set of stakeholders.
- Focusing on making the wording of recommendations very **specific**, and highlighting key **constraints and dependencies** that may influence uptake.
- Outlining the **roles and responsibilities** associated with recommendations, and linking the delivery of recommendations, wherever feasible, to **existing initiatives and structures.**
- Ensuring that the recommendations of this project are **complementary** to existing mechanisms for identifying and resolving evidence gaps (e.g. OWEKH, ScotMER) and align, where appropriate, with the recommendations on the [ORJIP Closing the Loop Project](#) that has taken place in parallel with this project.
- A particular focus on identifying recommendations that have potential to **begin immediately and to rapidly (e.g. within the next 12 months) deliver benefit.**
- A summary of the potential for **wider, strategic changes** (e.g. towards a plan-level and ecosystem-level approach to assessment) to deliver benefits for the treatment of uncertainty, and the

features of implementation of these changes that would need to be considered in order to maximise these benefits.

- Producing a **roadmap** in order to promote dissemination of the outcomes of this project, particularly to build engagement and uptake with actors in the sector who may not have been directly involved with the stakeholder engagement of this project.

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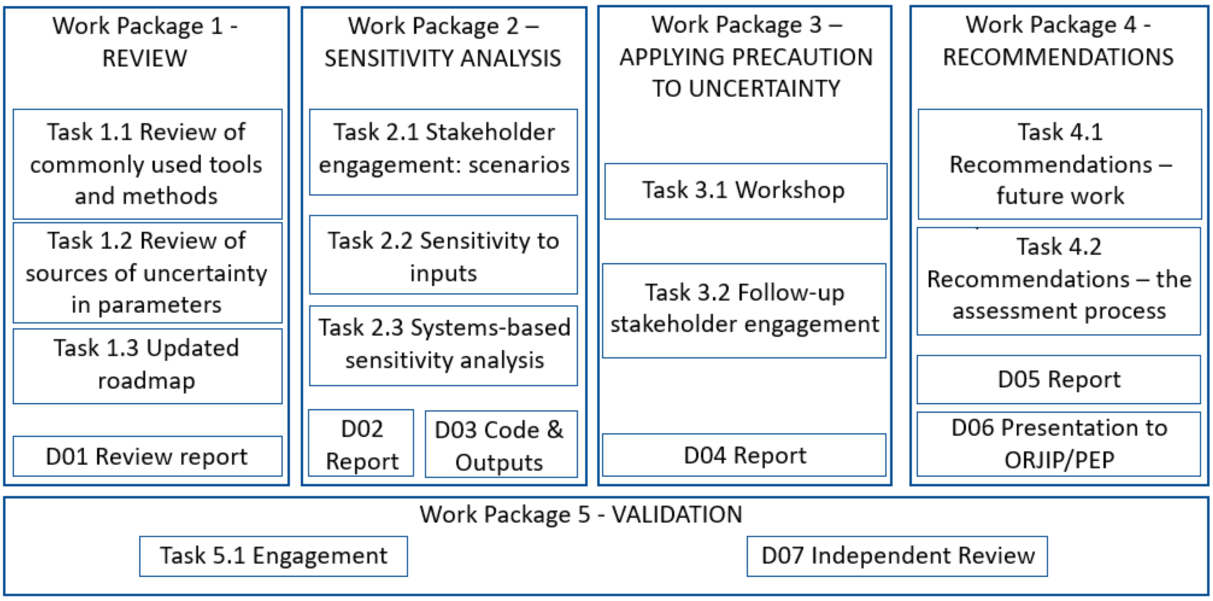
Appendix 1: Project Structure



Appendix 2: Illustrative case study around evaluation of precaution in relation to uncertainty

Methods

We consider two simple models in which there are a number of input parameters and a single output. We assume that:

1. the model that generates the output either (a) multiplies the inputs together or (b) adds the inputs together;
2. there are either 2, 4 or 6 input parameters; and,
3. uncertainty in the input parameters can be captured either as a uniform distribution (over the range 0.2 to 0.8) or a normal distribution (with mean 0.5 and standard deviation 0.1).

We therefore consider a total of 12 scenarios.

Although clearly based on an extremely simplified system, these models are relevant to calculations in key elements of actual assessments: multiplying inputs is used in the Displacement Matrix and in calculating flux for collision risk modelling, whilst adding inputs is used when combining mortality estimates across months, seasons, projects and impact mechanisms.

