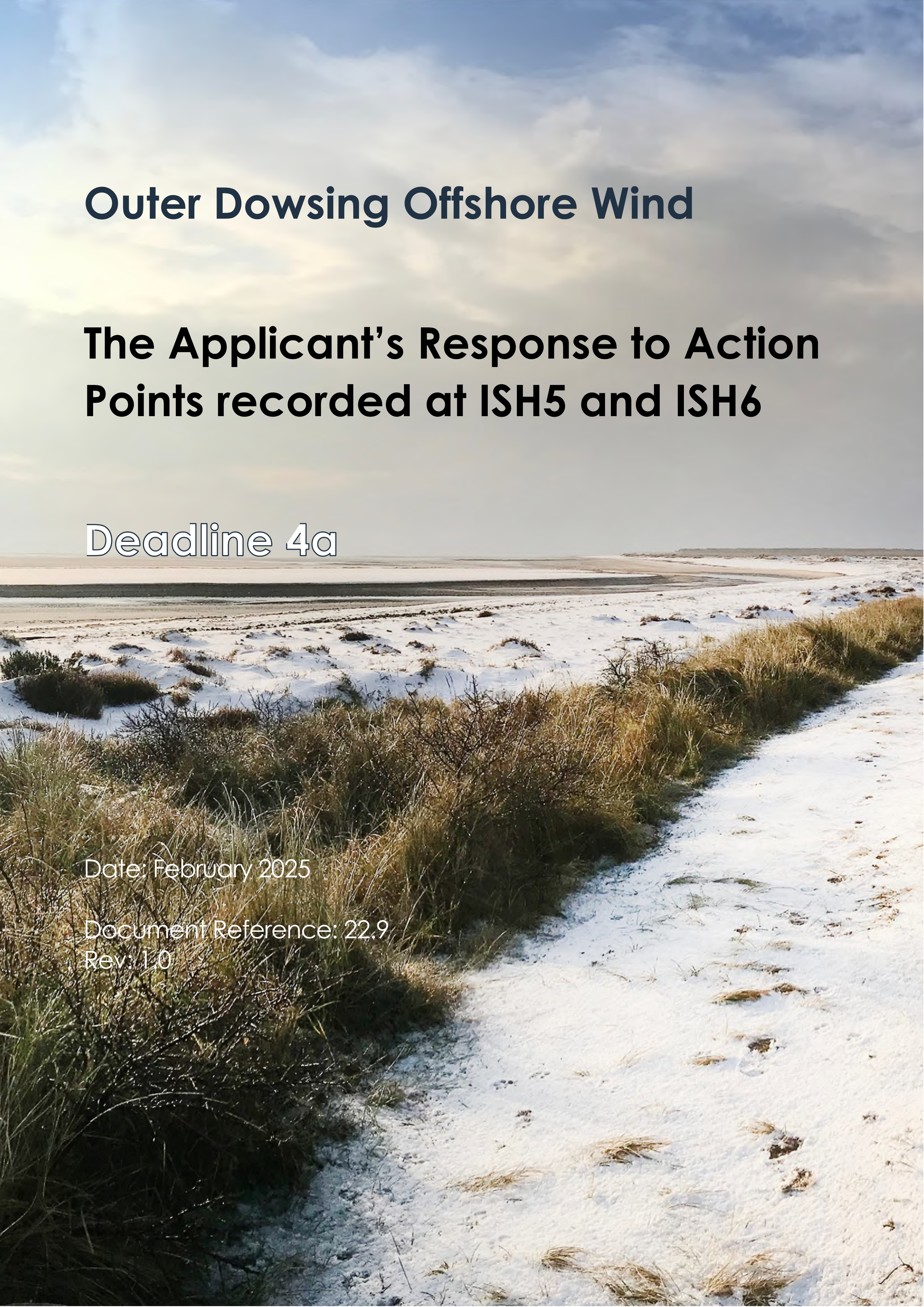

Outer Dowsing Offshore Wind

The Applicant's Response to Action Points recorded at ISH5 and ISH6

Deadline 4a

Date: February 2025

Document Reference: 22.9
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Company:	**Outer Dowsing Offshore Wind**	Asset:	**Whole Asset**
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1.0	February 2025	Deadline 4a	Dalcour Maclaren GoBe SLR	Outer Dowsing	Shepherd & Wedderburn	Outer Dowsing

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Acronyms & Definitions

Abbreviations / Acronyms

Abbreviation / Acronym	Description
AMS	Agricultural Management Strategy
BNG	Biodiversity Net Gain
CLG	Community Liaison Group
DAD	Design Approach Document
DCO	Development Consent Order
DPS	Design Principles Statement
DRP	Design Review Panel
ECC	Export Cable Corridor (offshore ECC or indicative onshore ECC)
EIA	Environmental Impact Assessment
EMP	Ecological Management Plan
ES	Environmental Statement
ExA	Examining Authority
GIS	Geographic Information System
GW	Gigawatt
IDB	Internal Drainage Boards
ISH	Issue Specific Hearing
JNCC	Joint Nature Conservation Committee
LCC	Lincolnshire County Council
LMP	Landscape Management Plan
LPA	Local Planning Authority
ODOW	Outer Dowsing Offshore Wind (The Project)
OLEMS	Outline Landscape and Ecological Management Strategy
PAMP	Public Access Management Plan
PEIR	Preliminary Environmental Information Report
PRoW	Public Right of Way
SoC	Statement of Commonality
SoCG	Statements of Common Ground

1 The Applicant's Response to Action Points from ISH 5

1. This section is provided in response to Action Points arising from Issue Specific Hearing ("ISH") 5 held on Wednesday 12 February 2025.

1.1 Applicant's Response to Action Point 2

ID	Response to Action Point 2 from Issue Specific Hearing 5	Applicant Response
ISH5 AP2	Discuss with the Marine Management Organisation (MMO) and then submit additional wording for Condition 13 in relation to the Offshore Reactive Compensation Platform (ORCP) design, and any revisions to the Outline ORCP Design Principles Statement.	The Applicant has updated the wording of condition 13(1)(a), Part 2, Schedule 11 of the DCO to secure the ORCP design principles statement. This wording has been agreed with the MMO. The Applicant has also updated the wording of the ORCP Design Principles Statement to reflect this.

1.2 Applicant's Response to Action Point 3

ID	Response to Action Point 3 from Issue Specific Hearing 5	Applicant Response
ISH5 AP 3	Provide further details of the applicant's position regarding the duty to further the purposes of National Landscapes contained on the recent DEFRA guidance.	The Applicant has provided its position in Appendix 1 of Document 22.4 The Applicant's Written Summary of Oral Case put at the Issue Specific Hearing 5 held on 12 February 2025

1.3 Applicant's Response to Action Point 6

ID	Response to Action Point 6 from Issue Specific Hearing 5	Applicant Response
ISH5 AP6	Undertake discussions regarding the need, or not, for a badger and otter licence or Letter of no Impediment (LoNI) and provide a note on the outcome of these discussions as well as discussing other outstanding matter from the Risk & Issues Log.	The Applicant has engaged with Natural England in respect of all outstanding matters from the Risk and Issues Log and will be in a position to provide a further update by Deadline 5 including specifically an update on the outcome of Natural England's internal discussions as to the issue of whether badger and otter licences or LONIs are necessary.

1.4 Applicant's Response to Action Points 7 and 8

ID	Response to Action Point 7 and 8 from Issue Specific Hearing 5	Applicant Response
ISH5 AP7	Submit its preferred approach to dealing with any additional mitigation for the Wash Special Protection Area (SPA) qualifying features.	The Applicant's position is that the existing mitigation measures are adequate to avoid an adverse effect on the integrity of The Wash SPA and Ramsar site, as evidenced in Sections 9.5 and 10.5 of the Report to Inform Appropriate Assessment (RIAA) [REP-032] and summarised in the Applicant's response to points five and seven of the Natural England Risk and Issues Log [REP4-113]. The Applicant met with Natural England on 20 February 2025 to discuss the additional pink-footed goose mitigation options requested by Natural England. Following that meeting, and in addition to the existing mitigation measures, the Applicant has committed to developing a management plan for pink-footed goose. The outline proposals are documented in Section 3.7.5 of the OLEMS (version 6, deadline 4a).
ISH5 AP8	Provide comments on whether additional land might be available outside of the Order Limits in relation to an additional mitigation scheme (in relation to Option 2).	The outline management plan proposals provided in the OLEMS (version 6, deadline 4a) describe that firstly construction activities will be coordinated with local farmers to seek to avoid key crops utilised by foraging pink-footed geese in the core winter period. Where that is not possible, additional food resource would be provided, within a location within the Project Order Limits therefore it is intended that no additional land outside the Order Limits would be required to deliver this measure, further details of the proposals will be developed post consent in conjunction with Natural England as set out within the OLEMS .

1.5 Applicant's Response to Action Point 9

ID	Response to Action Point 9 from Issue Specific Hearing 5	Applicant Response
ISH5 AP9	Consider amendments to the wording in the OLEMS and Outline Code of Construction Practice (OCoCP) in relation to severed land and the compensation potential for skylark and yellow wagtail.	Section 6.14 of the Code of Construction Practice (document reference 8.1 version 6) and the corresponding section within the OLEMS (document reference 8.10 version 6) has been updated accordingly in respect of the provisions relating to the use of severed land and how this can be utilised for compensation for skylark and yellow wagtail. Provisions for agreeing the extent of land which is impractical to farm and therefore will qualify as severed land under these sections are set out in the voluntary Heads of Terms which have been secured with 95% of landowners along the ECC route. To date, the Applicant has secured 42% of option agreements across the Onshore ECC which all contain provisions with regard to severed land. The Applicant is therefore confident that agricultural land which will be temporarily severed due to the nature of the agricultural operations in this area and the size of machinery required, would be able to provide the compensatory habitat required for the skylark and yellow wagtail. The Applicant is therefore confident that the mitigation measures are secured and can be implemented. Final details of the management measures for the severed land will be set out in the final Ecological Management Plan to be submitted under Requirement 12 and approved by the LCC in consultation with the relevant parties set out in that Requirement, as secured within section 3.7.5 of the OLEMS (document reference 8.10 version 5) .

1.6 Applicant's Response to Action Point 10

ID	Response to Action Point 10 from Issue Specific Hearing 5	Applicant Response
ISH5 AP10	Assess the wording of the relevant documents to either improve the commitment to achieving a degree of biodiversity gain or to indicate where in the submitted documentation this commitment is already secured.	The Applicant has commitment to delivering a net gain in biodiversity, is set out in paragraph 105 - 106 of 9.5 Biodiversity Net Gain Project Principles and Approach (APP-302). The commitment reads as follows: *"If there is a shortfall in overall biodiversity units from any metric type (habitat, hedgerow, or river), as a result of the Project, offsite habitat enhancement to deliver an overall net gain for the Project will be agreed and incorporated.* *The delivery of offsite enhancements will be secured through an agreement between the Applicant, or it's agent and the landowner/responsible body."* To provide certainty that this commitment is secured, the same wording has been added to the new section 9 of the update version of the OLEMS, submitted at Deadline 4a.

1.7 Applicant's Response to Action Point 11

ID	Response to Action Point 11 from Issue Specific Hearing 5	Applicant Response
ISH5 AP11	Consider any knock-on consequences for other documents should a legal agreement be signed for the Ecological Steering Group, Environment Compliance Officer and Ecology Enhancement Fund	Should a s106 agreement be entered into the following provisions within the OLEMS will be updated to reference the provisions currently set out in the draft agreement namely: ▪ Section 3.9.1.1. Compliance Audits to be updated to reference the role of the Environmental Compliance Officer ▪ References to external review group in section 3.9.1 will be updated to refer to the Ecological Steering Group ▪ References to the Ecology Enhancement Fund will be included where biodiversity net gain commitments are currently set out

1.8 Applicant’s Response to Action Point 12

<table>
<tr><th>ID</th><th>Response to Action Point 12 from Issue Specific Hearing 5</th><th>Applicant Response</th></tr>
<tr><td>ISH5 AP12</td><td>Provide a breakdown of the predicted Agricultural Land Classification (ALC) grade for the permanent infrastructure and habitat enhancement and disturbed / undisturbed land.</td><td>
The table below provide a detailed list of all infrastructure types, both temporary and permanent, and details how they impact upon the different agricultural land classification (ALC) grades across the Project Order Limits (assessed on a worst case basis).
For context, these have also been presented as percentages of the latest regional and national Utilised Agricultural Area (“UAA”)1 2 3.
<table>
<tr><th>Total Area by Impact</th><th colspan="4">Provisional ALC Grade Areas (Ha)</th><th>Ha</th><th>As a percentage of regional UAA</th><th>As a percentage of National UAA</th></tr>
<tr><th>Infrastructure Type and Impact</th><th>Grade 1</th><th>Grade 2</th><th>Grade 3</th><th>Ungraded</th><th>Grand Total</th><th>1,172,000.00 Ha</th><th>8,746,899.82 Ha</th></tr>
<tr><td>Total Area Of Onshore Order Limits</td><td>477.29</td><td>184.10</td><td>181.23</td><td>12.79</td><td>855.41</td><td></td><td></td></tr>
<tr><td>Disturbed</td><td>244.32</td><td>118.00</td><td>106.95</td><td>0.00</td><td>469.27</td><td>0.040%</td><td>0.0054%</td></tr>
<tr><td>Permanent Impact</td><td>36.28</td><td>0.06</td><td>0.14</td><td>0.00</td><td>36.48</td><td>0.003%</td><td>0.0004%</td></tr>
<tr><td>Infrastructure</td><td>16.24</td><td>0.06</td><td>0.14</td><td>0.00</td><td>16.44</td><td>0.001%</td><td>0.0002%</td></tr>
<tr><td>Habitat Enhancement</td><td>20.04</td><td>0.00</td><td>0.00</td><td>0.00</td><td>20.04</td><td>0.002%</td><td>0.0002%</td></tr>
<tr><td>Temporary Impact</td><td>208.04</td><td>117.94</td><td>106.82</td><td>0.00</td><td>432.79</td><td>0.037%</td><td>0.0049%</td></tr>
<tr><td>Infrastructure</td><td>208.04</td><td>117.94</td><td>106.82</td><td>0.00</td><td>432.79</td><td>0.037%</td><td>0.0049%</td></tr>
<tr><td>Undisturbed</td><td>232.85</td><td>66.16</td><td>74.33</td><td>12.79</td><td>386.13</td><td>0.033%</td><td>0.0044%</td></tr>
<tr><td></td><td>477.17</td><td>184.16</td><td>181.29</td><td>12.79</td><td>855.41</td><td></td><td></td></tr>
</table>
The table shows that of the total Order Limit area of 855.41 Ha, on a worst case assessment up to 36.48 Ha will be permanently impacted. Of this 16.44 Ha will be resulting from permanent project infrastructure, and 20.04 Ha as a result from landscape planting / habitat enhancement. It is important to recognise that these values represent a maximum design scenario. The low resolution of the Provisional ALC mapping data does not distinguish between various current land uses, such as existing roads, farm tracks, hedges, and watercourses, all of which contribute to a reduction in available agricultural land. Upon completion of the detailed project design and comprehensive soil surveys, it will be possible to account for these finer details. This will demonstrate that the actual impact on land in agricultural use is less than indicated in the table above.
In addition to the above permanent infrastructure, a further 432.79Ha will be temporarily disturbed, whilst the remaining 386.13 will remain undisturbed. Areas within the Order Limits which are classed as undisturbed include; sections subject to trenchless construction techniques, where there will be no need to disturb the ground surface (excluding haul roads), and the temporary duct storage area, where again, surface excavation would not be required.
</td></tr>
</table>

[1] Agricultural Land Use in United Kingdom at 1 June 2024, Defra, 2024. Available at: https://www.gov.uk/government/statistics/agricultural-land-use-in-the-united-kingdom/agricultural-land-use-in-united-kingdom-at-1-june-2023 (accessed 25.02.2025)
[2] Agricultural facts: East Midlands region, Defra, 2024. Available at: https://www.gov.uk/government/statistics/agricultural-facts-england-regional-profiles/agricultural-facts-east-midland-region (accessed 25.02.2025)
[3] Agricultural Land Use and Crop Areas in England at 1 June, Defra, 2025. Available at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fassets.publishing.service.gov.uk%2Fmedia%2F66f52505e84ae1fd8592e918%2FAgricultural_land_use_in_england-26sep24i.ods&wdOrigin=BROWSELINK (accessed 25.02.2025)

ID	Response to Action Point 12 from Issue Specific Hearing 5	Applicant Response
		In preparing the response to this Action Point, the Applicant has identified an inaccuracy in the reported value of permanently lost agricultural land within ES Chapter 25: Land Use (AS1-050) and Chapter 29: Socio-Economic Characteristics (APP-084). Both chapters reported a permanent loss of 26.38 hectares of agricultural land, whereas the correct figure is 36.48ha as shown above. The conclusion of the assessment reported in Chapter 25 Land Use was that there would be a significant adverse effect using the adopted methodology. Whilst the area reported as lost is increased, that does not change the conclusion in that chapter. The conclusions of the assessment reported in Chapter 29 Socio-Economic Characteristics has not changed as a result of this increase in area, and continues to be a not significant effect. Both chapters have been revised and resubmitted at Deadline 4a to reflect the updated figure.

1.9 Applicant's Response to Action Point 13

ID	Response to Action Point 13 from Issue Specific Hearing 5	Applicant Response
ISH5 AP13	Provide the updated plan for the revised figure 1.14 Q1 LU 1.2 which maps the routes considered.	An updated version of The Applicant's Response to the Examining Authority's Written Questions 2 has been submitted at this deadline (document 21.2 version 2) which includes the updated plan for revised figure 1.14 Q1 LU 1.2.

Applicant's Response to Action Point 14

ID	Response to Action Point 14 from Issue Specific Hearing 5	Applicant Response
ISH5 AP14	Engage in discussions and provide a note of respective positions regarding the cable corridor width and ability for micro-siting.	The Applicant has outlined its position on cable corridor width and micrositing within 22.2 The Applicant's Comments on Responses to the Examining Authority's Written Questions **-** Q2 LU1.3 and 22.4 The Applicant's Written Summary of Oral Case put at the Issue Specific Hearing held on 12 February 2025. The Applicant has met with TH Clements on Wednesday 12th February and subsequently on Wednesday 19th February and Thursday 20th February. The Applicant then sent TH Clements the Applicant's position on cable corridor width in writing on the 20th February in an attempt to reach agreements on this matter before D4a. The Applicant has not received feedback from TH Clements regarding this matter and assumes that TH Clements will respond in writing to the ExA.