For each scenario we simulate a large number of inputs and outputs (100,000), and regard this as "truth". We then consider three different ways of applying precaution:

Approach 1. taking the 95% quantile of each input;

Approach 2. taking the mean of each input, and then applying precaution by multiplying the outputs by an adjustment factor of 1.2, 1.5 or 2;

Approach 3. taking the 95% quantile of the output.

Approach 1 relates to the application of precaution in relation to inputs, Approach 2 to the application of precaution in relation to outputs in situations where uncertainty is not propagated, and Approach 3 to the application of precaution in relation to outputs in a situation where uncertainty is propagated into the outputs. The choice of 95% is arbitrary, and used for illustrative purposes. In practice, the choice of the appropriate level of precaution to apply will depend on legal as well as scientific considerations. The key point, however, is that Approach 3 allows precaution to be defined in an explicit, directly interpretable way, in relation to the overall uncertainty within the system. Using the 95% quantile within Approach 3 would be appropriate if precaution is interpreted as requiring a 5% or less chance of the selected level of impact being exceeded.

Within Approaches 1 and 2 a level of "precaution" is also defined, but in each case the definition of precaution does not directly relate to the overall level of uncertainty within the system, so the interpretation of the level of precaution being used within each of these approaches is less clear. For Approach 1 we assume that a 95% quantile is also used for evaluation of precaution, and in Approach 2 we assume that precaution is captured by inflating the output by an adjustment factor. The appropriate value of adjustment factor to use is not clear, so, for illustrative purposes, we arbitrarily consider three possible values: 1.2, 1.5 or 2.

We compare Approaches 1 and 2 against Approach 3, for each of the 12 scenarios. Within the context of this simplified example we can reasonably regard Approach 3 as the "gold standard" for evaluating precaution in relation to uncertainty, since it allows the level of precaution to be explicitly specified in a way that directly relates to the overall level of uncertainty. Within this simplified context we can therefore interpret the results from Approaches 1 and 2 as "over-precautionary" if they produce larger output values than Approach 3 and as "under-precautionary" if they produce smaller output values than Approach 3. Note that this comparison, and direct interpretation of precaution in relation to uncertainty, is possible because (a) the "truth" is known within this simplified system, and (b) there are no non-quantitative elements of uncertainty within the system, which means that Approach 3 can, within this simplified system, directly represent the *intended* level of precaution in relation to uncertainty (e.g. based on legal considerations around acceptable levels of risk).

Results

For the additive model (Figure 1) we see that the evaluation of precaution in relation to inputs (Approach 1) is consistently over-precautionary (in the sense that the approach leads to outputs which are consistently higher than the 95% quantile of outputs), and that the level of over-precaution increases as the number of inputs increases. The approach evaluating precaution in relation to outputs without propagation of uncertainty can be either under-precautionary or over-precautionary depending on the adjustment factor used: with a factor of 1.5 or 2 it is over-precautionary, but with a factor of 1.2 if can be either under- or over-precautionary depending on the number of inputs and the distribution of inputs.

For the multiplicative model (Figure 2) the degree of over-precaution of Approach 1 (evaluating precaution in relation to inputs) is greater than for the additive model, and increases as the number of parameters increases. Approach 2 can again be either under-precautionary or over-precautionary depending on the adjustment factor used, but the detailed results differ substantially from those with the additive model: with a factor of 1.2 it is under-precautionary, but with factors of 1.5 or 2 if can be either under- or over-precautionary depending on the number of inputs and the distribution of inputs.

Table 4 provides a different way of summarising the same results that allows us to directly compare the levels of precaution implied by the different approaches (within the context of this simple system) by showing the proportion of simulations that exceed the values associated with Approaches 1 and 2 for each scenario (and, in the case of Approach 2, for each possible value of the “adjustment factor”). Note that the proportion of simulations exceeding the 95% quantile of outputs (Approach 3) is always, by definition, equal to 0.05, so that with the context of this simple system values within this table can be compared against this “gold standard” – where the values in the table are lower than 0.05 this implies over-precaution and where values in the table are greater than 0.05 this implies under-precaution. The table is equivalent to showing the quantile associated with each method (since the probability that outputs will exceed a particular level is simply one minus the quantile), but the probability of exceeding a specified level is potentially more readily interpretable than a quantile in relation to the level of precaution implied by each method. The results highlight even more directly than Figure 1 and Figure 2 that, within the context of this simple illustrative system, Approach 1 leads to systematically over-precautionary results, which Approach 2 can, depending on the properties of the model and the value of the adjustment factor, lead to either under-precautionary and over-precautionary results.

Figure 1: Histogram of outputs from simple 'additive' model of inputs, with 2, 4 or 6 inputs that are each assumed to have either a uniform or normal distribution, showing 95% quantile of outputs (truth - blue solid), output based on 95% quantile of inputs (red dotted) and 1, 1.2, 1.5 or 2 times the output based on the mean (green dotted).

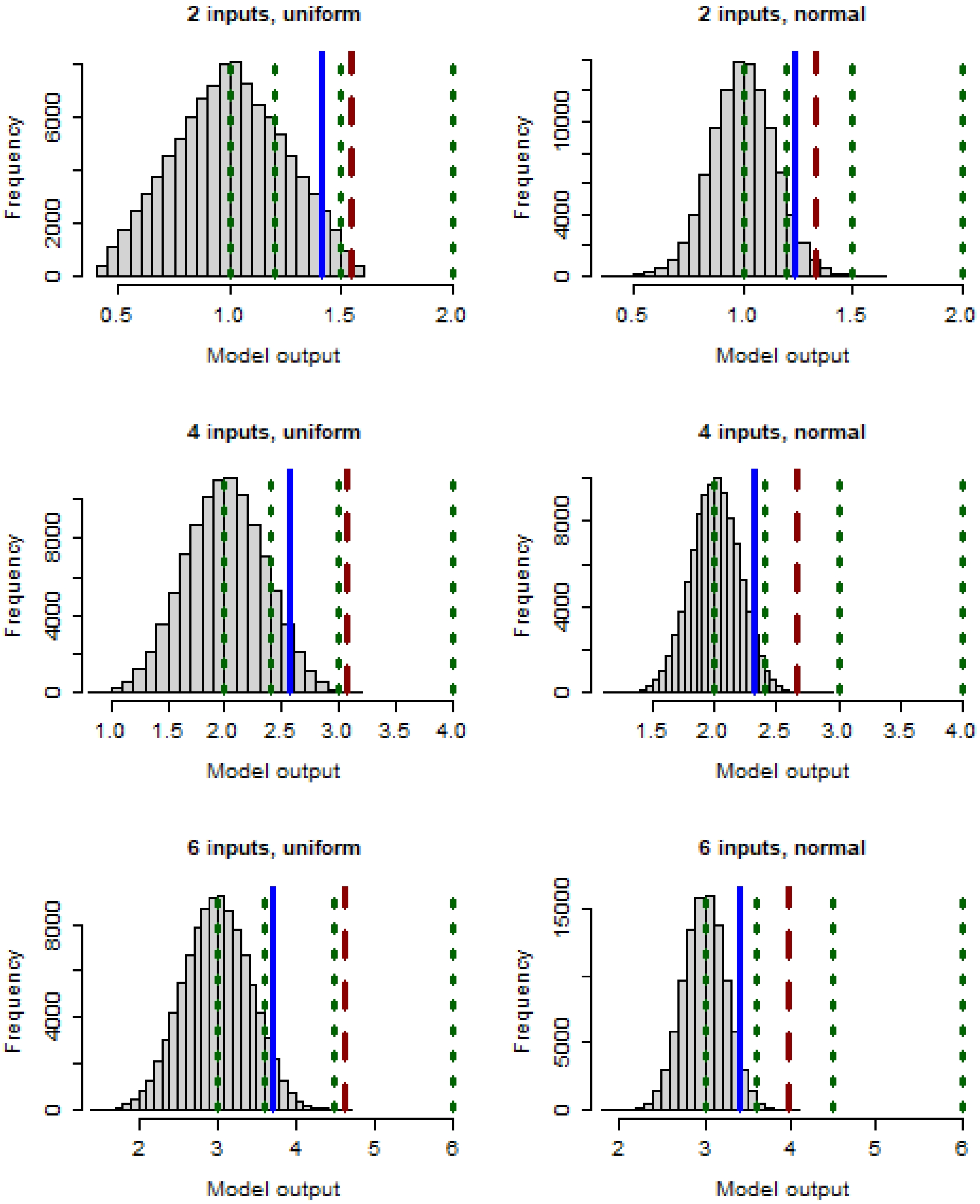


Figure 2: Histogram of outputs from simple 'multiplicative' model of inputs, with 2, 4 or 6 inputs that are each assumed to have either a uniform or normal distribution, showing 95% quantile of outputs (truth - blue solid), output based on 95% quantile of inputs (red dotted) and 1, 1.2, 1.5 or 2 times the output based on the mean (green dotted).