1.10 Applicant's Response to Action Point 15

ID	Response to Action Point 15 from Issue Specific Hearing 5	Applicant Response
ISH5 AP15	Consider additional wording to the drafting of the consultation requirements with affected landowners to be set out in the Soil Management Plan (SMP) and provide a commentary note on this and also on the issue of when after a period of heavy rain the land would be able to accommodate heavy machinery on it.	<u>oSMP consultation</u> It would not be practical to consult, in a timely manner, with every landowner and tenant on the content of final plans such as the CoCP and SMP on an individual basis. A decision was therefore made for the LIG, who represent 88.75% of landowners affected by the project, to be the consultees. Following ISH5, where TH Clements made a request to be a consultee, the Applicant has also committed in paragraph 3 of section 2.1 that the views of TH Clements and the LIG will be submitted to the discharging authority with the final CoCP and SMP. The outline Organic Land Protocol ("oOLP") has also been updated to mirror the requirement that the views of the LIG will be submitted to the discharging authority with the final oOLP. <u>Heavy Rain/adverse weather</u> The oSMP Section 1.19 sets out requirements for soil handling in the event of adverse weather. The measures set out within this section are derived from guidance within Code of practice for the sustainable use of soils on construction sites (DEFRA) and Good Practice Guide for Handling Soils in Mineral Workings (IQ, 2021). In relation to soil handling after periods of heavy rain the following criteria must be met before soil handling can recommence "If sustained heavy rainfall (e.g., >10mm in 24 hours) occurs, soil handling operations must be suspended. Soil operations must not restart until the ground has had at least one full dry day or an agreed moisture criteria of the soil can be met (such as 'drier than the plastic limit') as advised by the SCoW;" After heavy rain, soils can become overly saturated and exceed their plastic limit, which can lead to compaction and soil structure damage. Understanding the plastic limit and ensuring soils are below their plastic limit before handling ensures that soil handling operations are conducted efficiently and safely, minimising environmental impact and ensuring structural stability.

ID	Response to Action Point 15 from Issue Specific Hearing 5	Applicant Response
		It was noted during ISH5, that TH Clements requested it would be more appropriate that s1.19 be amended to state that 'soil operations must not restart until the ground has had at least one full dry day and an agreed moisture criteria of the soil can be met (such as 'drier than the plastic limit') as advised by the SCoW;' The Applicant maintains the position that this should be 'or' as currently drafted as this follows best practice guidance within DEFRA Construction Code of Practice for the Sustainable Use of Soils on Construction Sites and the Institute of Quarrying Good Practice for Handling Soils.

1.11 Applicant's Response to Action Point 16

ID	Response to Action Point 16 from Issue Specific Hearing 5	Applicant Response
ISH5 AP16	Clarification to be provided on the current and future role and status of the Land Interest Group and any implications for the appropriate consultation body for the outline SMP and oCoCP.	In Autumn 2022, The Applicant was advised that a working group of land agents had formed known as the Land Interest Group (LIG) who represent 88.75% of landowners affected by the Project. To date the Applicant has used this forum to share project updates, to develop Heads of Terms and to obtain feedback on application documents such as the oCoCP and the oSMP. Going forward, this group will continue to be used for sharing project updates and obtaining feedback as and when required. The Applicant is of the opinion that this group is very much needed through to the end of Examination and on-going in the lead up to construction to streamline communication with landowners given there are over 160 interests affected by the Project. It would not be practical to consult, in a timely manner, with every landowner and tenant on the content of final plans such as the CoCP and SMP on an individual basis

1.12 Applicant's Response to Action Point 19

ID	Response to Action Point 19 from Issue Specific Hearing 5	Applicant Response
ISH5 AP19	Consider providing amendments to the wording of the Soil Management Plan to ensure there is no deterioration of the ALC grade, whilst also safeguarding the need to restore soil profiles to their pre-construction condition.	The Applicant has amended the paragraph 92 of the oSMP (document 8.1.3) to clarify that the approach proposed by the Applicant of reinstating land to its pre-development quality as far as is reasonably practicable will result in the land being returned to its baseline agricultural land classification, and is therefore in compliance with NPS EN-5 paragraph 2.9.25 as it relates to mitigating effects on ALC grade land.

1.13 Applicant's Response to Action Point 20

ID	Response to Action Point 19 from Issue Specific Hearing 5	Applicant Response
ISH5 AP20	Amend wording in the CoCP to remove the 'where practical' tailpiece in regard to cable burial depth.	The Applicant has at Deadline 4a updated 8.1 Outline Code of Construction Practice (revision 6) paragraph 109 to accommodate the changes discussed at ISH5 and set out in 22.4 The Applicant's Written Summary of Oral Case put at the Issue Specific Hearing held on 12 February 2025. Revised wording has been shared with TH Clements and the revised wording has been updated to state '*The cable shall be installed 300mm below any current drainage system or any alternative drainage system installed by the Applicant'* The Applicant has removed

ID	Response to Action Point 19 from Issue Specific Hearing 5	Applicant Response
		the wording '*where practical*' at the request of TH Clements but has, as set out at ISH5 (document 22.4) added *'or any alternative drainage system installed by the Applicant'* in order to account for drainage buried at significant depths. For example, this would be relevant where land drainage outfalls can be up to 2m deep and it would not be practical for the Applicant to bury cables 300m below this depth. In instances where this occurs, a post construction drainage scheme would be installed above the cable to ensure the integrity of the land drainage in the field. The Applicant has been advised that TH Clements do not agree with the amendments that have been made. The Applicant will continue proactive discussions with TH Clements.

1.14 Applicant's Response to Action Point 21

ID	Response to Action Points 21, from Issue Specific Hearing 5	Applicant Response
ISH5 AP21	Arrange discussions to investigate any disparities between their respective assessments of severed land now that the relevant shapefiles have been reviewed	The Applicant understands that TH Clements is now content with the approach to severed land within the oCoCP (document 8.1, version 6). The Applicant had issued plans to the land agent for review pre ISH5, and following ISH5 on 12th February, TH Clements' agent met with the Applicant on 19th February to review the indicative severed land plans and jointly marked up plans which show the indicative area of severed land to be 42.9 acres for the land in which TH Clements either own or occupy. The Applicant awaits confirmation from the agent that they are in agreement with this figure.

1.15 Applicant's Response to Action Point 23

ID	Response to Action Point 23 from Issue Specific Hearing 5	Applicant Response
ISH5 AP23	Confirm how the final documents will take account of the detailed construction data once the Principal Contractor is appointed and will account for evolving best practices in relation to dust contamination.	The Outline Air Quality Management Plan (AQMP) (document 8.1.2, version 2) has been updated to confirm that the construction dust assessment will be revised as part of the final AQMPs for each stage of the onshore transmission works. This revision will incorporate detailed construction data once the Principal Contractor is appointed and will reflect evolving best practices in dust mitigation and control.

1.16 Applicant's Response to Action Point 26

ID	Response to Action Point 26 from Issue Specific Hearing 5	Applicant Response
ISH5 AP26	Respond to Natural England's recommendations regarding the Peat Management Plan	See response to 22.2 The Applicant's Comments on Responses to the Examining Authority's Written Questions 2, Document 22.2, Q2 LU 1.5.

1.17 Applicant's Response to Action Point 27

ID	Response to Action Point 27 from Issue Specific Hearing 5	Applicant Response
ISH5 AP27	Respond to the argument put forward by TH Clements in regard to climate change and the increased frequency of heavy rainfall event will leave less time for land to drain	See response to 22.2 The Applicant's Comments on Responses to the Examining Authority's Written Questions 2, Document 22.2, section 2.3 Applicant's Comments on T.H. Clements Responses to ExA WQ2 – Q2 LU1.12

1.18 Applicant's Response to Action Point 28

ID	Response to Action Point 28 from Issue Specific Hearing 5	Applicant Response
ISH5 AP28	Applicant to examine the wording of their response to ExQ2 DCO 1.2 and clarify the extent of external independent reviews of the OnSS design that will be undertaken as part of the detailed design process.	Post-consent, ongoing consultation will involve Lincolnshire County Council (LCC), the Community Liaison Group (CLG), the Local Design Panel, the Design Review Panel (DRP) and local landowners. The Local Design Panel includes representatives from the CLG and LCC. The DRP is a separate and external independent review group who were appointed by the Applicant in June 2024 to provide impartial feedback on the design of the onshore substation. This involved a design review session, with a site visit to a selection of the LVIA viewpoints around the onshore substation, followed by a workshop session to discuss issues relating to the onshore substation design more fully. The Applicant proposes to continue engagement with the DRP by instructing a DRP review at critical stages in the development of the detailed design. The number and frequency of these engagements will be determined by the evolution of the design process, with an anticipation that the DRP's feedback will be most valuable at stages when options are being explored, for example the design of the roof structures, the application of colour on the buildings, and the interaction between landscape and built form. The Applicant proposes to update the Design Approach Document (DAD) (REP4-075) for the Deadline 5, which will further outline an indicative process for post-consent consultation with all interested parties, including the DRP. The Design Principles Statement (DPS), Table 3.1 will also be updated to ensure the commitment to this review process is further secured. The Applicant will engage with LCC ahead of Deadline 5 to ensure they are in agreement with the wording of the updated DAD. The DPS is currently secured under Requirement 9 of the dDCO (document 3.1, version 8). The Applicant is proposing to commit the process as outlined above, by including the DAD as a secured document. The dDCO has been updated with this commitment at Deadline 4a. At ISH 5, under Agenda Item 3.6, a discussion was recorded regarding how the Applicant planned to secure good design [Agenda Item 3.6, page 47 – 51 of Document 22.4]. Despite there not being an action point on this issue included in the Planning Inspectorate's 'Hearing Action Points' [EV9-001], the Applicant considers this issue requires further explanation and, as such, has included the following written response to outline the Applicant's plans with regard to securing good design. In response to feedback from the Planning Inspectorate through the Examination Process, updates were made at Deadline 4 to the Design Approach Document (DAD) [REP 4-075] and Design Principles Statement (DPS) [Rep 4-077] and further updates are to be made at Deadline 5. These updates clarify the process through which good design will be secured. The route to good design is embedded in the draft DCO [Rep 4-008], starting with Requirement 9 (1), which requires that the Applicant produce detailed design covering the layout, scale, building elevations and external appearance of the onshore substation. Requirement 9 (3) then requires that the detailed design will be in accordance with the DAD and DPS produced by the Applicant. (At Deadline 4a the Applicant has updated Requirement 9(3) of the draft DCO so that the design details specified in Requirement 9(1), also must be in accordance with the DAD). As Requirement 9 (1) stipulates that the construction of the onshore substation will not commence until the detailed design has been submitted and approved by Lincolnshire County Council (in consultation with the relevant planning authority), the onus is on the Applicant to ensure good design is delivered, following the process and principles set out in the DAD and DPS, and implemented through the careful consideration of the detailed design. Securing good design will require close collaboration and consultation with Lincolnshire County Council, as well as engagement with the Design Review Panel, Community Liaison Group and independent Design Review Panel. This will ensure an open and transparent process and will give interested parties the opportunity to provide feedback at important stages of the detailed design.

ID	Response to Action Point 28 from Issue Specific Hearing 5	Applicant Response
		The DAD and DPS combine to ensure that the emerging detailed design for the onshore substation will comply with current policy on good design, with Section 1.2 of the DPS setting out how the project has taken on board the Planning Inspectorate's 'Advice on Good Design' and Section 3.2 of the DAD setting out how the project's process fulfils design guidance set out in the National Policy Statements. Furthermore, page 48 to 52 of the Policy Compliance Document (REP4-090) and Table 6-6 of the Planning Statement (APP-297) sets out how 4.7 of EN-1 (Criteria for good design for Energy Infrastructure) are complied with through the approach taken by the Applicant. Should the DCO be granted, the above route map will ensure that the Applicant, and those it instructs and employs, will be required to comply with the DCO and hence ensures that good design is secured.

1.19 Applicant's Response to Action Point 29

ID	Response to Action Point 29 from Issue Specific Hearing 5	Applicant Response
ISH5 AP 29	LCC to provide a list of consented orders that include a table listing the 'relevant planning authority' and both parties to have further discussions and update the ExA on this matter.	The Applicant's position remains as outlined in The Applicant's Written Summary of Oral Case Put at Issue Specific Hearing 5 held on 12 February 2025 that amending the DCO as suggested by LCC does not address their concerns regarding being able to enforce the relevant provisions of the DCO. To address this issue, the Applicant has proposed a new Article 48 (Transfer of functions of the relevant local planning authority) which provides for the transfer of enforcement functions under Part 8 of the Planning Act 2008 of the relevant local planning authority to Lincolnshire County Council, for the purposes of the Outer Dowsing Offshore Wind Farm Order only, in respect of certain specified articles and requirements.

1.20 Applicant's Response to Action Point 30

ID	Response to Action Point 30 from Issue Specific Hearing 5	Applicant Response
ISH5 AP30	Applicant to update and check the wording of works plans to match the wording within Schedule 1, Part 1	The Applicant has at Deadline 4a submitted an updated Works Plan Onshore (document 2.1, version 4), and Works Plan Offshore (document 2.2, version 4), to align with the wording within 3.1 Draft Development Consent Order, Schedule 1, Part 1.

1.21 Applicant's Response to Action Point 32

ID	Response to Action Point 32 from Issue Specific Hearing 5	Applicant Response
ISH5 AP32	Applicant to provide confirmation of work Nos that it proposes to maintain for the lifetime of the project and expand on the relationship between Requirements 10 and 11(2). LCC to be consulted and to also provide a response in this regard.	Work No. 23, as set out in the draft DCO (document 3.1, version 8), covers '*landscaping works including bunding and planting, drainage works, and formation of footpaths and access*'. The Applicant proposes that this Work No will be maintained for the lifetime of the Project, in respect of the final mitigation planting plan associated with the onshore substation, and the Outline Landscape and Ecological Management Strategy (OLEMS) (document 8.10, version 7) has been updated at Deadline 4a to provide further clarity on this. Requirement 10 of the draft DCO (document 3.1, version 8) requires the Applicant to submit a landscape management plan(s) and associated work programme(s), which will present the detail regarding the implementation of the replacement planting and will also detail the works required for the management and maintenance of Work Nos 23 over the lifetime of the project, with guidance on the implementation of adaptive management that will be necessary to respond to our changing climate. Requirement 11(1) of the draft DCO requires that all landscaping works are carried out in accordance with the landscape management plan(s) approved under requirement 10 (provision of landscaping), and in accordance with the relevant recommendations of

ID	Response to Action Point 32 from Issue Specific Hearing 5	Applicant Response
		appropriate British Standards. Requirement 11(2) then goes on to set out that unless the approved landscape management plan(s) require something different, the Applicant is required to replace any planting within a period of five years after planting, where specimens have died, are seriously damaged or diseased or have been removed. This commitment applies to all planting associated with the Project, including planting proposed at the landfall, along the onshore cable corridor and around the onshore substation. Landscape management at the landfall and along the onshore ECC will cover a five year period. Landscape management at the onshore substation will cover the lifetime of the Project. In respect of all onshore infrastructure, including the landfall, onshore ECC and onshore substation, there will be a five year replacement planting period. There is a difference between landscape management generally and what is to be done to trees which die within the first 5 years. The landscape management plan for the onshore substation will provide details of the measures that will be employed to maintain the landscaping forming part of Work No. 23 for the lifetime of the development to ensure appropriate screening remains in place, however, it would not necessarily be appropriate to replace trees beyond the five-year period set out in Requirement 11(2). This is because beyond five years the potential for plant failures to arise reduces notably. Moreover, five years marks the point at which thinning of planting will be undertaken to ensure the healthiest specimens are given the space required to establish more strongly. Damaged, diseased and dead plants will be removed as part of the thinning process but would not be replaced as overstocking would hamper the continued development of the stronger plants emerging. Requirement 11(2) does not therefore provide for replacement planting of the landscaping forming part of Work No. 23 for the lifetime of the Project. Appropriate ongoing maintenance will be secured in the landscape management plan to be submitted and approved under Requirement 10. The Applicant has shared this response with LCC and can confirm at they are in agreement with the approach in principle, but will await reviewing the OLEMS (document 8.10, version 7) once submitted at Deadline 4a for final confirmation.

1.22 Applicant's Response to Action Point 33, 34 and 35

ID	Response to Action Point 33, 34, 35 from Issue Specific Hearing 5	Applicant Response
ISH5 AP33	Applicant and MMO to set out why there is such a gap in their relative interpretations of Article 6 and what further steps each party will undertake to reach agreement prior to the close of the examination.	The Applicant has continued to engage with the MMO in relation to this matter, including most recently at a meeting on 20 February 2025. The Applicant considers that this is a matter on which the Applicant and the MMO are unlikely to reach agreement by the close of the Examination. Following the meeting on 20 February 2025, the Applicant and the MMO agreed the following statement: *The Applicant and the MMO have continued to engage in relation to their differing views on the inclusion of Article 6 (Benefit of the Order) of the Development Consent Order, including most recently at a meeting on 20 February 2025. Both parties acknowledge that provisions similar to those set out in Article 6 have been included in numerous previous DCOs for offshore wind farms. However, the Applicant and the MMO disagree on the principle of whether such a mechanism ought to be included in DCOs. The Applicant and the MMO consider it unlikely that a resolution will be reached in respect of this issue prior to the close of Examination.* The Applicant has set out its position and summarised its understanding of the key difference in views between the Applicant and the MMO at reference 1.3.3, Applicant's Comments on Deadline 4 Submissions (22.3).
ISH5 AP34	Applicant and MMO to seek alignment of the wording in paragraph 29 of Schedule 1 with the wording set out in the DMLs.	The Applicant notes that the wording of requirement 29(2) is substantially the same as the wording in paragraph 9 of Part 2, Schedules 10-15 and paragraph 8 of Part 2, Schedule 16, which is stated to be agreed in the MMO's Deadline 4 submission (REP4-129). Following discussions with the MMO at a meeting on 20 February 2025, the Applicant understands that this issue is now resolved.

ID	Response to Action Point 33, 34, 35 from Issue Specific Hearing 5	Applicant Response
ISH5 AP35	Applicant and MMO to provide reports updating on their most recent discussions following the meeting proposed to be held after the hearings.	The Applicant and the MMO have had two further meetings on 20 and 24 February 2025 to discuss the outstanding matters between the parties. Table 2 of the Applicant's Comments on Deadline 4 Submissions (22.3) responds to each of the points raised by the MMO including identifying, where appropriate, the areas in which matters have progressed as a result of these further discussions.