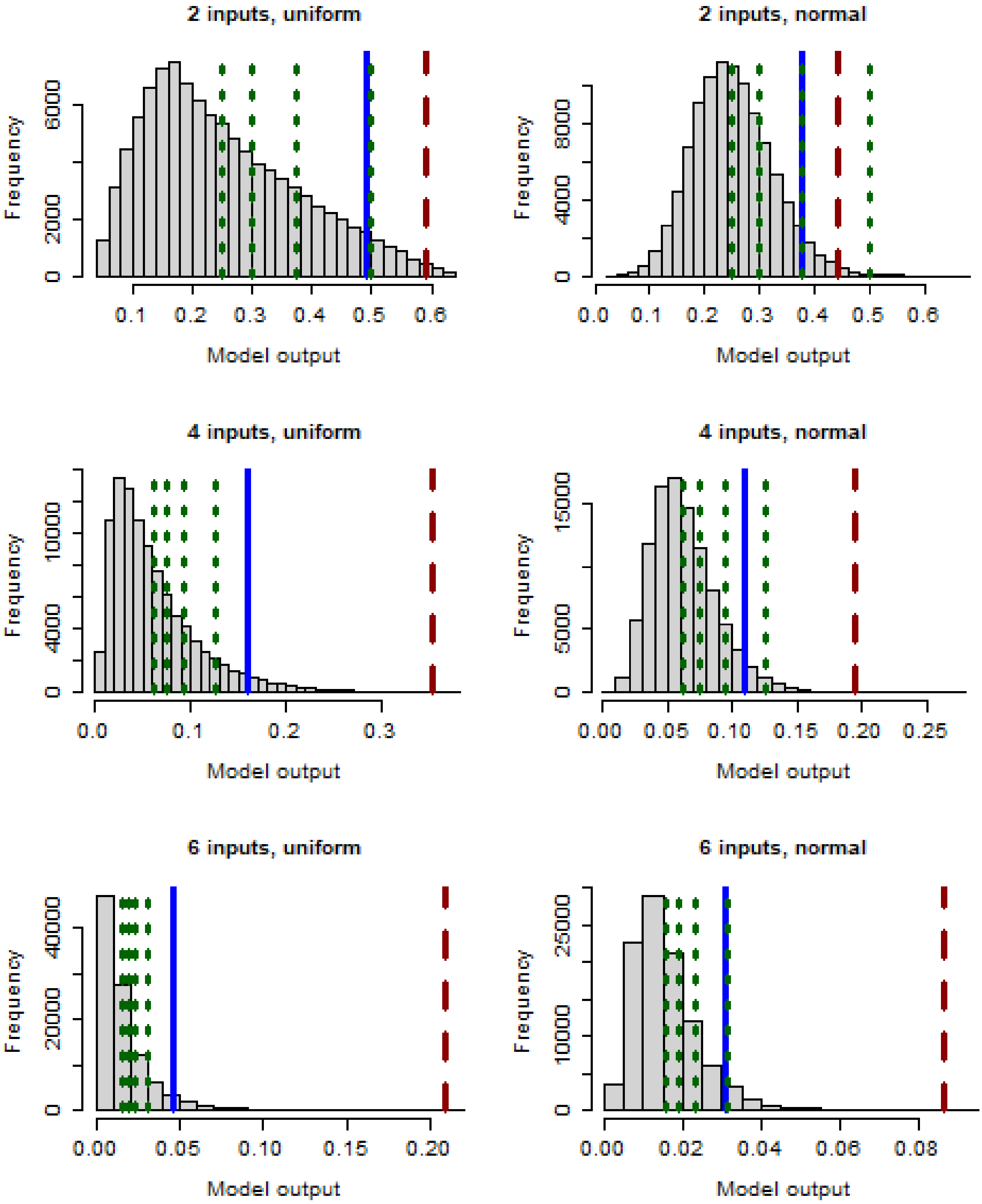


Table 4: Proportion of simulations in which outputs exceed (a) the output value derived by using the 95% quantile of each input parameter or (b) the output value derived by using the mean of input values and then multiplying the resulting output value by an adjustment factor of 1, 1.2, 1.5 or 2. Results relate to simple "additive" and "multiplicative" models involving $p = 2$, 4 or 6 input parameters which assume either a uniform or normal distribution for each parameter. Within the context of this simple system, results can be compared against 0.05 (the proportion of simulations that, by definition, exceed the 95% quantile of outputs).

Model	p	Distn of inputs	Proportion of simulations that exceed				
			Output based on 95% quantile of each input	Output based on using mean of inputs & multiplying output by adjustment factor			
				1	1.2	1.5	2
Additive	2	Uniform	0.00480	0.50082	0.22267	0.01340	0.00000
		Normal	0.00997	0.49946	0.07786	0.00020	0.00000
	4	Uniform	0.00012	0.50085	0.13022	0.00064	0.00000
		Normal	0.00050	0.50099	0.02260	0.00000	0.00000
	6	Uniform	0.00001	0.50061	0.08097	0.00003	0.00000
		Normal	0.00004	0.50078	0.00724	0.00000	0.00000
Multi-plicative	2	Uniform	0.00476	0.43019	0.31255	0.17852	0.04471
		Normal	0.00875	0.47211	0.23189	0.04966	0.00148
	4	Uniform	0.00012	0.38089	0.29166	0.19798	0.10331
		Normal	0.00030	0.43983	0.27156	0.11470	0.02200
	6	Uniform	0.00001	0.34422	0.27534	0.19942	0.12041
		Normal	0.00002	0.41953	0.28258	0.14748	0.04709

Appendix 3: Propagation of uncertainty through the assessment process

The key practical, technical prerequisite for quantifying uncertainty in the final quantitative outputs from assessments (such as PVA metrics) is the ability to propagate uncertainty in inputs through models (into tools) and between tools - ideally in the form of simulations or bootstrap samples, or, where this is not possible, in the form of summary statistics (e.g. mean, standard deviation, and an assumed distribution).

Motivating examples

Example 1. Consider an extremely simple example in which we have two inputs, and our "model" just involves summing these two inputs together to obtain an output, but where the inputs both contain uncertainty that we can represent quantitatively – for example, that they have a mean and standard deviation that can be derived from empirical data, and it may be reasonable to assume that they are normally distributed.

In this case, if we simply summed together the mean values of the inputs together then we would not be propagating uncertainty through into the output. Similarly, but less obviously, we would also not be propagating uncertainty through into the output if we summed together the 95% quantiles of the inputs, because the sum of the 95% quantiles will not correspond to the 95% quantile of the outputs. We also cannot propagate uncertainty by summing together the standard deviations, because the standard deviation of the output is not, in general, the sum of the standard deviations of the inputs.

Within this extremely simple example, there is a mathematical formula that we could use to derive the probability distribution of the output, given the distributions of the inputs, so we could propagate uncertainty from the inputs into the output by simply applying this formula. Within realistically complicated examples relevant to the assessment process, however, such formula will rarely, if ever, exist. Simulation provides a less elegant, but conceptually simple and much more widely applicable, alternative: we can simulate a large number of values of each of the inputs using the mean, standard deviation and distributional assumption (e.g. that they have a normal distribution). If we simulate 10000 values of each input, we can, for each of these 10000 simulations, sum together the simulated values of the two inputs in order to obtain the outputs. This provides us with 10000 simulations of the output, which capture uncertainty in the output – they approximate the probability distribution of the output, and we can increase the accuracy of this approximation by increasing the number of simulations.

Example 2. We now extend this motivating example to assume that the outputs from this first simple model form the input to a second model. We assume that the second model is also very simple: e.g. that it simply squares the value of the input, and then adds on normally distributed random noise, in order to produce an output.

If we use the mean or a quantile from the first model to provide the input value we are using for this second model then this does not propagate uncertainty into the second model – the output from the second model will be uncertain (because of the random noise being added within the model), but this uncertainty will not account for uncertainty in the inputs.

Assuming that (as will be the case for the models using in assessments) a specific mathematical formula for the propagation of uncertainty does not exist for the models in question, we rely on a simulation-based approach in order to propagate uncertainty between the models. If we have, say, simulated 10000 values of the output from the first model, then we could either:

(a) "run" the second model (e.g. square the value, and add random noise) using each of the 10000 outputs from the first model as inputs to the second models, in order to produce 10000 simulated outputs from the second model; or,

(b) summarise the outputs from the first model (for example by calculating the mean and standard deviation), and then use these summaries to simulate inputs to the second model.