2 The Applicant's Response to Action Points from ISH 6

2. This section is provided in response to Action Points arising from ISH 6 held on Thursday 13 February 2025.

1.23 Applicant's Response to Action Point 2

ID	Response to Action Point 2 from Issue Specific Hearing 6	Applicant Response
ISH6 AP2	Confirm in Environmental Statement (ES) Chapter 12 [AS1-040] Tables 12.25 and 12.27 whether the final 2 columns should refer to the construction phase percentage increase in baseline mortality, or whether those final two columns should instead refer to the operation and maintenance phase, and amend, if required, in the updated version of ES Chapter 12 that is due to be submitted.	The Applicant has amended Tables 12.25 and 12.27 in the updated version of Chapter 12 Offshore and Intertidal Ornithology (Document Reference 6.1.12, V3 submitted at Deadline 4A)

1.24 Applicant's Response to Action Point 3

ID	Response to Action Point 3 from Issue Specific Hearing 6	Applicant Response
ISH6 AP3	Confirm that the second and third columns of Tables 7.1 and 7.2 of the Without Prejudice Additional Measures for Compensation of Guillemot and Razorbill [REP4-065] that give potential compensation figures for guillemot and razorbill based on a 'high' or a 'low' compensation scenario have been labelled incorrectly.	The Applicant has updated Tables 7.1 and 7.2 to correct the table labels in the updated version of Without Prejudice Additional Measures for Compensation of Guillemot and Razorbill (Document Reference 7.7.6, V3 submitted at Deadline 4A).

1.25 Applicant's Response to Action Point 4

ID	Response to Action Point 4 from Issue Specific Hearing 6	Applicant Response
ISH6 AP4	RSPB to submit the following two papers into this Examination: • Madsen et al (2015) 'Renewable energy developments in an uncertain world: the case of offshore wind and birds in the UK' • Searle et al (2023) 'A framework for improving treatment of uncertainty in offshore wind assessments for protected marine birds'.	The Applicant notes that this was an action formally directed at the RSPB but the Applicant has provided the two papers requested in Appendix 5 of this document, in order to assist the Examining Authority and will provide further commentary as appropriate at Deadline 5. The Applicant notes that the papers identify causes of uncertainty in assessment and advocates for next steps to be taken in reducing the level of uncertainty in assessments to improve decision-making. The Applicant does not dispute that there are uncertainties in the assessments – this is an inherent feature of environmental assessments, is recognised in the Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 through the requirement to identify "*details of difficulties (for example technical deficiencies or lack of knowledge) encountered compiling the required information and the main uncertainties involved*, which the Applicant has done throughout the assessment. The Applicant and Natural England disagree on the level of precaution which should be applied in order to address these uncertainties. The Applicant maintains that it has applied an appropriate level of precaution throughout the assessment, proportionate to the level of uncertainty in the assessment. In this regard the Applicant makes the following observations. *Searle et al* (2023) states at page 2: "*In impact assessments, following the precautionary principle, the degree of precaution applied should be proportional to the extent of scientific uncertainty, but due to mistreatment of uncertainty, precaution may often be applied incorrectly.*" The Applicant agrees with this statement and confirms that it has applied a suitable level of precaution across the assessments. *Searle et al* goes on to explain the challenges with layering precaution on precaution, as the Applicant has highlighted throughout the Examination at page 9 (emphasis added):

ID	Response to Action Point 4 from Issue Specific Hearing 6	Applicant Response
		"End-to-end propagation of uncertainty *Additional structural uncertainty may arise within the framework either if there are impacts other than those currently considered within the assessment process or if components between the tools interact. For example, displacement and collision risks are assessed independently and their impacts are added together, which ignores any biological interaction between the movement and the behavioural processes that underpin displacement and collision effects.* ***At present, precaution can be magnified through this process, with precautionary outcomes from each stage of the assessment (Figure 2) compounded together****."* Finally, *Searle et al* concludes by warning of the consequences of failing to correctly recognise and quantify the level of uncertainty in models and data and that this results in "*poorly informed decision-making where the rationale is unclear, rather than providing transparent, objective, evidence-based decision-making informed by proportionate risk assessment. It is therefore imperative that we undertake ornithological* [offshore renewable energy development] *impact assessments with properly quantified uncertainty to inform the appropriate degree of precaution*."

1.26 Applicant's Response to Action Point 5

ID	Response to Action Point 5 from Issue Specific Hearing 6	Applicant Response
ISH6 AP5	Provide any updates required in relation to the reduction of lead-in times for guillemot and razorbill at Artificial Nesting Structure(s)	The Applicant has provided a response to this action in Appendix 1 of this document - "Lead-in periods for guillemot and razorbill on ANS".

1.27 Applicant's Response to Action Point 6

ID	Response to Action Point 6 from Issue Specific Hearing 6	Applicant Response
ISH6 AP6	Provide a note to clarify the meaning of the use of 'best endeavours' in regard to the updated wording provided in paragraph 42 of [REP4-084] and paragraph 30 of [REP4-086]	The Applicant has considered this question and provided a response in detail in Document 22.7, Clarification Note: Meaning and use of Best Endeavours.

1.28 Applicant's Response to Action Point 7

ID	Response to Action Point 7 from Issue Specific Hearing 6	Applicant Response
ISH6 AP7	Applicant and MMO to provide an update on their respective positions in respect to the spread of Invasive Non-Native Species following their upcoming meeting	The Applicant has updated the Offshore In Principle Monitoring Plan (document reference 8.03) at Deadline 4A to include monitoring of INNS, as requested by the MMO.

1.29 Applicant's Response to Action Point 8

ID	Response to Action Point 8 from Issue Specific Hearing 6	Applicant Response
ISH6 AP8	In response to the MMO's concern mentioned in Section 3.2, paragraph 3.2.1 of [REP4-129], the Applicant will signpost and provide further information regarding the assessment of	The Applicant has responded to the MMO's concerns in The Applicant's Comments on Deadline 4 Submissions (Document Reference 22.3, submitted at Deadline 4A)

ID	Response to Action Point 8 from Issue Specific Hearing 6	Applicant Response
	potential impacts from sediment mobilised due to erosion occurring during scour development.	As outlined in Section 7.12.2.2 of Chapter 7 Marine Physical Processes (APP-062), scour around foundations will be limited by the installation of scour protection where required for engineering purposes (as outlined in Chapter 3 Project Description (APP-058)). As a result, potential impacts from the remobilisation of sediments due to erosion occurring during scour development are within the envelope assessed for seabed preparation around foundations as they will occur within the construction phase and over a smaller spatial footprint than seabed preparation activities. Elevated SSC is predicted to become indistinguishable from background levels within several tidal cycles, and therefore sediment plumes are not considered additive.

1.30 Applicant's Response to Action Point 10

ID	Response to Action Point 10 from Issue Specific Hearing 6	Applicant Response
ISH6 AP10	Applicant to provide an update to their approach to supporting habitat and NE to respond to this approach.	The Applicant has undertaken the analysis of supporting habitat for *Sabellaria spinulosa* with a view to defining areas where removable cable protection could be deployed based on the advice provided by Natural England. This information was provided to Natural England for review via email on the 18th February 2025, with a view to seeking agreement on the interpretations of the methodology and results of the mapping exercise. The Applicant received feedback from Natural England related to this issue on 24 February 2025 which it is considering. The Applicant has proposed a commitment to the installation of removeable cable protection on the defined areas of supporting habitat for *S. spinulosa* reef within the IDRBNR SAC as further mitigation for the impacts of the Project on the IDRBNR SAC at this deadline, Deadline 4A (see change notification submitted by the Applicant on 20th February 2025 (Document Reference 21.22)). The Applicant has updated the Outline Specification and Installation Plan (8.5) and the Outline Scour Protection and Cable Protection Management Plan (8.21) to introduce this commitment.

1.31 Applicant's Response to Action Point 11

ID	Response to Action Point 11 from Issue Specific Hearing 6	Applicant Response
ISH6 AP11	Applicant to provide an update on their proposed benthic compensation measures, outlining those that they are proposing to keep and those they are proposing to drop, with reasons.	The Applicant welcomes alignment with Natural England on the appropriateness of the Applicants preferred primary measure of compensation and the confirmation through the Written Ministerial Statement and associated interim guidance that the strategic extension of Marine Protected Area will be delivered by Defra, should the Secretary of State ("**SoS**") deem compensation necessary for the Project. It is expected that, should compensation be required in relation the IDRBNR SAC, then the measure to be used would be the strategic extension of Marine Protected Areas delivered by Defra through the MRF. However, it should be noted that until the SoS has made their decision on any necessary compensation, and detail on magnitude, cost and timing on any MPA designation or extension delivered by Defra is available, it is prudent for the Applicant to retain the ability to deliver other measures, even in the event there is a lack of agreement with Natural England on those measures the Applicant is proposing to retain. It will be for the SoS to make the final decision on which method will ultimately be delivered (if deemed necessary), noting the Applicant's full agreement with Natural England on the appropriateness in principle of Marine Protected Area designations and/or extensions delivered by Defra.

ID	Response to Action Point 11 from Issue Specific Hearing 6	Applicant Response
		The Applicant's proposed compensation measures are set out below. On the basis of this, and in light of the ExA's acceptance of "Change 2" described in the Applicant's Change Notification dated 20 February 2025, the Applicant will be updating the following documents at Deadline 5: - Without Prejudice Sandbank Compensation Plan (REP4-047); - Without Prejudice Biogenic Reef Compensation Plan (REP4-049); and - Without Prejudice Benthic Compensation Evidence Base and Roadmap (REP4-051). Measures to be retained under Schedule 22 of the DCO The Applicant proposes to keep the following measures within the DCO for the reasons outlined above, notwithstanding the current status of agreement with Natural England: • Anthropogenic Pressure Removal – Redundant Infrastructure The Applicant's position is that it would be possible to deliver this measure on a Project alone basis, as it has progressed conversations with telecommunication owners and has received a letter of comfort from British Telecommunications PLC (BT), the main asset owner (submitted at Deadline 2, REP2-063). The letter confirms that BT is supportive of the proposal to remove redundant telecommunications cable systems within designated sites that are within its ownership, if this is required. This demonstrates that BT would be willing to enter into an Out of Service Cable Recovery Agreement with the Project for such removal should such compensation be deemed necessary. Any such future agreement will, among other things, identify which section/s of cable are to be removed. • Anthropogenic Pressure Removal – Aggregate Industry Pressures The Applicant's position is that it would be possible to deliver this measure on a Project alone basis, as it has held initial conversations with aggregate licence holders and notes Natural England's previous support for this measure. The Applicant will update the ExA as further updates are available on this measure. • Creation of Biogenic Reef The Applicant's position is that it would be possible to deliver this measure on a Project alone basis. The Applicant has submitted a Letter of Comfort into the examination process at Deadline 4 (Document Reference 21.17; REP4-122) from The Oyster Restoration Company (TORC), which states that they are able to provide the necessary services that would be required for this compensation measure, should it be required. This letter serves to provide confidence that adequate oyster seed and cultch can be provided to create a self-sustaining native oyster reef to the scale that might be required on a worst-case assumption. The Applicant also refers to the letter of Comfort from The Crown Estate (REP2-062) which confirms their ability to grant the rights which are anticipated as being required in respect of the construction of the biogenic reef within territorial waters, assuming the conditions set out in the letter can be met. Measures to be removed under Schedule 22 of the DCO It is acknowledged that there is significantly increased confidence in the availability of strategic delivery of the Applicant's and Natural England's preferred measure through the MRF. Therefore, as proposed in the Change Notification of 20 February 2025 accepted by the ExA, the Applicant is removing the following measures from the DCO:

ID	Response to Action Point 11 from Issue Specific Hearing 6	Applicant Response
		• Alternative protection measures The Applicant proposes to drop this Project alone measure from its proposed compensation measures considering the increased likelihood of the availability of the agreed preferred measure through the MRF and the fact that the necessary alternative protection measures required are beyond the control of the Applicant. • Anthropogenic Pressure Removal and Marine Debris and Awareness campaign The Applicant proposes to drop this Project alone measure from its proposed compensation measures considering the increased likelihood of the availability of the agreed preferred measure through the MRF, noting Natural England's position on the measure and difficulties in delivery encountered by other projects. • Seagrass Habitat Creation/Restoration The Applicant proposes to drop this Project alone measure from its proposed compensation measures considering the increased likelihood of the availability of the agreed preferred measure through the MRF, noting Natural England's position on the very small amount of compensation that this measure could (e.g. less than <10% of the required compensation and/or potential adaptive management and only as a delivering that as part of a package of compensation measures). The Applicant also acknowledges the likely difficulty in delivering this measure.

1.32 Applicant's Response to Action Point 15

ID	Response to Action Point 15 from Issue Specific Hearing 6	Applicant Response
ISH6 AP 15	Applicant to explain how the wake loss assessment methodology differs from that considered for Mona Offshore Wind Farm.	The Applicant has provided this explanation in Document 22.8 The Applicant's Wake Loss Methodology Clarification Note

1.33 Applicant's Response to Action Point 17

ID	Response to Action Point 11 from Issue Specific Hearing 6	Applicant Response
ISH6 AP 11	Provide an update on the requirement for the Ørsted IPs Protective Provisions.	The Applicant has set out its explanation as to why protected provisions are not required in the Applicant's Comments on Responses to the Examining Authority's Written Questions 2 (document reference 22.2 submitted at Deadline 4a) and the Applicant's Written Summary of Oral Case Put at the Issue Specific Hearing 6 held on 13 February 2025 (document reference 22.5 submitted at Deadline 4a). The Applicant's Wake Loss Technical Note (REP4-114) shows that the Applicant has demonstrated that potential wake loss effects even when considered on a precautionary basis cannot, in the context of the Project, be considered significant in EIA terms or materially affect the overall planning balance. There is therefore no justification for the inclusion of protected provisions.

1.34 Applicant's Response to Action Point 19

ID	Response to Action Point 19 from Issue Specific Hearing 6	Applicant Response
ISH6 AP19	Applicant to provide an update on discussions with the Defence Infrastructure Organisation (DIO) regarding whether mitigations for primary surveillance radar will be in place before 2030 when the project might be operational, and provide drafting of the related requirement.	The Applicant wrote to the Defence Infrastructure Organisation (DIO) via e-mail requesting a meeting to seek further progress in relation to mitigation for primary surveillance radar on 13th February 2025. The Applicant wrote the DIO again on 18th February 2025 and provided a draft of the requirement included within the draft DCO at Deadline 4a (document reference 3.1, version 8) requesting comments by Friday 21st February 2025 in order to provide an update to the ExA at Deadline 4a in response to this action. No responses have been received from the DIO.

1.35 Applicant's Response to Action Point 21

ID	Response to Action Point 215 from Issue Specific Hearing 6	Applicant Response
ISH6AP21	Add the DIO as a consultee for requirement 18 of the draft Development Consent Order.	The Applicant has provided an update to Requirement 18 in the draft DCO submitted at Deadline 4a (3.1).

1.36 Applicant's Response to Action Point 22

ID	Response to Action Point 22 from Issue Specific Hearing 6	Applicant Response
ISH6 AP 22	Applicant to confirm whether the commitment expressed in table 3.1 of the updated Design Approach Document [REP4-075] to construct a maximum of 50% of foundations as gravity-based structures refers to the offshore construction area as a whole or only to the construction of the Offshore Reactive Compensation Platforms. Alternatively provide signposting to where this confirmation can be found in documents already submitted to this examination.	Requirement 4(1), Part 3, Schedule 1 of the DCO requires that the maximum number of gravity base structure foundations must not exceed 50% of the total number of wind turbine generators, offshore electrical installations, accommodation platform and offshore artificial nesting structures combined. On 20 February 2025, the Applicant submitted a Change Notification advising the ExA that it proposes to remove the option to install gravity base structure foundations for the Offshore Reactive Compensation Platforms. The Applicant is not proposing to amend Requirement 4(1) as a result of this change.

Additional Requests from ISH 6

3. In addition to the Action Points raised during ISH 6, the requests below were made by the ExA of the Applicant. Responses to these requests are provided below.

ID	Response to Action Point 22 from Issue Specific Hearing 6	Applicant Response
1	Applicant to provide a post hearing note to set out how the Hornsea compensation methodologies (03 and 04) apply across a suite of species and compensation measures	The Applicant has provided a response to this action in Appendix 3 - Compensation calculation at 'additional south-west sites'.
2	Annex 1 (NE HOW04 and philopatry), submitting D4 WQ response again	The Applicant has appended this to the resubmitted The Applicant's Responses to the Examining Authority's Written Questions 2 (Document Reference 21.2, V2 submitted at Deadline 4A).
3	Summary of the offshore ornithology calculations (NE vs applicant) - precaution note	The Applicant has provided a response to this action in Appendix 2 - The effect of precaution in the assessment of impacts and calculation of compensation
4	Applicant to respond to NE requests in App K, if we can update assessments/ why not	The Applicant has responded to Natural England's Appendix K in The Applicant's Comments on Deadline 4 Submissions (Document Reference .22.3, submitted at Deadline 4A))

Appendix 1 Lead-in periods for guillemot and razorbill on ANS

4. The Applicant has presented a without prejudice derogation case for guillemot and razorbill in the event that the Secretary of State concludes that adverse effects on these species at the Flamborough and Filey Coast SPA cannot be ruled out.
5. For both guillemot and razorbill, the Applicant maintains that the Plémont Seabird Reserve can deliver the full requirement of compensation based on the Applicant's approach to calculating compensation. Any additional requirement would then be addressed through disturbance reduction measures to be implemented at the suite of sites in Devon and Cornwall, for both species or through allocation of space on an ANS. The Applicant has also allowed for compensation to be delivered through collaboration of through the Marine Recovery Fund (including predator reduction measures) within the Development Consent Order. As such the Applicant notes that the question of lead-in periods for guillemot and razorbill on ANS should be considered in light of the fact that this forms part of a package of proposed measure and is unlikely to be relied upon as a sole measure, unlike the proposed kittiwake compensation.
6. Where compensation measures rely on the generation of new breeding pairs, Natural England advise that an appropriate lead-in period should be in place so that measures can provide compensation at the point at which the impact begin. The provision of a lead-in period aims to reduce (but cannot guarantee to eliminate) the accrual of compensation debt (a compensation debt is accrued where the level of compensation required has not been generated by the compensation measure(s)).
7. The Applicant considers that a more appropriate and realistic approach to addressing potential accruals of compensation debt is to overcompensate during the lifetime of the Project.
8. The Applicant has provided growth models within REP4-104 which show that, in the case of the Applicant's approach with an ANS with 300 AONs, the compensation provided for kittiwake over the anticipated approximate 35-year lifetime of the Project would outweigh the cumulative requirement by over 800 birds.
9. Production of a comparison similar to that provided for kittiwake is not possible for auks. In REP4-104, colony growth and cumulative outputs (i.e. the number of young surviving to adulthood summed over the years of operation) are compared against summed impacts (i.e. the annual impact of the Project, summed over the years of its operation). For kittiwake, cumulative outputs have been modelled using an impact agreed with Natural England and assuming all of the impact is addressed by the ANS. In the case of guillemot and razorbill, the impact has not been agreed with Natural England and there are two other measures providing compensation. As such, the specific requirement from the ANS is unknown and therefore cannot be compared to modelled outputs from the ANS.
10. Confidence that an ANS could provide adequate compensation for auks during the lifetime of the Project can be found from a study of an existing ANS. Data from a bespoke ANS auk colony in the Baltic Sea demonstrates that colonisation and colony growth at an ANS can be rapid (Carlsen et al., 2025) (much more so than for kittiwake). Using data from this ANS to inform a model that calculates the growth and outputs from the proposed Project ANS suggests that a structure that can accommodate approximately 1,600 breeding pairs of guillemot would take approximately 13 years to reach capacity . The cumulative contribution of this structure over 35 years would be 10,702 adult birds; this value is just below the cumulative summed impact for guillemot, based upon Natural England's preferred approach to impact assessment and a 1:1 ratio, of 13,132 birds.
11. Data from the same auk colony suggest that razorbill colonisation and growth is slower than that of guillemot and that, at the point of a fully established guillemot colony, a razorbill colony on the Applicant's ANS may number approximately 400 pairs. An ANS accommodating a razorbill colony of this scale would be within the design parameters proposed for the Project ANS and therefore the Applicant is confident that the ANS can be colonised to full capacity. Razorbill impacts using the Applicant's approach are 10.5 birds; razorbill impacts under Natural England's approach are substantially lower than that of guillemot (69 razorbills compared to 375 guillemot). The Applicant therefore considers that it is highly likely that suitable overcompensation can be provided in order to offset any compensation debt accrued.
12. In summary, the Applicant maintains that a more appropriate and realistic approach to addressing potential accruals of compensation debt (as opposed to a specific lead in time) is to overcompensate during the lifetime of the Project. The Applicant is confident that, based on published colonisation data for auks, should compensation be required for these species, in addition to that which can be delivered by predator eradication measures at the Plemont Seabird Reserve and the disturbance reduction measures at the suite of south-west English sites, this can be provided by a Project ANS.

Appendix 2 The effect of precaution in the assessment of impacts and calculation of compensation

13. The levels of precaution introduced within each stage of the assessment, apportioning process and subsequent calculation of compensation quanta, have been discussed in REP2-057, REP3-059 and within subsequent responses to written questions and submissions.
14. In order to illustrate how precaution is introduced, the Applicant has provided a worked example using the guillemot assessment; this example highlights the effect that introducing each element of precaution has on the outcomes of the assessments and the calculation of compensation.
15. Precaution is introduced into assessments as mitigation against scientific uncertainty; the levels of precaution used should be proportionate to the levels of uncertainty, in line with the purpose of the precautionary principle.
16. The Applicant maintains that the levels of precaution used in the Applicant's approach, within both the impact assessment and the compensation calculations, are suitably evidence based and proportionate to the levels of uncertainty; whereas using the Applicant's understanding of Natural England's preferred approach results in levels of compensation calculated which are significantly disproportionate.
17. Using the Applicant's approach to impacts, an annual impact of 18.2 guillemots has been predicted. Using the Applicant's preferred approach to compensation calculation (Hornsea Four) results in a compensation requirement of 75 breeding pairs.
18. Table 2 presents the effects that introducing each additional level of precaution recommended by Natural England has on the impact, both individually and in-combination, with the other already applied elements of precaution.

Table 1. Effects of precautionary elements in the impact assessment for guillemot

Element of Precaution	Applicant approach	Natural England approach	Individual effect of using Natural England rate on Applicant approach (increase in impact – in birds)	Individual effect of using Natural England rate on Applicant approach (percentage increase in impact)	Effect in combination with other precaution applied (percentage increase in impact)	Combined precaution
Density estimate	Mean estimate	UCI estimate	7.6	41.7%	-	-
Bioseasons	Furness 2015	Furness 2015 + bespoke post-breeding bioseason	30	164.9%	330.1%	NE bioseasons + UCI
Apportioning to SPA – breeding and post-breeding	50%	100%	47.3	259%	452.3%	NE bioseasons + UCI + NE Apportioning
Adult proportion	57%	100%	12.2	67.2%	636%	NE bioseasons + UCI + NE Apportioning + NE ad proportion
Displacement rate	50%	70%	7.3	40%	932%	NE bioseasons + UCI + NE Apportioning + NE ad proportion + NE displacement
Mortality rate	1%	2%	18.2	100%	1962%	NE bioseasons + UCI + NE Apportioning + NE ad proportion + NE displacement + NE mortality

19. As presented in Table 2, the additional precaution advised by Natural England for the assessment stage alone increases the impact by 1,962% from that predicted by the Applicant's precautionary approach.
20. Table 3 presents how the compensation calculation stage further amplifies this precaution. In Table 3, the outputs of Natural England's preferred approach to calculating compensation are compared to the Applicant's predicted compensation requirement at ratios of 1:1, 2:1 and 3:1. The example uses the impact derived from the Natural England preferred approach for assessment and compares the compensation outputs with those derived from the Applicant's approach to impact assessment and to compensation calculation.

Table 2. Effects of use of precautionary compensation calculation method (Hornsea 3 part 2) when compared to the Applicant's approach which requires compensation of 75 breeding pairs.

	Compensation requirement (pairs)	**Percentage increase on Applicant's approach**
Compensation increase from Applicant approach using NE approach (1:1)	5,222.1	7,062.9%
Compensation increase from Applicant approach using NE approach (2:1)	10,444.3	14,125.7%
Compensation increase from Applicant approach using NE approach (3:1)	15,666.4	21,188.6%

21. Table 3 shows that, using Natural England's preferred approach for calculating compensation, the compensation requirement increases by 7,063% at a 1:1 ratio and by 21,119% when a 3:1 ratio is applied. The Applicant maintains that a compensation requirement of 15,666 pairs of guillemot to compensate for impacts that the Applicant has precautionarily calculated to be 18.2 birds per year is entirely inappropriate.

1.36.1 Areas of greatest amplification

22. Across the whole process, the use of Natural England's preferred approach to compensation calculation has the greatest single effect on the compensation requirement calculated for guillemot and razorbill.
23. Within the assessment process, the addition of the bespoke post-breeding bioseason (along with the bespoke apportioning rate to be used of 68.5%) has the greatest single effect on the impact calculated. Other precautionary elements of the assessment also have substantial impact on the assessment, with the use of Natural England's preferred apportioning, adult proportion and mortality rate each effectively doubling the impact. Removing these two precautionary elements (i.e. calculating compensation using Natural England's approach across the piece but with the Applicant's bioseasons and the Applicant's compensation calculation (using the Hornsea Four approach)) reduces the compensation required, at a 1:1 ratio, from 3,224 (UCI impact) or 2,352 (mean impact value) pairs of guillemot to 948 (UCI impact) and 683 (mean impact value) pairs of guillemot. The Applicant still considers this to incorporate an unreasonable level of precaution.
24. For razorbill, there are a number of parameters that have a substantial impact on the assessment. Use of the published apportioning rate for the post-breeding bioseason (as opposed to the bespoke rate advised by Natural England) reduces (mean) impacts from 68.9 birds to 48.4. Increasing the mortality rate from 1% to 2% doubles any impacts and the use of Natural England's precautionary adult proportion of 100% (as opposed to the 57% published in Furness 2015) increases impacts from 38.9 to 68.9 birds. Using the Applicant's approach in each of these scenarios reduces the compensation required (calculated using the mean impact value and using the Hornsea Four approach) from 424.8 (Natural England's preferred approach) pairs to 298.4 pairs (using the Furness post-breeding bioseason apportioning rate), 212.7 pairs (using the 1% mortality rate) and 242.3 pairs (using the Furness adult proportion). Using the UCI value, the respective reductions would be from 667.1 pairs to 433.3 pairs (using the Furness post-breeding bioseason rate), 366.0 pairs (using the 1% mortality rate) and 379.8 pairs (using the Furness 2015 adult proportion). Table 2 and 3 demonstrate both the influence that individual elements of precaution can have in calculating impacts and compensation requirements, and how multiple incidences of precaution can amplify impacts or compensation requirements. The Applicant considers that their approach to predicting impacts and calculating compensation is suitably precautionary (as evidenced in REP2-057 Levels of precaution in the assessment and compensation calculations for offshore ornithology, REP2-058 Consideration of bioseasons in the assessment of guillemot and REP2-059 Rates of displacement in guillemot and razorbill) and that the additional multiple layers of precaution advised by Natural England is not required in this case.

Appendix 3 Compensation calculation at 'additional south-west sites'

25. Guillemot and razorbill colonies in the south-west of England have been selected from a long list of potential sites for without prejudice compensation for impacts to FFC SPA from the Project (Table 51). Of these sites, five colonies were selected to form the basis of a potential compensation implementation plan. These sites have been monitored throughout the 2024 breeding season to better understand how the sites are used by both species, potential sources of anthropogenic disturbance, and identify other key pressures such as predators and incidences of habitat loss through vegetation encroachment.
26. Unlike ANS, where potential benefits can be calculated by multiplying the number of available nests by a standard productivity rate, consideration of the potential benefits from the proposed measures in the south-west is more complex.
27. As the presence of pressures can impact both productivity and the size of a colony (to the point of total collapse in some cases), the calculation of the benefits of the proposed measures must consider both productivity and population. A reduction in anthropogenic disturbance is highly likely to have positive impacts on both parameters.
28. The methods used to calculate the benefits of the south-west compensation measures (measured in increased population and productivity) are outlined below and are based on productivity and colony size. It should be noted that the success of, or the need for, adaptive management (as opposed to the benefit) should be measured through a reduction in the levels of disturbance around sites.
29. To estimate compensation, each site requires:
    - A population (in breeding pairs – i.e. the count of individual birds of each species multiplied by 0.667; Walsh *et al*., 1995).
    - Productivity for the colony (a colony-specific rate generated from recent data).
30. Historical and current site populations were taken from the Seabird Monitoring Programme (SMP) database (BTO, n.d.). Site-specific survey data were also used to determine site populations.
31. Projected regional productivity rates for guillemot (0.82) and razorbill (0.64) (Horswill and Robinson, 2015) have been used to calculate the compensation potential at each site. Current site-specific productivity rates (based on 2024 monitoring) have been used to calculated existing productivity at the selected sites.
32. Where productivity has been monitored at a site during the 20204 surveys and no productivity has been recorded, (i.e. productivity data were collected, but no young were fledged), expected productivity rates have been applied to the highest known colony count to calculate potential outputs from that site.
33. Across all sites, the calculation of potential compensation considers the expected productivity at the regional rate for all new breeding pairs generated and, for existing breeding pairs, the colony specific rate subtracted from the regional rate is used, in order to generate a number of additional individual fledglings. The region-specific productivity rate, as presented in Horswill and Robinson (2015), has been used for this calculation; for the SW sites this is 0.82 for guillemot and 0.64 for razorbill. Both of these rates are higher than the national average productivity, but as they are region-specific, and productivity is expected to be higher in an environment with reduced pressures, the Applicant considers that they are appropriate.
34. For sites where current populations are lower than historical peaks, the calculation of potential benefit from the measures considers the potential for a site's population to return to a previous high as a result of increased productivity, along with the associated retention of adults. Therefore, for these sites, the potential colony growth in relation to the historical peak population must be added to the expected change in productivity for the recent population.
35. The potential benefit of the measures can be calculated as follows:
    - A site with 300 IND guillemot has 200 pairs (300*0.667) (Note: 0.667 is the standard rate applied when converting individuals to pairs for auks).
    - The colony at the site has a current site-specific productivity rate of 0.5.
    - The historical peak of this population is 400 IND guillemot, which equates to 268 pairs.
    - Potential individual fledglings generated would therefore be (200*(0.82–0.5)) + (68*0.82). (Note: 0.82 is the published regional productivity rate for guillemot).
    - Therefore, in this case, the number of new fledglings generated per year would be 119.8.
36. For sites that are currently at their peak population, the current population (in pairs) is multiplied by the change in productivity rate between the expected regional productivity and the current productivity.
37. An example of this calculation is given below.
    - A site has 200 guillemot pairs and a current productivity rate of 0.5.
    - Potential new birds generated would be (200*(0.82–0.5)).
    - Therefore, in this case, the number of new individual fledglings generated per year would be 64.

In summary, the calculation of compensation benefit from the south-west measures differs from the calculation used when considering ANS or any other measures that generates a new colony. This is because the south-west measures will be implemented at existing colonies. This appendix provides worked examples of how the benefits of compensation will be calculated should compensation be required and this measure is taken forward.

Appendix 4 Response to the Report on the Implications for European Sites (RIES)

38. The Examining Authority's Report on the Implications for European Sites (RIES) was published on the Monday 17th February 2025.
39. The Applicant agreed during the attendance of the ISH6 on Thursday 13th February 2025, that they would respond to as many of the RIES questions as possible for Deadline 4a. The remaining questions will be responded to at Deadline 5.
40. The table below provides the Applicant's response on questions outlined in the RIES.

RIES ID	RIES Question / Extract	Question Addressed to	Applicant Response
RIES Q.1	Figure 5.4 in [REP4-037] identifies the River Derwent SAC and this site is further identified in table 3.1 of [REP4-039]. Please confirm where the conclusions relating to this site have been provided?	The Applicant	The inclusion of the River Derwent SAC within Figure 5.4 of REP4-037 and Table 3.1 of REP4-039 is a mistake from a previous iteration of the application documents. Given the distance between all aspects of the Proposed Development and the site (>100km) and the feature of relevance designated at the site (sea lamprey), the Applicant can confirm that no LSE has been identified for this site and therefore there is no AEoI for this site from the Project either alone or in-combination.
RIES Q.4	[REP4-030], paragraph 108, sets out a single set of conservation objectives for the 7 benthic and subtidal ecology sites assessed for AEoI. A similar approach is taken for sites in the marine mammals receptor group. Can the applicant confirm the conservation objectives applied to all these sites, and provide appropriate references to where this information derives from?	Natural England The Applicant	The Applicant can confirm that the conservation objectives outlined in paragraph 115 (REP4-030) apply to all 7 benthic and subtidal ecology sites. The Applicant can confirm that the conservation objective information for SACs is derived from Natural England's Access to Evidence website where available. (https://publications.naturalengland.org.uk/). Inner Dowsing, Race Bank and North Ridge SAC: https://publications.naturalengland.org.uk/file/6165144 Wash and North Norfolk Coast SAC: https://publications.naturalengland.org.uk/file/5213489320951808 Humber Estuary SAC: https://publications.naturalengland.org.uk/file/6294287600058368 For the North Norfolk Sandbanks and Saturn Reef SAC, the best available information was derived from the JNCC 2017 document, "Conservation Objectives for North Norfolk Sandbanks and Saturn Reef Special Area of Conservation" , available at https://data.jncc.gov.uk/data/d4c43bd4-a38d-439e-a93f-95d29636cb17/NNSSR-2-Conservation-Objectives-v1.0.pdf As Ramsar sites do not have conservation objectives of their own, the objectives of the underpinning designated sites were used to consider the Ramsar features as follows: Humber Estuary Ramsar (derived from the Humber Estuary SPA): https://publications.naturalengland.org.uk/publication/5382184353398784 Gibraltar Point RAMSAR (derived from the Gibraltar Point SPA): https://publications.naturalengland.org.uk/file/6182824961114112 The Wash RAMSAR (derived from the Wash SPA): https://publications.naturalengland.org.uk/file/4748062010638336
RIES Q.5:	The information provided as to whether a site is in favourable or unfavourable condition is either not present or unclear. The applicant is requested to confirm which sites screened into the assessment of adverse effects are in unfavourable condition.	The Applicant	The Applicant notes that the condition status is assigned per feature rather than by site. It is worth noting, that not all sites and features have been assessed by Natural England and given a FCS, and those sites where such an assessment has not been undertaken are not presented here. Transboundary sites also do not have a condition status assigned to them and therefore their condition is unknown. For those sites without a condition status, due to this lack of information, the assessment has been based on a precautionary condition status of unfavourable. The Applicant has listed below the sites and features considered within the assessment which have a status of unfavourable condition assigned to them: Inner Dowsing, Race Bank, and North Ridge SAC: ▪ Sandbanks which are slightly covered by sea water all the time; and ▪ Reef.

			The Wash and North Norfolk Coast SAC: ▪ Sandbanks which are slightly covered by sea water all of the time (predominantly in a favourable condition, however 28% of the feature at this site is considered to be unfavourable-but recovering); ▪ Mudflats and sandflats not covered by seawater at low tide; ▪ Large shallow inlets and bays (60% of the feature at this site is considered to be unfavourable-no change); and ▪ Reefs.
RIES Q.28	Confirm whether MMO request can be addressed in Outline Offshore In-Principle Monitoring Plan.	The Applicant	In Table 3.1, item 3.1.6 Pre-construction surveys of the Report on the Implications of European Sites (PD-022) the MMO requested "that the outline offshore in-principle monitoring plan include drop-down video at the previous areas where substantial low and medium reef was observed in still images as it is known to be difficult to distinguish reef from the surrounding coarse/ mixed sediments." The Offshore In-Principal Monitoring Plan (document reference 8.3) has been updated at Deadline 4a to incorporate this request.
RIES Q.32	The ExA upon review of [REP4-082] is not able to locate the commitment to disposal upstream of the sandbank qualifying features or the use of a fallpipe. The applicant is requested to provide references for these commitments or provide further commentary.	The Applicant	The Outline Cable Specification and Installation Plan (document reference 8.5) has been updated at Deadline 4a to include the following commitment: *"In the event that disposal of dredged sediment (associated with seabed preparation works or cable installation) is required, material will be deposited, upstream, within an area of similar sediment characteristics, in close proximity to the dredge location, in order to retain sediment within the sediment transport system."* The Applicant is not able to commit to the use of a fallpipe as the sandwave clearance operations that may occur on the applicable areas will fall under the final detailed design of the competent contractor in accordance with approval by the client (The Applicant) and in accordance with the DCO (including dMLS) and all other relevant obligations. The Project cannot confirm at this stage of the development process which contractor or methodology will be proposed; this flexibility needs to be retained in order to ensure that any procurement process remains competitive. It is not common that many dredger vessels utilise rigid pipe solutions for dredging and disposal. Environmental constraints, such as shallow water depth and high currents, may necessitate other methods such as ROV operable dredging spreads, mass flow pumps, or shore/platform based suction dredging. The constraint to only use a rigid fall pipe dredging vessel (e.g. trailer hopper suction dredger) may also have a number of negative effects that will be considered in the engineering of the final solution. This includes the lower operating weather limits for a dredging vessel operating in shallow water with high currents, which in turn may adversely affect the overall construction schedule. Secondly, fall pipes are limited to their disposal rates, lengthening the offshore working time.
RIES Q.34	Provide the full reference details for Kraus and Carter (2018).	The Applicant	Kraus, C. and Carter, L. (2018) 'Seabed recovery following protective burial of subsea cables-Observations from the continental margin'. *Ocean engineering*, *157*, pp.251-261.
RIES Q.44	Provide full reference details for Peritus International Ltd (2022).	The Applicant	Peritus International Ltd. (2022) 'Scour and Cable Protection Decommissioning Study'. NECR403. Natural England.
RIES Q.85	Alternative protection methodologies. Can the applicant confirm whether this measure will be removed following the publishing of DESNZ guidance referred to above.	The Applicant	The Applicant has set out its position of benthic compensation measures in writing in response to the Examining Authorities ISH6 Action Point 11 which is provided in ISH6 AP11 in this document. This position includes information about the removal of several compensation options and why these conclusions have been reached. The draft DCO has also been updated to remove this option (3.1).