It is clear from this simple example that approach (b) essentially involves additional steps and assumptions (around the distribution of the outputs from the first model) that are avoided by approach (a). Approach (a) is therefore preferable, but Approach (b) may need to be used in situations where approach (a) is infeasible.

Propagation of uncertainty within the assessment process

These motivating examples illustrate that a simulation-based approach to the propagation of uncertainty between a series of tools is conceptually straightforward, even in complicated situations. Propagation using this approach ideally involves taking a set of simulations that have been produced by one tool and using these simulated values as the inputs to the next tool within the series, whenever the structure of the tools themselves allows this to happen. In some cases, the simulated outputs from one tool will need to be summarised (e.g. as a mean and standard deviation) in order to provide inputs to another tool, because this is the format of input required by the latter tool.

Within the context of tools currently used widely within the ornithological assessment process:

- The Displacement Matrix is not normally regarded as a probabilistic approach, but the CEF includes a "simulation-based" version of the Displacement Matrix in which the displacement and displacement mortality rates used in the Displacement Matrix are simulated from distributions, and this approach (which is technically very straightforward to implement) could also easily be implemented outwith the CEF.

- The sCRM (and underlying stochLAB package) can propagate uncertainty in most biological inputs through into collision risk modelling outputs – the distributions of some inputs (project-level densities, and flight heights) can either be provided as summary statistics or as a set of simulated (bootstrapped) values, whilst the distributions of other inputs are specified through summary statistics.

- SeabORD can propagate uncertainty in certain key parameters (e.g. prey level), and inter-individual variability in biological inputs such as adult mass, through into outputs. Uncertainty in outputs also arises from stochasticity within the model itself.

- Uncertainty is not quantified within the tools current used for apportioning within assessments.

- The NE/JNCC PVA tool can incorporate uncertainty around annual mortalities (e.g. from the sCRM and/or Displacement Matrix) through summary statistics (mean and SD), whilst the CEF extension of this tool allows simulations from other tools (e.g. the sCRM) to be passed directly as inputs to the PVA tool. In both cases variability in baseline demography is specified through summary statistics. These sources of uncertainty and variability are propagated through the tool into PVA metrics.

Code developed within the CEF is designed to provide a standardised and streamlined process of propagating uncertainty between assessments, but propagation of uncertainty involves simple steps, and exploits functionality already present within tools such as the sCRM, the NE/JNCC PVA Tool and SeabORD, and so is also possible to implement the propagation of uncertainty without using the CEF (assuming that, where displacement risk is relevant, a simulation-based version of the Displacement Matrix is used).

Challenges can arise in the process of propagation, but pragmatic solutions to these challenges are available:

1. Different tools may use differing numbers of simulations, largely for computational reasons - more computationally intensive tools, for example, will typically use a smaller number of simulations, for pragmatic reasons. Whilst this imposes caveats on the results, since the accuracy of the approximation involved in using a simulation-based approach will be higher when the number of simulations is higher, it does do not prevent uncertainty from being propagated between tools that use differing number of simulations (e.g. when combining results from the sCRM and Displacement Matrix, or SeabORD and Displacement Matrix). Where necessary random subsampling or resampling can be used to standardise the number of simulations across tools prior to their outputs being consider, for example.

2. Uncertainty in some inputs or tools may not be quantified at all. While this imposes important caveats around interpretation of uncertainty in outputs (since it means they will not capture uncertainties from all sources), it does not, in a practical sense, prevent a simulation-based approach to the propagation of uncertainty being used – values for inputs or tool outputs that do not contain uncertainty can be regarded, for the purposes of the simulation-based approach to propagate, as if they are simulated values in which all simulated values are identical. As in (1), a standardised number of simulations can therefore be used in order to combine results across tools, and non-stochastic values can simply be repeated as need in order to match this number of simulations.

   The key benefit in practice of using CEF code for propagation is that it uses an extended version of the NE/JNCC PVA Tool that includes the option to accept simulated values of impacts as inputs – when propagating uncertainty outwith the CEF impacts need to be summarised as means and standard deviations in order to be inputted into the NE/JNCC PVA Tool. This requires additional distributional approximations, but is possible.

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