RIES Q.88	Anthropogenic pressure measure / debris awareness. Provide an update on views on the inclusion of this measure.	Natural England The Applicant	The Applicant has set out its position of benthic compensation measures in writing in response to the Examining Authorities ISH6 Action Point 11 which is provided in ISH6 AP11 in this document. This position includes information about the removal of several compensation options and why these conclusions have been reached. The draft DCO has also been updated to remove this option (3.1).
RIES Q.90	Seagrass restoration measure. Can the applicant confirm whether it is progressing with this measure.	Natural England	The Applicant has set out its position of benthic compensation measures in writing in response to the Examining Authorities ISH6 Action Point 11 which is provided in ISH6 AP11 in this document. This position includes information about the removal of several compensation options and why these conclusions have been reached. The draft DCO has also been updated to remove this option (3.1).

Appendix 5 Madsen et al (2015) and Searle et al (2023)

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Short Communication

Renewable energy developments in an uncertain world: The case of offshore wind and birds in the UK

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ABSTRACT

As marine renewable energy applications are increasing in the UK, environmental and cumulative impacts and their assessments are receiving considerable attention. The uncertainty, particularly surrounding cumulative impacts, however remains high and is becoming a cause of delay in the consenting process. This study examines the sources of uncertainty in environmental impact assessments and provides recommendations as to how these may be reduced, using the example of birds and wind farms. In the assessment of environmental impacts, uncertainty not only enters through the availability of empirical data but also data collection and analysis methods, linguistics and policy frameworks. Identifying and quantifying sources of uncertainty in environmental and cumulative impact assessments is critical to facilitating the development of an environmentally sustainable offshore wind industry.

1. Introduction

As governments pledge to invest in reducing carbon emissions, they are increasingly focussing on renewable-energy solutions, to reduce reliance on fossil fuels, though the environmental effects of such developments remain highly uncertain. Growing numbers of proposed marine renewable energy developments within strategic development zones create increasing pressures on the environment, making cumulative impacts, i.e. the environmental impacts from multiple projects or activities, a timely issue. Such has been the case in the UK, where concerns have been raised over the negative impacts of wind farms on birds [1], and where the scale of development now represents an unprecedented industrialisation of the marine environment.

Within the UK, the legal framework for the assessment of environmental and cumulative effects related to marine renewable energy refers to the EIA Directive (85/337/EEC), through The Marine Works (Environmental Impact Assessment) Regulations 2007, as well as ornithological impacts being considered in relation to the Birds Directive (2009/147/EC) and the Habitats Directive (92/43/EEC). In recent years the quality of assessments of ornithological impacts of renewable energy developments in the UK has been improving, with cumulative impacts now routinely considered. Variation remains however, in the quality and quantity of information provided and uncertainty still surrounds cumulative impacts and their inclusion in environmental impact assessment (EIA). There is also little recognition of the inherent uncertainty within the EIA process (including cumulative impact assessment; CIA) despite the fact that "…the knowledge base available for decision-making on environmental risks…is characterized by imperfect understanding of the complex systems involved" [2]. The aim of this paper is to highlight uncertainty within environmental and cumulative impact assessments, so to streamline the assessment and application process for marine renewable energy developments, whilst adequately assessing the potential impact of developments on marine wildlife. Sources of uncertainty are discussed and recommendations provided for methods of presenting and reducing uncertainty in environmental assessments. We focus on uncertainty relating to birds and offshore wind farms in the UK, but the principles are broadly transferable.

2. Types of uncertainty

"There are almost as many definitions of uncertainty as there are treatments of the subject" [3]. In this article we define

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0308-597X/

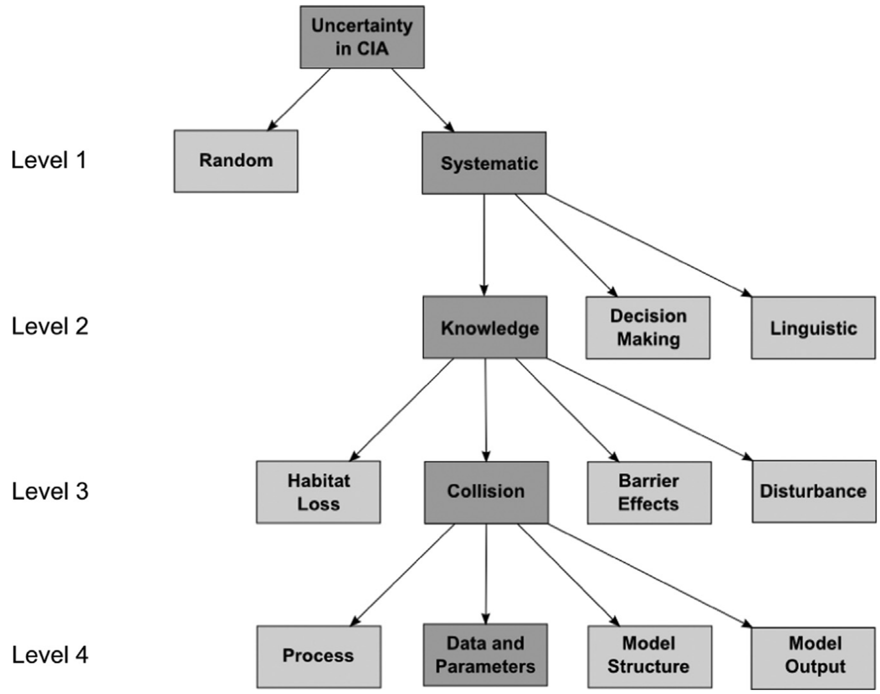

Fig. 1. Hierarchical description of uncertainty within wind farm cumulative impact assessments. Dark grey boxes depict uncertainty in data and model parameters, on which collision risk estimation depends.

uncertainty as a lack of knowledge, or "incomplete information about a particular subject" [4]. In order to manage uncertainty, it must first be identified and categorised and it is useful to consider a hierarchical framework when determining where uncertainty enters the environmental assessment process Fig. 1.

2.1. Level 1: Random and systematic uncertainty

Uncertainty can be categorised as random or systematic. Random (or aleatory) uncertainty is the natural variability related to the randomness or stochasticity of ecological systems. Systematic (or epistemic) uncertainty is therefore the non-random portion of uncertainty and is a function of human understanding and measurement of a situation or environment; for example, our perception of how a bird may be affected by a wind turbine and the subsequent measurement and collection of data. Increasing amounts of data can often reduce systematic uncertainty but this is not the case for random uncertainty particularly if the environment is inherently variable, though the natural variability can be characterised if measured [5].

2.2. Level 2: Linguistic, decision-making and knowledge uncertainty

2.2.1. Linguistic uncertainty

Linguistic uncertainty (or ambiguity) arises because language is vague and/or the precise meaning of words changes over time or between disciplines [5]. For example, cumulative impacts have previously been defined as "Impacts that result from incremental changes caused by other past, present or reasonably foreseeable actions together with the project" [6], with much ambiguity in phrases such as "reasonably foreseeable".

2.2.2. Decision-making uncertainty

Decision-making uncertainty relates to how knowledge and predictions are interpreted, communicated and used in the management and policy arena. It includes uncertainty in the priorities of decision-makers, e.g. government policies regarding renewable energy, as well as uncertainty in the regulatory process and surrounding the values of society. Decision-making uncertainty can be closely linked to linguistic uncertainty. For example, "When high uncertainty is not properly explained or understood, it can delay action or cause the selection of an inappropriate management decision" [5]. This is increasingly becoming a problem for wind farm applications where uncertainty surrounding cumulative impacts leads to a delay in the application process. Uncertainty also enters the decision making process in relation to CIA because data may not always be available for all proposed developments at the same time; this is therefore linked to knowledge uncertainty. Furthermore, this uncertainty increases where the application of legislation is unclear. For example, governments have a legal responsibility to maintain the integrity of the Natura network of protected sites, under Directive 79/409/EEC, as amended. However, in the context of already declining populations of seabird species, it is often unclear how legislation should be applied in consenting decisions for wind farm developments.

2.2.3. Knowledge uncertainty

Knowledge uncertainty refers to the limitation of our knowledge and understanding of a system. It may be caused by a lack of data, particularly because ecological data can be difficult to collect. Knowledge uncertainty is of particular importance when considering cumulative impacts because multiple projects will be involved such as the wind farms in the Firths of Forth and Tay in Scotland, each with associated knowledge uncertainty, thus knowledge uncertainty likely increases with increasing numbers of projects in a cumulative impact assessment.

2.3. Level 3

It is thought that birds are affected via four main pathways regarding offshore wind farms: habitat loss, collision mortality, barrier effects, and disturbance [7,8]. It is possible however, that our scientific understanding of the interactions of birds and wind farms is incomplete and the four main processes described above may not encapsulate all of the processes by which wind farms may affect birds. Knowledge is constantly changing and theories are challenged.

2.4. Level 4

Within each of the four main processes in Level 3 there may be uncertainty surrounding not only the theoretical understanding of the problem but also data collection and analysis. This can affect both our understanding of the probability of occurrence of an event and the severity of the event. For example, birds are known to collide fatally with wind turbines but the issue is one of frequency of interaction, persistence, conservation status, resilience of populations and how collisions may be minimised, all of which require understanding of the mechanisms leading to a collision. These mechanisms include the ecological attributes of species that may make them more or less likely to collide, but can be difficult to quantify [9]. Collision mortality uncertainty can be sub-divided into the uncertainty associated with: i) the understanding of the collision process i.e. the interaction between the bird and the wind turbine(s), ii) data and parameters, iii) model structure e.g. choice and structure of collision risk models and iv) model output. Further, for data and parameters, there may be uncertainty in data collection methods (for example, survey design), or in parameter estimation.

3. Reducing uncertainty in environmental assessments

3.1. Linguistic uncertainty

The first step to reduce overall uncertainty in environmental assessments is to reduce linguistic uncertainty and develop a standardised vocabulary. Reduced linguistic uncertainty will ensure that the expectations of those involved in assessments are aligned at an early stage of a project. Careful and consistent use of terms in documents across the renewable energy sector will help to reduce some of this uncertainty with a necessary addition being a glossary of terms to ensure there is no ambiguity in definitions. Establishing standard guidance documents and case study examples will also help to achieve reduced linguistic uncertainty [7,10–12].

3.2. Decision-making uncertainty

To minimise decision-making uncertainty, results from environmental assessments must be conveyed adequately to decision-makers to be useful in the policy arena. Keeping results and findings clear and simple where possible is important. There is a balance to be achieved between i) presenting a simplified account of a more complex situation which may be persuasive though pay insufficient attention to the reliability of the results and ii) emphasising the uncertainties in the results which may make them less accessible and less usable for policy-makers [4]. For example, when estimating the potential impacts of wind farms on birds, a deterministic model of collision mortality [13] may sometimes suffice, but not always; therefore the importance of uncertainty must be assessed in terms of the decision-making process.

3.3. Knowledge uncertainty

Uncertainty is inherent in scientific research and need not be detrimental. It may not always be possible or necessary to minimise knowledge uncertainty and often we simply need to know enough and know how to best use the available information to inform a decision. This dictates however, that the uncertainty should always be described either quantitatively where possible or qualitatively, to provide a measure of confidence in the data which underpin decisions.

Current environmental assessments often lack measures of uncertainty around impacts that have been measured. It is not always possible to provide a quantitative measure of uncertainty, but a qualitative measure should be given. Equally, if an estimate for a parameter is cited, a measure of uncertainty should be given with this estimate [14]. The Intergovernmental Panel on Climate Change (IPCC) provide a system which comprises seven descriptors [15]. The uncertainty associated with underlying theories should also be assessed. For example, is the understanding of a system well-established and agreed upon [16]? The IPCC also suggest a verbal scale to express confidence in the theoretical understanding of a system using qualifiers such as 'low', 'medium' and 'high' [15]. This scale was recently used by Thompson et al. [17] to summarise their confidence in the data available in their study and should be used in all CIAs to present knowledge uncertainty.

There are well-established quantitative methods for calculating and expressing uncertainty, such as confidence limits which may be estimated directly or by techniques such as bootstrapping [4,16]. These metrics present a measure of confidence in the data which is unambiguous. It is often necessary to also consider the potential effect of any uncertainty. This is possible using sensitivity analyses and can show potential variation in key results should information or data in the study be incorrect. Sensitivity analyses were used to assess the effects of data uncertainty in a population viability analysis of the north Norfolk Sandwich tern population related to wind farm developments [18]. Not only do sensitivity analyses provide information on the implications of uncertainty but they can help to direct future studies or data collection [17] and therefore should be carried out wherever possible.

4. Conclusions

With increasing numbers of renewable energy developments, environmental and cumulative impact assessment is becoming ever more important. This paper has focussed on uncertainty within environmental assessments, which is one aspect which needs attention. There is much uncertainty surrounding the environmental impacts of the renewable energy sector and this uncertainty is not only associated with knowledge and data but also more strategically within language and decision-making processes. The task of assessing the environmental impacts of multiple developments will likely be a challenge for many years to come, but current methods should address and highlight uncertainties in the assessment process. In doing so, the challenges ahead may become more tractable and it may then be possible to cope with those uncertainties that are irreducible. In the case presented, more certain assessments of developments can be made to the benefit of sustainable offshore renewable industry and internationally important populations of seabirds [19].

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References

[1] Stewart GB, Pullin AS, Coles CF. Poor evidence-base for assessment of wind-farm impacts on birds. Environ Conserv 2007;34:1–11.
[2] Van der Sluijs JP. Uncertainty and precaution in environmental management: insights from the UPEM conference. Environ Model Softw 2007;22:590–8.

[3] Argote L. Input uncertainty and organisational coordination in emergency hospital units. Adm Sci Q 1982;27:420–34.
[4] Harwood J, Stokes K. Coping with uncertainty in ecological advice: lessons from fisheries. Trends Ecol Evol 2003;18:617–22.
[5] Ascough JC, Maier HR, Ravalico JK, Strudley MW. Future research challenges for incorporation of uncertainty in environmental and ecological decision-making. Ecol Model 2008;219:383–99.
[6] Hyder Consulting, Guidelines for the assessment of indirect and cumulative impacts as well as impact interactions. 1999.
[7] Masden EA, Fox AD, Furness RW, Bullman R, Haydon DT. Cumulative impact assessments and bird/wind farm interactions: developing a conceptual framework. Environ Impact Assess Rev 2010;30:1–7.
[8] Fox AD, Desholm M, Kahlert J, Christensen TK, Petersen IK. Information needs to support environmental impact assessment of the effects of European offshore wind farms on birds. Ibis 2006;148:129–44.
[9] Furness RW, Wade HM, Masden EA. Assessing vulnerability of marine bird populations to offshore wind farms. J Environ Manag 2013;119:56–66.
[10] King S, Maclean I, Norman T, Prior A. Developing guidance on ornithological cumulative impact assessment for offshore wind farm developers. COWRIE CIBIRD Stage 2009;2:1–25.
[11] MacArthur Green. Ornithological cumulative impact assessment methodology: Pentland Firth and Orkney Waters wave and tidal projects. 2013.
[12] RenewableUK. Cumulative impact assessment guidelines: Guiding principles for cumulative impacts assessment in offshore wind farms. 2013.
[13] Band W, Madders M, Whitfield DP. In: De Lucas M, Janss GFE, Ferrer M, editors. Developing field and analytical methods to assess avian collision risk at wind farms. Madrid: Quercus; 2007.
[14] Thaxter CB, Lascelles B, Sugar K, ASCP Cook, Roos S, Bolton M, et al. Seabird foraging ranges as a preliminary tool for identifying candidate marine protected areas. Biol Conserv 2012;156:53–61.
[15] Mastrandrea MD, Field CB, Stocker TF, Edenhofer O, Ebi KL, Frame DJ, et al. Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties. 2010 (Intergovernmental Panel on Climate Change).
[16] Sense about Science. Making sense of uncertainty: Why uncertainty is part of science. 2013.
[17] Thompson PM, Hastie GD, Nedwell J, Barham R, Brookes KL, Cordes LS, et al. Framework for assessing impacts of pile-driving noise from offshore wind farm construction on a harbour seal population. Environ Impact Assess Rev 2013;43:73–85.
[18] Centrica. Population viability analysis of the north Norfolk Sandwich tern (*Sterna sandvicensis*) population. 2009.
[19] Udovyk O, Gilek M. Coping with uncertainties in science-based advice informing environmental management of the Baltic Sea. Environ Sci Policy 2013;29:12–23.

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Review Article

A framework for improving treatment of uncertainty in offshore wind assessments for protected marine birds

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Governments worldwide are setting ambitious targets for offshore renewable energy development (ORD). However, deployment is constrained by a lack of understanding of the environmental consequences of ORD, with impacts on protected birds forming a key environmental consenting challenge. Assessing the impacts of ORD on marine birds is challenging, utilizing interlinked approaches to understand complex behavioural, energetic, and demographic processes. Consequently, there is considerable uncertainty associated with ORD assessments for marine birds, with current methods failing to quantify uncertainty in a scientifically robust, evidence-based manner. This leads to a high degree of precaution and a lack of confidence in the evidence used to inform ORD consenting decisions. We review the methods used to estimate ornithological ORD impacts in the UK, a country at the forefront of ORD. We identify areas in which uncertainty quantification could be improved through statistical modelling, data collection, or adaptation of the assessment process. We develop a framework for end-to-end quantification of uncertainty, integrating uncertainty estimates from individual stages of the assessment process. Finally, we provide research recommendations to better quantify and reduce uncertainty, to lower future ORD consenting risk. These recommendations extend beyond the UK and could improve impact assessments in other countries with different legislative frameworks.

Keywords: environmental variation, impact assessment, marine birds, offshore wind energy, precaution, seabirds, uncertainty.

Introduction

Ambitious targets for expansion of offshore renewable energy power generation are being set by governments in many countries around the world. Environmental policies in these countries require that this growth is delivered in a sustainable manner. At the heart of this sustainability goal is the need to quantify effects on protected wildlife and, in some regulatory contexts, demonstrate no adverse effect on populations of protected species, in particular top predators such as seabirds. For example, under the EU Birds Directive, Special Protection Areas (SPAs), classified for their nationally and internationally important aggregations of seabirds, require a Habitats Regulation Appraisal (HRA) where any planned development is deemed to potentially have an adverse effect on an SPA (https://www.gov.scot/policies/environmental-assessment/habitats-regulations-appraisal-hra/). Offshore renewable energy developments (ORDs) have the potential to affect protected seabird populations through collisions with turbine blades and through displacement from important habitat (Drewitt and Langston, 2006; Busch *et al.*, 2013; Thaxter *et al.*, 2015; Dierschke *et al.*, 2016; Welcker and Nehls, 2016). Seabirds are long-lived animals, meaning their populations are sensitive to small increases in adult mortality. Survival and productivity rates could be impacted by ORDs, and because these developments have long proposed lifespans spanning several decades, the potential population consequences of the developments on protected seabird populations could be significant.

Assessing the impacts of ORDs on protected marine bird populations requires the use of data from multiple sources and a range of modelling approaches to understand a set of complex behavioural, energetic, and demographic processes in the context of a dynamic marine environment. Inevitably, results from these assessments have considerable uncertainty associated with them (Masden *et al.*, 2015). Where scientific data do not exist or are incomplete and it is therefore not possible to complete a full evaluation of the possible risks an activity may cause to the environment, regulators in many countries implement the precautionary principle (De Sadelaar, 2009; RSPB, 2019). For example, the European Commission advises that "The implementation of an approach based on the precautionary principle should start with a scientific evaluation, as complete as possible, and where possible, identifying at each stage the degree of scientific uncertainty" (https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2000:0001:FIN:EN:PDF). However, the un-

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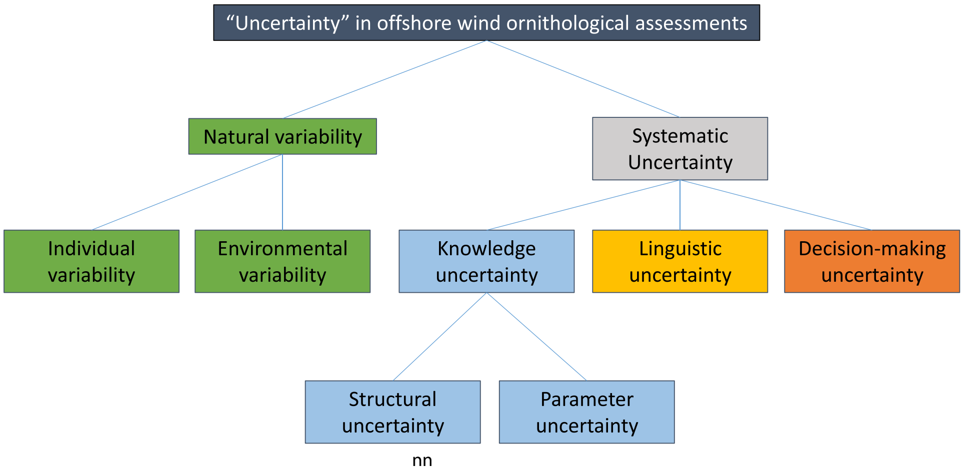

Figure 1. Summary of the sources of uncertainty affecting ornithological offshore windfarm assessments. Redefined from Masden *et al.* (2015).

certainty itself can be difficult to evaluate and propagate through the assessment process due to data paucity, the modelling of complex environments, and the limitations of statistical techniques. Current assessment processes do not quantify the overall uncertainty associated with the impacts of ORDs in a scientifically robust, evidence-based manner (Green *et al.*, 2016). In impact assessments, following the precautionary principle, the degree of precaution applied should be proportional to the extent of scientific uncertainty, but due to mistreatment of uncertainty, precaution may often be applied incorrectly. Approaches for quantifying uncertainty vary between different stages of the assessment process, and there is a lack of consensus on how uncertainty should be presented and interpreted. Historically, uncertainty has been viewed by the offshore wind sector as a feature of the process that can only be managed through additional empirical data collection. However, better statistical treatment of uncertainty and a holistic approach to managing uncertainty from the beginning to the end of the assessment process are likely to yield greater confidence in predicted impacts and quantitative estimates of uncertainty associated with them, thereby reducing the degree of precaution that needs to be applied in key policy mechanisms such as HRA. Ultimately, improved treatment of uncertainty in the assessment process will lead to better evidence use in decision making, and the first step in this process is acknowledging that uncertainty exists. Removing uncertainty is not the goal; rather, the objective is to make a good decision, which requires a robust assessment of the relevant uncertainties (Bickel and Bratvold, 2008).

Here, we review the relevant sources of uncertainty in ornithological offshore wind assessments and the current estimation and use of uncertainty in assessments. We use the UK as an example because it holds internationally important populations of marine birds (Mitchell *et al.*, 2004) and has recently set out plans to accelerate ORD power generation [British Energy Security Strategy (https://www.gov.uk/government/publications/british-energy-security-strategy)]. We provide a generic framework for the end-to-end propagation of uncertainty throughout the ORD assessment process, alongside a series of recommendations for improved quantification and reduction of uncertainty in future research.

Defining and identifying sources of uncertainty

When assessing environmental impacts, the level and form of uncertainty depend on the availability of relevant empirical data, data collection and sampling methodologies, analysis and modelling methods, the linguistics used by different stakeholders, and policy frameworks (Masden *et al.*, 2015). We redefine the framework developed by Masden *et al.* (2015) to recognize how understanding ecological processes relies on separating and quantifying the contributions and impacts of systematic uncertainty versus natural variability (Figure 1; see the Glossary for full definitions of key terms, Supplementary Material S1). Natural variability is a property of natural systems, which may have many causes. For seabirds, variability exists between individuals within a breeding colony relating to physiology, age, or sex (termed *individual variability*), between sub-colonies through social processes and local gene flow, between colonies due to differing habitat characteristics, and across years due to environmental conditions or other aspects of the ecosystem (termed *environmental variability*; Figure 1). As natural variability is a property of the ecological system, it cannot be reduced. However, it can be characterized and quantified through measurement, such as by including explanatory covariates used within models or analyses of ecological processes, ideally clearly separating its impacts from those arising from uncertainty. However, characterizing and quantifying natural variability to successfully differentiate it from uncertainty may require substantial data collection over long time periods, particularly for long-lived species such as seabirds.

Uncertainty is introduced due to limitations in describing, measuring, and representing an ecological system. This has been termed *knowledge uncertainty* (Masden *et al.*, 2015; Figure 1). Within ornithological offshore wind assessments, knowledge uncertainty arises from constraints in understanding and representing the ecological processes through which seabirds are affected by ORDs and in understanding their baseline dynamics. For example, in the UK, three types of seabird interactions are typically considered: displacement from habitat, barrier effects, and collision impacts. These categories capture many underlying behavioural mechanisms, some of which may be explicitly represented within the assessment process. However, many behaviours are currently

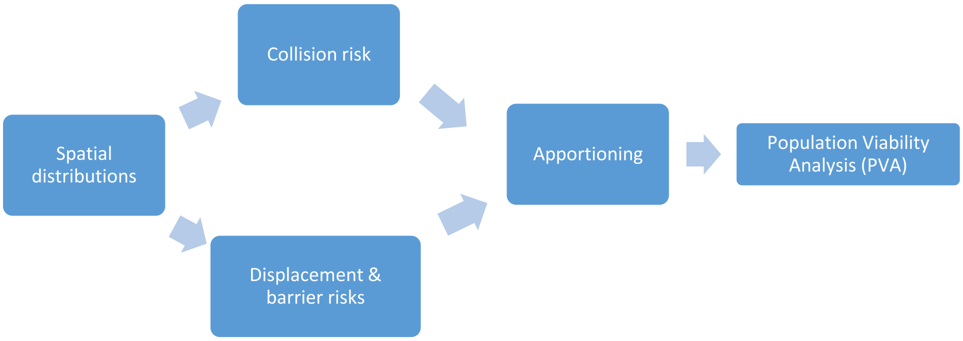

Figure 2. A schematic diagram summarizing the modelling tools involved in the ornithological offshore wind impact assessment process in the UK.

not included, such as habituation, impacts on other trophic levels affecting predator–prey interactions, and foraging site fidelity. Most of the underlying behavioural mechanisms can only be partially described and measured, resulting in knowledge uncertainty that affects ornithological assessment outcomes. Furthermore, all behaviours have energetic and fitness consequences for individuals, which translate to long-term effects on demographic rates for populations and can only partially be described and measured. These limitations all contribute to knowledge uncertainty in assessments.

Knowledge uncertainty is comprised of structural uncertainty and parameter uncertainty. *Structural uncertainty* depends on how fully the mathematical representation of a model captures ecological processes. Our definition of *parameter uncertainty* depends on the quality of the data used to parameterize the model so that measurement and sampling errors are adequately described (Figure 1). Although natural variability is often characterized as a component of parameter uncertainty, we decouple these definitions so that the treatment of each element can be considered in isolation. Better data collection through experimental design, improvements in data analyses, and more advanced statistical modelling approaches can reduce knowledge uncertainty, leading to more precise estimates.

Within ornithological impact assessments, uncertainty also arises through linguistic and decision-making processes. *Linguistic uncertainty* arises because language is vague and/or the precise meaning of words changes over time or between disciplines (Masden *et al*., 2015). For instance, the use of the word "precautionary" within assessments was established to have a precise meaning and interpretation, yet it has a different interpretation for various stakeholders. Moreover, the term "precautionary" is often used with qualifiers such as "overly" or "excessive", further clouding the definition of the term and its use within decision-making. *Decision-making uncertainty* relates to how knowledge and predictions are interpreted, communicated, and used in the management and policy arenas (Masden *et al*., 2015). Whilst important, we do not consider these two additional sources of uncertainty in depth within this review, instead focusing on knowledge uncertainty and environmental variability.

This paper focuses on how environmental variation and structural and parameter uncertainty are recognized, quantified, and propagated through the assessment process. These two processes—natural variability and knowledge uncertainty—are often confused by practitioners and can be difficult to disentangle, but conflating variability with uncertainty can lead to incorrect specification of error (see Supplementary Material S1 for an example). The complexities of natural systems and limitations of ecological data collection mean that uncertainty cannot be, in practice, either perfectly quantified or reduced to zero. Yet, its importance within impact assessment approaches results in a critical need for improvements aimed at both uncertainty quantification and reduction.

Review of current modelling tools and estimation of uncertainty: UK example

In the UK, the current modelling framework for the assessment process comprises interlinked modelling tools that address aspects of seabird ecology or ORD impact, including the spatial distributions of seabirds at sea, collision risk, displacement, and barrier risks, the apportioning of seabirds at sea to protected breeding colonies, and population viability analysis (PVA; Figure 2).

At-sea surveys and tracking data (e.g. from Global Positioning System tags, "GPS") as well as biotic (e.g. colony counts) and abiotic (e.g. environmental data) information are synthesized to define baseline spatial distributions of birds, potentially separated by behaviours such as flight or foraging, to produce continuous maps of mean density estimates with uncertainty (e.g. Johnston *et al*., 2015; Waggitt *et al*., 2018). The spatial distribution maps serve as inputs, along with energetic and growth information, prey data, windfarm-specific characteristics, and behavioural responses to ORDs, to estimate displacement and barrier effects in different seasons. The spatial maps are also combined with models of the behavioural responses to ORDs to provide estimates of collision risk in the breeding and non-breeding seasons. To understand the impacts of displacement, barrier, and collision risks of the proposed ORD on protected populations, most often in Special Protected Areas (SPAs), apportioning is used within the assessment process to attribute effects on seabirds in the breeding and non-breeding seasons to each candidate population. Finally, PVA produces predictions of long-term population consequences, which are the final outputs of this approach (Butler et al. 2020a). Below, we summarize the current methods used to estimate uncertainty within the ORD ornithological assessment process in the UK.

Spatial distributions

Spatial data are used in the assessment process at varying scales: broad-scale, offshore wind farm project-level, and breeding colony-level. Broad-scale data are usually based on offshore aerial or boat-based surveys, capturing spatial distributions of birds and providing insight into seasonal space use (Waggitt *et al*., 2020), which may then be used for marine spatial planning. Project-level abundance data are collected through surveys of ORD footprints and analysed using either design- or model-based methods. Design-based methods use formulae for estimating the quantity of interest (e.g. mean abundance) directly from the raw data, based solely on the survey design used for data collection, without the need for a model. Design-based methods can be used for analysing project-level data because they are collected using a simple, standardized design (i.e. a systematic survey). Model-based methods instead use an explicit model and so rely on additional assumptions. In the context of project-level abundance data, this involves using spatial smoothers and covariates to estimate abundance in unobserved areas within the survey region (e.g. Mackenzie *et al*., 2013). Simpler model-based approaches, such as generalized linear models (GLMs), could also be used, but the advantage of including a spatial smoother is that it can account for underlying spatial patterns that cannot be explained by the covariates. Whilst mean estimates of project-level abundance from spatial models are robust, the models perform poorly for species present in low numbers, so it is necessary to use design-based estimates with bootstrapping to obtain confidence intervals. In contrast, if missing data (e.g. transects missed due to weather conditions) mean that the data collection does not reflect the intended design, then design-based approaches are unlikely to be appropriate and model-based approaches will be needed. In many situations, it will be appropriate to apply both design-based and model-based approaches to investigate the causes of any substantive differences.

Finally, colony-level utilization distributions of birds in the breeding season are derived from tracking data (e.g. Wakefield *et al*., 2017) and are used to provide spatial estimates of the space use and density of birds in the marine habitat around each breeding colony. Here, GLMs or their variants (GLMMs, GAMMs) are used to empirically describe the colony-specific spatial distributions of birds in relation to both accessibility (distance to the breeding colony) and environmental heterogeneity, although residual autocorrelation is typically not accounted for within these models and so uncertainty cannot be defensibly quantified.

Displacement and barrier effects

Quantifying the consequences of displacement by ORDs on a seabird population requires estimates of the proportion of birds displaced and the impact of that displacement on the population's demographic rates. Displacement is estimated through distributional changes in seabirds before and after the wind farm is built, usually based on comparisons of pre- and post-construction monitoring data (e.g. Vanermen *et al*., 2015; Dierschke *et al*., 2016). However, such changes could result from some other cause operating in parallel or from natural seasonal and yearly variability in space use. Therefore, this distributional approach suffers from the conflation of both natural variability and knowledge uncertainty. Until recently, accurately estimating the proportion of birds displaced has proved challenging (but see Heinänen *et al*., 2020; Peschko *et al*., 2020a, b, Peschko *et al*., 2021), with natural variability in the marine environment compounding the difficulty in quantifying displacement rates. Historically, this problem has been exacerbated by inconsistent approaches, low statistical power (Maclean *et al*., 2013), and poor design of post-construction monitoring studies (Marine Management Organization, 2014). However, more recently, the MRSea package in R (Mackenzie *et al*., 2013) provides a more consistent approach to address some of these issues by defining and producing a range of outputs and metrics that are relevant to the estimation of displacement and by providing a modelling framework that can be used to derive these from project-level data. The spatial modelling approach used within MRSea is not the only statistical approach that could be used to estimate displacement. More sophisticated statistical approaches (e.g. R-INLA) and simpler approaches (e.g. GLMs or generalized additive models, GAMs) could also be used, and the application of these different approaches is context-dependent. However, MRSea has the advantage of being specifically tailored to the estimation of displacement and is widely known and accepted in the offshore renewable energy industry. Studies have also highlighted clear inter-specific differences in displacement rates. For example, divers, gannets, and to a lesser extent auks, show a consistent negative response to wind farms, whereas others, such as cormorants, show evidence of attraction, and several other species show no clear response (Dierschke *et al*., 2016). This highlights the need for species-specific approaches to estimating displacement and barrier effects.

Having quantified the proportion of birds displaced from an ORD, it is necessary to consider the impact of this displacement on protected populations. At a population level, displacement may affect birds through a reduction in survival due to the energetic costs associated with losing an area used for commuting, foraging, or other essential behaviours and/or a reduction in breeding success due to the increased energetic costs of provisioning young or increased predation risk of eggs and chicks due to adults spending longer away from the nest. At present, there is little evidence with which to quantify the impacts of displacement on demographic rates, although biologging is increasing our understanding of the behaviour and energetics of marine birds (Dunn *et al*., 2020; Duckworth *et al*., 2022; Buckingham *et al*., 2023) and enabling the effects of behavioural change arising from ORDs on demography to be estimated empirically. Studies that estimate these links will be critical because analyses suggest that increased energetic costs can have a more significant effect on adult survival than has been assumed in previous assessments (Searle *et al*., 2020). Furthermore, life history theory predicts long lived species such as seabirds will prioritize their own survival over that of their dependent young. Evidence suggests that seabirds do attempt to buffer the impacts of increased energetic costs through reduced parental investment in chicks (Suryan *et al*., 2006; Regular *et al*., 2014), potentially reducing productivity.

Two methods have been used to estimate the demographic impacts arising from the displacement effects of ORDs: the "Displacement Matrix" approach (hereafter the *matrix approach*) and the use of individual-based models (IBMs). The two methods differ in terms of the complexity of the approach, the data required, the outputs, and the treatment of uncertainty. The matrix approach uses the density of birds within the wind farm footprint (and a buffer area around the wind farm where birds are predicted to be affected) estimated from local at-sea survey data multiplied by a displacement rate (percentage of adult birds within the footprint and buffer that are assumed to be displaced, ranging from 0 to 100%) and a displacement mortality rate (percentage of birds that are assumed to suffer mortality as a consequence of displacement, ranging from 0 to 100%; Joint-SNBC 2017). The resulting matrix approach table (i.e. proportion of birds potentially displaced or dying as a result of ORD development) provides a visual and qualitative consideration of uncertainty in displacement impacts. The matrix approach only considers the mortality of adult birds, with no consideration of potential effects on dependents and, therefore, breeding success. An alternative approach to estimating displacement is the use of stochastic IBMs (e.g. SeabORD, Searle *et al.*, 2014, 2018). IBMs still require an input for displacement rates but improve the biological realism of displacement mortality rates by incorporating seabird behaviour, energetics, and demographic processes into the model, as well as providing estimates of impacts on both adult birds and their dependents. Current models include some quantification of uncertainty (e.g. impact of prey levels) and are relatively sophisticated in the way that variability (e.g. individual variation in body mass or susceptibility to displacement and choice of foraging location) is accounted for, and these are aggregated and represented in model output using confidence intervals (Searle *et al.*, 2018). However, there are many other parameters within SeabORD for which temporal and inter-individual variability are not considered, largely due to a lack of available information on the level of variability that might plausibly be expected (Searle *et al.,* 2022a).

Collision risk

In the absence of empirical estimates of collisions that can be generalized to new locations, collision risk models are used in EIAs to estimate risk. Whilst there are a variety of collision risk models available (Masden and Cook, 2016), the most widely used of these is the Band *et al.* (2007) model, subsequently adapted for the offshore environment (Band, 2012), and then into a simulation tool to account for stochastic variation in parameters (the stochastic Collision Risk Model, sCRM; Masden, 2015, McGregor *et al.*, 2018). Three sets of parameters are used in the model (McGregor *et al.*, 2018): site-specific seabird data (monthly densities of birds in flight, site-specific or generic flight height distributions), generic seabird data (biometrics, flight characteristics), and turbine and wind farm data (rotor size, hub height, RPM, etc.). The model itself is highly sensitive to particular input parameters for which there is often limited empirical data, resulting in further uncertainty surrounding predicted impacts (Masden *et al.*, 2021). This problem is exacerbated because there is often substantial natural variation in many of these parameters (e.g. flight speed and height), linked to underlying environmental conditions, and these relationships are not captured by existing models. Finally, alternative options are available for implementing the sCRM, which results in impact assessments presenting several alternative versions of the collision predictions, introducing additional complexity in interpretation.

Apportioning

Apportioning is currently used within the assessment process to identify individuals that are likely to be affected by an ORD and are part of a protected SPA population. In the UK, apportioning in the breeding season is currently based either on a simple distance–decay relationship (the NatureScot tool[1]), or on spatial models derived from GPS tracking data (Butler *et al.*, 2020b; Wakefield *et al.*, 2017). In both cases, the proportion of individuals originating from an SPA within a particular area of sea is assumed to be equal to the product of the estimated usage of the area of sea by individuals from the colony (based on colony-specific spatial models) and the colony size. Apportioning in the non-breeding season is currently based on a simpler regional approach, Biologically Defined Minimum Population Sizes (BDMPS; Furness, 2015), which accounts for individuals from non-UK as well as UK colonies. None of the current apportioning tools account for variability or uncertainty.

Population viability analysis

Population Viability Analysis (PVA) provides an established statistical framework for translating effects on annual demography into impacts on longer-term population trajectory (Soulé, 1986; Beissinger and McCullough, 2002). Population models are run forward in time for impacted and unimpacted populations and then compared against each other using a range of metrics (Cook and Robinson, 2016; Jitlal *et al.*, 2017). Metrics used in assessments that provide relative comparisons of impacted and baseline simulations are preferred because they are less sensitive than absolute comparisons to misspecification of baseline demographic rates and initial population sizes (Cook and Robinson, 2016). Currently, these are the counterfactual of population size (CPS), which is the ratio of the final population size of the impacted population divided by the final population size of the unimpacted population, and the counterfactual of population growth rate, defined as the CPS raised to the power of the inverse of the number of years of impact. Key inputs to PVAs are the initial population size, the estimated combined annual impacts of the ORDs on demographic rates, and the baseline demographic rates (age-specific survival, productivity, and age at first breeding). PVAs used for impact assessments typically assume closed populations (no immigration or emigration), and some models incorporate forms of density dependence. However, PVAs do not usually include ongoing impacts such as projected changes to baseline demographic rates under climate or other environmental change (Horswill *et al.*, 2022, Searle *et al.*, 2022b).

Recommendations for improving treatment of uncertainty in the impact assessment process

Research prioritization

Decision-making in the face of uncertainty can be strengthened by recognizing which sources of uncertainty are "controllable", meaning they can be minimized and managed, and which are "important", having a significant and qualitative effect on management outcomes (Milner-Gulland and Shea, 2017). We have used these concepts to lay out a set of research priorities, identifying current evidence gaps that can be addressed by scientific approaches and that are likely to lead to positive management outcomes through better quantification and a reduction in uncertainty. The recommendations focus on future empirical data collection and the use of modern analytical methods to exploit information, mapping them to the current modelling framework. Quantifying uncertainty is as important as reducing it in the context of supporting the decision-making process (Milner-Gulland and Shea, 2017). Where uncertainty appears to be reduced but is not properly evaluated overall, the risk of unanticipated outcomes increases. Therefore, for each research priority, we provide a qualitative assessment of its contribution to the full quantification of uncertainty and to reducing uncertainty (high or medium; Table 1). In the remainder of this section, we make recommendations for a full evaluation of uncertainty across the framework, identify the added value of incorporating post-construction monitoring data, and set out future developments of statistical models that will help fill the evidence gaps. Research priorities are mapped to the main text through bold number referencing, e.g. (**1**).

Spatial distributions

Understanding the space use of birds, including behaviour-specific habitat preference, and how these vary between individuals and in response to environmental variation, is a key area in which uncertainty in assessments can be better quantified and reduced (Table 1). More data are being collected in relation to ORDs and spatial planning, with technological advances leading to new survey methods and data types becoming available: aerial and boat-based surveys (Hammond *et al.*, 2002, 2013, 2018), drones (Rush *et al.*, 2018), camera imaging on wind farms to assess collisions (Skov *et al.*, 2018), biologging devices that track location and collect in-situ environmental information (Cleasby *et al.*, 2015; Isaksson *et al.*, 2021), movement through accelerometers (tri-axial movement) (Chimienti et al. 2016), and behaviour through time-depth records (Peschko *et al.*, 2020, Duckworth *et al.*, 2021). These advances in data collection present questions as to the best use of these varying data types. Data collected using different surveying techniques often has varying structures that require specific statistical analysis techniques to address intrinsic issues such as autocorrelation and replication. For example, boat-based observations generate information about the abundance of animals at a snapshot in time. By contrast, tracking data, generated from tags attached to individuals, provides spatial and temporal information for one animal. Greater knowledge will be gained, and hence uncertainty reduced, if at least some of these data types can be integrated (Matthiopoulos *et al.*, 2022; Schaub and Kery, 2021). For effective integration, two criteria need to be met: data must overlap or align either spatially or temporally, and statistical methods must be developed to deal with intrinsic data issues and propagate uncertainty through the model. For example, data integration could advance seabird assessments by addressing the current failure to adequately consider the distribution of non-breeding birds during the breeding season, leading to differences between assessments based on tracking data and those based on at-sea surveys (Sansom *et al.*, 2018; Searle *et al.*, 2020). New year-round tracking datasets will allow this to happen (Merkel *et al.*, 2016; Buckingham *et al.*, 2022; Duckworth *et al.*, 2022). Integrated modelling would allow the distribution of non-breeding birds to be estimated and the uncertainty associated with this component of the population to be quantified (**1**).

Movement models are used to predict behaviours (e.g. foraging, resting at sea, diving) and estimate activity budgets of seabirds fitted with biologgers to investigate flight paths with respect to collision risk, barrier effects, and displacement (Cleasby *et al.*, 2015; Warwick-Evans *et al.*, 2017; Peschko *et al.*, 2020). A class of movement models used for analysing tracking data are hidden markov models (HMMs), which are state–space time series models that assume the observed (state-dependent) time series is driven by an unobservable (hidden) state process. They sequence behaviours (states) and can account for serial dependence between observations (Patterson *et al.*, 2008; Langrock *et al.*, 2012). Depending on the complexity of the behavioural states required, combining locational data with ancillary information such as accelerometers, time-depth recorders (TDRs), or environmental covariates can produce more plausible models. Using movement models in the context of assessments can improve the quantification and reduction of uncertainty because they can provide more information about how birds are using an area of sea, particularly if two current limitations can be addressed: model validation and propagating uncertainty. Typically, model validation is difficult to achieve because ground-truth data are generally unavailable. However, where animals have been fitted with a device that records Global Positioning System (GPS) and time-depth records (TDR), there is an opportunity to fit a movement model using only location data and use the depth information to validate the model's accuracy in determining behavioural states (Browning *et al.*, 2018). Validating a location-only movement model could be useful in circumstances where only some individuals had TDRs and/or accelorometers but all had GPS functionality in the tag and a general movement model was required (**2**).

Typically, HMMs do not consider observation error on location but treat the state as part of a stochastic process (Patterson *et al.*, 2008). Continuous-time Markov chain Monte Carlo models calculate velocity and momentum and allow for behavioural switching to occur continuously in time rather than at (discrete) observational times (Parton and Blackwell, 2017). They can account for observation error and for irregular observations. Using continuous-time models allows for uncertainty to be quantified and for more biologically realistic trips to be simulated (Blackwell, 2019). In this way, GPS and at-sea survey data could be integrated through sampling from a utilization distribution generated by the movement model (**1, 2**).

Non-breeding season distributions present a large component of current uncertainty within ORD assessments and should be prioritized for future research (**3**). Due to the ethical and logistical challenges of deploying GPS tags on marine birds for extended periods, non-breeding season utilization distributions are typically estimated from data from Geolocators (GLS), which are light-level data loggers. They are lightweight and long-lasting devices that can be attached to leg rings, meaning they are suitable for deploying on marine birds for extended periods. However, because a bird's position is estimated using ambient light intensities and elapsed time, GLS locations have relatively large locational uncertainties up to hundreds of km (Merkel *et al.*, 2016), which hinders their use in assessments relative to the scale of individual offshore wind farms. Nevertheless, these data can offer insight into the long-distance movements and distributions of seabirds during the non-breeding season (Merkel *et al.*, 2016; Buckingham *et al.*, 2022; Duckworth *et al.*, 2022) and will be particularly useful for reducing uncertainty in the apportioning methods used in the non-breeding season (**3**).

Species distribution or habitat preference maps that form the inputs to displacement and collision risk models are produced using spatial data (Wakefield *et al.*, 2017, Waggitt *et al.*, 2019). Habitat preference models associate animal space use with characteristics of their environment (Aarts *et al.*, 2008). When these models are used to predict space use, choosing appropriate explanatory covariates is important; however, the marine environment is dynamic and mostly inaccessible, so

Table 1. Summary of research priorities for better estimating and reducing uncertainty in seabird offshore wind farm assessments, moving beyond current tools and methodologies.

	Research priorities and relevant stage of assessment	Contribution to quantifying uncertainty	Contribution to reducing knowledge uncertainty
1	Data integration from different sources and seasons for better knowledge of year-round distributions to quantify and reduce uncertainty ***Spatial distributions and apportioning***	High	High
2	Improving uncertainty quantification in movement models ***Spatial distributions and apportioning***	High	Medium
3	Better understanding and quantification of year-round distributions and impacts of displacement to quantify and reduce uncertainty ***Spatial distributions, displacement, and apportioning***	Medium	High
4	Better understanding and quantification of predator–prey interactions, relationship between prey density and availability, impacts of ORDs on prey distributions and availability to quantify and reduce uncertainty ***Spatial distributions, displacement, and collision***	High	High
5	Estimate link between displacement effects and changes in demographic rates (productivity and survival) to better quantify and reduce uncertainty ***Spatial distributions, displacement, and apportioning***	High	High
6	Effects of displacement on different age classes, e.g. immatures and non-breeders to better quantify and reduce knowledge uncertainty ***Displacement***	Medium	Medium
7	Improve uncertainty quantification within IBMs to better characterize and reduce structural and parameter uncertainty ***Displacement and collision***	High	Medium
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 ***Collision***	Medium	Medium
9	Improve estimates of flight speed and height for species to better characterize and reduce parameter uncertainty, quantify influence of environmental conditions to better characterize natural variability, and understand how variation in flight speed and flight height is related to behaviour (e.g. commuting versus foraging) to reduce knowledge uncertainty ***Collision***	Medium	Medium
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 characterize natural variability; improve understanding of the contribution of model error to predicted collision rates and the implications of this for estimates of avoidance rates ***Collision***	High	High
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 ***PVA***	High	High
12	Empirical estimation of correlation in demographic rates and influence of environmental stochasticity to better characterize natural variability and improve quantification of structural and parameter uncertainty ***PVA***	Medium	High
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 characterize natural variability ***PVA***	High	High
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 ***PVA***	Medium	Medium
15	Sensitivity analyses for PVAs to help prioritize efforts to reduce structural and parameter uncertainty ***PVA***	Medium	Medium
16	Better understanding and quantification of density dependent processes in populations to reduce knowledge uncertainty ***PVA***	Medium	Medium

Priorities are grouped into "medium" and "high" contributions to (a) full quantification of uncertainty and (b) reduction of knowledge uncertainty. Note that the order of priorities within the table broadly follows their relevance to each stage of the assessment process (shown in bold), moving from estimating spatial distributions of birds and apportioning to quantifying displacement and collision impacts and comparison of impacts via population modelling and PVA. The assignment of each research category into "medium" or "high" was done 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.

collecting and defining appropriate covariates can be challenging. Currently, covariates that represent proxies for prey fields are used due to the paucity of information (Tremblay *et al.*, 2009; Johnston *et al.*, 2015; Waggitt *et al.*, 2018). Associating top predators with oceanographic covariates such as sea surface temperature amidst many complex biological and physical processes can make habitat association modelling difficult due to weak explanatory power where covariates do not adequately capture heterogeneity in environmental space (Skov *et al.*, 2016; Wakefield *et al.*, 2017; Waggitt *et al.*, 2018). However, impact assessments need to account for pre, during, and post-development activities, along with seasonal variation in seabird habitat use due to life history stages (pre-breeding, breeding, chick incubation, non-breeding, and migratory), as well as population response to environmental variability. An overriding issue is that a full understanding of the complexity of ORD impacts on seabird behaviour and activity budgets, as well as proper quantification of uncertainty, can only be achieved through the collection of good quality covariates from direct prey of seabirds. Using prey data (instead of proxies) accounts not only for environmental variability but also provides a direct link to the causal mechanisms of key drivers in seabird demographics. Information on prey fields can then be combined with oceanographic covariates to identify and characterize different scales of seabird distribution and the underlying mechanisms that drive change over space and time (**4**, **5**).

Apportioning

Where apportioning is derived from habitat utilization models developed using GPS tracking data (e.g. Butler *et al.*, 2020b), more thorough statistical approaches are needed to properly address the intrinsic complexities of spatial and temporal autocorrelation associated with such data. Use of such approaches would mean that uncertainties around estimated habitat utilization distributions could be incorporated into assessments (**1**, **2**). For species where colony-specific GPS tracking data are not yet available or are unobtainable due to difficulties in accessing birds for deployment, the rate of decay of utilization with distance can be estimated using foraging ranges derived from published distributions (e.g. Woodward *et al.*, 2019), rather than being fixed as a constant as is the current approach. Foraging ranges can also be disaggregated by population, region, or meta-population as appropriate (**2**), and the inter-population variability in foraging ranges is used to quantify uncertainty in apportioning percentages. Within the non-breeding season, models of geolocator data can, where available, be used as a basis for apportioning in place of the BDMPS, with these models accounting for the locational uncertainty associated with geolocator data (**3**).

Displacement and barrier risks

In the context of ORD displacement impacts, current IBMs have limited uncertainty quantification. Structural uncertainty within IBMs should also be addressed with future research prioritizing improved representation of: flight paths and estimated bird density maps (**2**); behaviour, energetics, and ORD interactions outside the chick-rearing period (**3**); overall prey availability and spatial heterogeneity in prey (**4**); the joint distribution between seabirds and prey spatio-temporal dynamics (**4**); and the relationship between adult mass at the end of the chick-rearing period and overwinter survival [(**5**); e.g. Daunt *et al.*, 2020]; and better understanding and incorporation of impacts on immatures and nonbreeders (**6**). Uncertainty estimates in IBMs can be improved by estimating parameters for which empirical data are not available, through calibration of the model against observed data (**7**). Standard calibration processes involve fitting against observed data to identify the sets of input parameters that provide the best match, according to some metric (e.g. sum of squared differences, deviance), to observed data on one or more of the model outputs. However, many commonly used calibration methods do not account for the uncertainty associated with calibration. Methods of likelihood-free inference, such as Approximation Bayesian Computation (ABC; Beaumont *et al.*, 2002; Marjoram *et al.*, 2003; Sisson *et al.*, 2007) do allow for uncertainty to be estimated but are infeasible in practice due to computational processing time. A potential solution is emulation, which approximates the IBM using a statistical model (Kennedy and O'Hagan, 2001). An emulator runs the IBM for a relatively small number of sets of input parameters and constructs a statistical model that describes how the key outputs of the mechanistic model vary in relation to the values of the input parameters (Oyebamiji *et al.*, 2017; Pietzsch *et al.*, 2020). Uncertainty associated with calibration can be quantified whilst accounting for the uncertainty that arises from the relatively small number of runs of the process-based model.

Collision risk

By incorporating stochasticity, the sCRM better accounts for parameter uncertainty than the deterministic model on which it is based. However, that underlying model remains unchanged and lacks what are likely to be important features of seabird behaviour, such as relationships with environmental conditions, variation across life history stages, and interactions with the turbines themselves, thereby contributing to structural uncertainty within the model. The current model also lacks explicit consideration of covariance in model parameters and its impact on model output (**8**). Tracking of flight paths in three dimensions through wind farms would benefit collision estimates by reducing structural uncertainty in how birds respond to turbines (**9**). This will require high-resolution GPS tags (e.g. Thaxter *et al.*, 2018; Johnston *et al.*, 2015, 2022), high-resolution cameras, and tracking algorithms or combinations of both (Skov *et al.*, 2018). Such technology is available but requires deployment on a large scale to obtain sample sizes sufficient to begin addressing the behavioural and interaction questions of interest and to enable robust assessment of potential device effects. Significant data collection is likely to be needed before any substantial reduction in this component of structural uncertainty within collision models can be achieved. Collision predictions from the sCRM are highly sensitive to assumptions about avoidance rates, and this is a critical focus for impact assessment purposes (**10**). Avoidance rates for the sCRM are estimated by comparing the number of collisions recorded at a wind farm to those that the model predicts would have occurred in the absence of any avoidance. As such, they combine the behavioural response of the birds to the wind farm or turbine with structural uncertainty arising from the simplified model assumptions and parameter uncertainty due to imperfect underpinning data. Current estimates are based on an amalgamation of data sources, very little of which has been collected at operational offshore wind farms due to the difficulty of undertaking long-term studies at these locations (Cook *et al.*, 2018).

Population viability analysis

We have identified three broad areas in which improvements can be made to better characterize and reduce uncertainty in PVAs: the representation of structural uncertainty and natural variability within PVA models, the validation and calibration of population models used in PVAs, and efforts specifically aimed at reducing structural uncertainty in PVA models.

First, PVA should improve methods for representing structural uncertainty and natural variability. Knowledge uncertainty and natural variability in initial population size could be accounted for through the development of a plausible statistical model of observation error for seabird count data (**11**). Most PVAs currently assume that stochastic variation in demographic rates is independent over time, and that variation in demographic rates (productivity and survival) are uncorrelated. Yet inter-annual variation in demographic rates is unlikely to be independent because the underlying drivers, such as climate, exhibit patterns of temporal dependence and because of carryover effects on demographic rates (Bogdanova *et al.*, 2017). Correlations between demographic rates are likely to arise because stochastic environmental effects act simultaneously on demographic processes (e.g. adults may prioritize their survival over productivity). Recent work has estimated correlations in seabird demographic rates for a single species breeding in the UK (Horswill *et al.*, 2021), and further work would improve uncertainty representation within PVAs (**12, 13**). In populations for which sufficient long-term data are available, this approach would produce more defensible annual estimates of both survival and productivity.

Second, validation and calibration of models underpinning PVAs should be progressed (**14**). Running PVA models retrospectively (using the initial population size from a past year) allows the resulting predicted trends to be compared against observed trends seen in the population abundance data. Discrepancies between predicted and observed trends indicate either errors in the values of PVA inputs and/or structural errors in the model underpinning the PVA. Statistical models have been developed that use this discrepancy to estimate poorly known demographic rates, which lack direct empirical data and may only be poorly constrained by inference from expert judgement, as is common for juvenile survival in most seabird species. Although these models have been used in some contexts (e.g. Freeman *et al.*, 2014), they have not been widely implemented. They are effectively a partial form of data integration that can be used to quantify, and often reduce, parameter uncertainty in parameters that are otherwise difficult to estimate and have a broader application than has currently been utilized within assessments.

Third, efforts should be made to reduce structural uncertainty within PVAs. The most substantive improvement for PVA models in resolving structural errors is making their underlying assumptions more biologically realistic. These include linking environmental stochasticity to prey availability and climate change (**12**), empirically parameterizing density-dependent processes (**16**), consideration of inter-specific interactions, inclusion of interactions between different ORD impacts (e.g. determining whether such impacts are synergistic or antagonistic), consideration of carry-over effects, and including dispersal, immigration, and emigration within the context of metapopulations (**11**). Prioritizing these extensions requires consideration of appropriate model complexity, the defensibility of additional model parameters underpinned by existing or new data, and the likely impact of the extension upon the PVA model outputs.

Synthetic approaches to adequately characterizing and reducing uncertainty

Sensitivity analysis

Sensitivity analysis is a valuable tool for examining components of a mathematical or statistical abstraction of a system. This is particularly true in the case of simulations with Monte Carlo treatment of uncertainties, such as those found within the sCRM, IBMs, and PVAs. A sensitivity analysis evaluates the practical importance of the various inputs to a model by perturbing these with resulting changes in outputs examined in practical terms (e.g. Cook and Robinson, 2016; Donovan *et al.*, 2017; Jitlal *et al.*, 2017). Sensitivity analysis is also informative about where research efforts can be focussed to reduce structural uncertainty. If the analysis suggests the model is sensitive to assumptions or parameters, then research to confirm the assumptions or increase the precision of the parameter estimates can be prioritized. Conversely, non-influential assumptions or parameters warrant lesser consideration because model outcomes are more robust to these inputs. Sensitivity analysis can be used to indicate which model inputs contribute most to the precision of outputs and thereby to develop a priority list for reducing uncertainties. This is likely to be particularly helpful in the context of collision models (**8, 10**), but is also relevant to all modelling components of impact assessment whose contribution to uncertainty cannot be easily evaluated by inspection. For instance, in PVA, commonly used counterfactual metrics (e.g. ratios of impacted to baseline population characteristics) are sensitive to inputs that relate to annual ORD impacts on demographic rates and comparatively insensitive to the values of inputs relating to conditions such as baseline demographic rates and initial population size (Cook and Robinson, 2016; Jitlal *et al.*, 2017). Further sensitivity analysis can be used to determine whether potential extensions to PVAs are likely to lead to substantive changes in key PVA outputs, and prioritizing which of these extensions will lead to substantial improvements in the application of PVA within ornithological assessments (**15**).

End-to-end propagation of uncertainty

The standard assessment process for estimating ORD impacts on seabirds uses outputs from a linked set of modelling tools to inform the decision-making process. The choice of which tools are linked together is dependent on the context of the impact assessment and subjective user judgements such as the choice of input data. Additional structural uncertainty may arise within the framework either if there are impacts other than those currently considered within the assessment process or if components between the tools interact. For example, displacement and collision risks are assessed independently and their impacts are added together, which ignores any biological interaction between the movement and the behavioural processes that underpin displacement and collision effects. At present, precaution can be magnified through this process, with precautionary outcomes from each stage of the assessment (Figure 2) compounded together. Therefore, it is important to address both the characterization of uncertainty within individual tools and the quantification of the propagated uncertainty within the framework where multiple tools are linked together, termed *end-to-end uncertainty*. The framework of linked tools can be considered as a meta-model within which inter- and intra-tool uncertainty can be quantified.

The simplest approach for linking uncertainties between tools is via simulation. Each simulation randomly generates the values of any inputs that contain uncertainty and/or any internal tool components that involve stochasticity. This approach can account for both uncertainty and variability within the common framework. The distribution of the assessment process outputs (e.g. PVA metrics) across simulations then quantifies the end-to-end uncertainty associated with the assessment process. The limitations of the approach are that: end-to-end uncertainty will only be meaningful if uncertainty within individual tools and inputs is comprehensive and statistically defensible; a large number of simulations are required to produce stable estimates of uncertainty; and the approach assumes independence between tools. All of these represent potentially substantive issues in the context of ORD assessments. The first issue can be resolved through improved quantification of uncertainty within the individual tools or within the input data to the tools, and the second through computational approaches (e.g. parallel computing) that allow sufficiently large numbers of simulations to be used. Solutions to the final issue are likely to be context-dependent but may need to involve restructuring the current models so that there can be feedback between them (effectively making them components of a larger, overarching model rather than separate models).

Use of post construction monitoring

The tools within the assessment process predict the likely impacts of future ORDs. As developments become operational, a potential mechanism for reducing uncertainty is through the incorporation of data that quantifies the impacts of existing ORDs. These data include at-sea monitoring such as density and distribution data, radar and camera data to detect collisions and micro-avoidance, and land-based/coastal monitoring of foraging patterns, provisioning and nest attendance behaviour, demographic rates, and colony counts, which can be used to retrospectively assess the impacts of ORDs upon seabird populations. The most obvious use of post-construction monitoring data is to refine the estimates of key input parameters, such as displacement rates, collision rates, and avoidance behaviour, for use in future assessments. As the amount of available data to be included in parameterizing models increases, knowledge uncertainty and, in particular, parameter uncertainty should be reduced. The other key role of post-construction monitoring data is in data validation to detect additional structural errors within the tools used for assessment. Incorporating post-construction monitoring data in this feedback mechanism may appear to increase uncertainty if uncertainty is currently being underestimated (e.g. properly accounting for natural variability). However, identifying structural errors and providing the empirical basis to resolve them would lead to more biologically realistic modelling tools and greater confidence in impact assessments. Broader-scale data (e.g. on population size and abundance) can also be used to detect whether the overall ORD impacts produced by assessments are consistent with the levels of change in demography and abundance that are seen after construction. However, these data are not able to distinguish the cause of any discrepancies—which components of the assessment process are introducing error—and are also likely to have low statistical power to detect differences (Cook *et al*., 2019). The primary focus of post-construction monitoring data collection should therefore be on informing and validating specific assumptions, inputs, and component tools used within the assessment process.

Summary

Strategies to reduce uncertainty and obtain a better understanding of the impacts of offshore wind development on the environment whilst ensuring the sustainability of the marine ecosystem are only feasible if the sources of uncertainty are first identified and properly quantified. We have identified a broad range of areas in which uncertainty quantification could be improved. Delivering the underpinning science to enable accurate, robust, and defensible ornithological ORD impact assessments requires developing and advancing a credible line of inference from our conceptual understanding of the ecological and behavioural processes involved through to quantitative impact estimates with uncertainty (Hobbs and Hooten, 2015). This involves representing our knowledge and understanding of the interactions between seabirds and ORDs with models and observations of the key processes shaping these responses, such as seabird spatial habitat use, displacement and barrier effects, and collision impacts. Many of the more substantial evidence gaps for which uncertainty could be reduced are ones that operate across large spatio-temporal scales. These should be addressed through strategic studies rather than at the level of individual offshore wind project post-construction monitoring studies. Administering such strategic studies through an advisory group with a core scientific remit and funding provided by the relevant stakeholders (wind farm developers/operators, regulators, and statutory agencies) would best facilitate the large-scale studies needed. Such an approach would benefit from cross-border and international research collaboration. All models, whether conceptual, theoretical, or statistical, are simplified abstractions of reality. We rely on the proper quantification of natural variability and uncertainty to bridge the gap between reality and our modelled representations to provide inference and to understand their validity for shaping decision-making and policy. Similarly, the data that we collect to inform a model will often only partially capture the true underlying state of the process we are trying to observe. A failure to recognize or quantify these uncertainties in models and data results in poorly informed decision-making where the rationale is unclear, rather than providing transparent, objective, evidence-based decision-making informed by proportionate risk assessment. It is therefore imperative that we undertake ornithological ORD impact assessments with properly quantified uncertainty to inform the appropriate degree of precaution.

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Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Conflict of interest statement

The authors have no conflicts of interest to declare.

Data availability statement

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References

Aarts, G., MacKenzie, M., McConnell, B., Fedak, M., and Matthiopoulos, J. 2008. Estimating space-use and habitat preference from wildlife telemetry data. Ecography, 31: 140–160.

Band, W., Madders, M., and Whitfield, D.P.. 2007. Developing field and analytical methods to assess avian collision risk at windfarms. M. De Lucas, G. Janss, and M. Ferrer. eds.

Band, W.. 2012. Using a collision risk model to assess bird collision risks for offshore windfarms. The Crown Estate Strategic Ornithological Support Services (SOSS) report SOSS02, SOSS Website.

Beaumont, M. A., Zhang, W, and Balding, D. J. 2002. Approximate Bayesian computation in population genetics. Genetics, 162: 2025–2035.

Beissinger, S. R., and McCullough, D. R. (Eds). 2002. Population Viability Analysis. University of Chicago Press, Chicago, IL.

Bickel, J. E., and Bratvold, R. B. 2008. From uncertainty quantification to decision making in the oil and gas industry. Energy Exploration & Exploitation, 26: 311–325.

Blackwell, P. G. 2019. Integrated continuous-time hidden Markov models. ArXiv, 1–18. arXiv:1807.11907v3.

Bogdanova, MI, Butler, A, Wanless, S, Moe, B, Anker-Nilssen, T, Frederiksen, M, Boulinier, T *et al.* 2017. Multi-colony tracking reveals spatio-temporal variation in carry-over effects between breeding success and winter movements in a pelagic seabird. Marine Ecology Progress Series, 578: 167–181.

Browning, E, Bolton, M, Owen, E, Shoji, A, Guilford, T, and Freeman, R.. 2018. Predicting animal behaviour using deep learning: GPS data alone accurately predict diving in seabirds. Methods Ecol Evol, 9: 681– 692. https://doi.org/10.1111/2041-210X.12926.

Buckingham, L., Bogdanova, M. I., Green, J. A., Dunn, R. E., Wanless, S., Bennett, S., Bevan, R. M. *et al.* 2022. Interspecific variation in non-breeding aggregation: a multi-colony tracking study of two sympatric seabirds. Marine Ecology Progress Series, 684: 181–197.

Buckingham, L., Daunt, F., Bogdanova, M.I., Furness, R.W., Bennett, S., Duckworth, J., Dunn, R.E. *et al.* 2023. Synchrony in peak non-breeding season energy expenditure for guillemots from four colonies: implications for severity of marine threats. Journal of Avian Biology, *in press*.

Busch, M., Kannen, A., Garthe, S., and Jessopp, M. 2013. Consequences of a cumulative perspective on marine environmental impacts: offshore wind farming and seabirds at North Sea scale in context of the EU marine strategy framework directive. Ocean & Coastal Management, 71: 213–224.

Butler, A., Carroll, M., Searle, K., Bolton, M., Waggitt, J., Evans, P., Rehfisch, M. *et al.* 2020b. Attributing seabirds at sea to appropriate breeding colonies and populations (CR/2015/18). Scottish Marine and Freshwater Science, 11: 140.

Butler, A., Searle, K., Mobbs, D.C., and Daunt, F. 2020a. A population viability analysis modelling tool for seabird species—tool testing: report for methodology and results for testing of tool. JNCC, Report No. 657, JNCC, Peterborough, ISSN 0963-8091. https://hub.jncc.gov.uk/assets/302a7a51-fe29-4633-95d1-b3ef458cb79a. [Last accessed date: February 2023].

Chimienti, M., Cornulier, T., Owen, E., Bolton, M., Davies, I.M., Travis, J.M.J., and Scott, B.E. 2016. The use of an unsupervised learning approach for characterizing latent behaviors in accelerometer data. Ecol Evol, 6: 727–741. https://doi.org/10.1002/ece3.1914.

Cleasby, I. R., Wakefield, E. D., Bearhop, S., Bodey, T. W., Votier, S. C., and Hamer, K. C. 2015. Three-dimensional tracking of a wide-ranging marine predator: flight heights and vulnerability to offshore wind farms. Journal of Applied Ecology, 52: 1474–1482.

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

Cook, A.S.C.P., Humphreys, E.M., Robinson, R.A., and Burton, N.H.K. 2019. Review of the potential of seabird colony monitoring to inform monitoring programmes for consented offshore wind farm projects. Research Report, BTO Research Report No. 712. British Trust for Ornithology. ISBN 978-1-912642-07-6.

Cook, A.S.C.P., and Robinson, R.A. 2016. Testing sensitivity of metrics of seabird population response to offshore wind farm effects. JNCC Report No. 553, JNCC, Peterborough, ISSN 0963-8091.

Daunt, F., Fang, Z, Howells, R, Harris, M, Wanless, S, Searle, KR, and Elston, D. 2020. Improving estimates of seabird body-mass survival rates. Scottish Marine and Freshwater Science, 11 (13):54.

De Sadeleer, N. 2009. The precautionary principle as a device for greater environmental protection: lessons from EC courts. Review of European Community & International Environmental Law, 18: 3–10.

Dierschke, V., Furness, R. W., and Garthe, S. 2016. Seabirds and Offshore Wind Farms in European Waters: Avoidance and Attraction. Biological Conservation. Elsevier Ltd., Amsterdam.

Donovan, C. R., Harris, C. M., Milazzo, L., Harwood, J., Marshall, M., and Williams, R. 2017. A simulation approach to assessing environmental risk of sound exposure to marine mammals. Ecology and Evolution, 7: 2101–2111.

Drewitt, A. L., and Langston, R. H. W. 2006. Assessing the impacts of wind farms on birds. IBIS, 148: 29–42.

Duckworth, J., O'Brien, S., Petersen, I. K., Petersen, A., Benediktsson, G., Johnson, L., Lehikoinen, P. *et al.* 2022. Winter locations of red-throated divers from geolocation and feather isotope signatures. Ecology and Evolution, 12: e9209.

Duckworth, J., O'Brien, S., Petersen, I.K., Petersen, A., Benediktsson, G., Johnson, L., Lehikoinen, P. *et al.* 2021. Spatial and temporal variation in foraging of breeding red-throated divers. Journal of Avian Biology, 2021: e02702.

Dunn, R., Wanless, S., Daunt, F., Harris, M.P., and Green, J.A. 2020. A year in the life of a North Atlantic seabird: behavioural and energetic adjustments during the annual cycle. Scientific Reports, 10: 5993.

Freeman, S., Searle, K., Bogdanova, M., Wanless, S., and Daunt, F. 2014. Population dynamics of Forth & Tay breeding seabirds: review of available models and modelling of key breeding populations. Ref MSQ-0006. Final Report to Marine Scotland Science,

Furness, R.W. 2015. Non-breeding season populations of seabirds in UK waters: population sizes for biologically defined minimum population scales (BDMPS). Natural England Commissioned Reports Number 164, http://publications.naturalengland.org.uk/publication/6427568802627584. [Last accessed date: February 2023].

Green, R.E., Langsten, H.W., McCluskie, A., McCuskie, A., Sutherland, R., and Wilson, J.D. 2016. Lack of sound science in assessing wind farm impacts on seabirds. Journal of Applied Ecology, 53: 1635–1641.

Hammond, P. S., Berggren, P., Benke, H., Borchers, D. L., Collet, A., Heide-Jørgensen, M. P., and Oien, N. 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology, 39: 361–376.

Hammond, P. S., Lacey, C., Gilles, A., Viquerat, S., Börjesson, P., Herr, H., and Øien, N. 2018. Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys. Wageningen Marine Research, 40pp.https://doi.org/10.1016/j.ijppaw.2016.02.001

Hammond, P. S., Macleod, K., Berggren, P., Borchers, D. L., Burt, L., Cañadas, A., and Vázquez, J. A. 2013. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation, 164: 107–122.

Heinänen, S., Žydelis, R., Kleinschmidt, B., Dorsch, M., Burger, C., Morkūnas, J., Quillfeldt, P. *et al.* 2020. Satellite telemetry and digital aerial surveys show strong displacement of red-throated divers (*Gavia stellata*) from offshore wind farms. Marine Environmental Research, 160: 104989.

Hobbs, N. T., and Hooten, M. B. 2015. Bayesian Models: A Statistical Primer for Ecologists. Princeton University Press, Princeton, NJ.

Horswill, C., Manica, A., Daunt, F., Newell, M., Wanless, S., Wood, M., and Matthiopoulos, J. 2021. Improving assessments of data-limited populations using life-history theory. Journal of Applied Ecology, 58: 1225–1236.

Horswill, C., Miller, J. A. O., and Wood, M. J. 2022. Impact assessments of wind farms on seabird populations that overlook existing drivers of demographic change should be treated with caution. Conservation Science and Practice, 4: e12644.

Isaksson, N., Cleasby, I.R., Owen, E., Williamson, B.J., Houghton, J.D.R., Wilson, J., and Masden, E.A. 2021. The use of animal-borne biologging and telemetry data to quantify spatial overlap of wildlife with marine renewables. Journal of Marine Science and Engineering, 9: 263.

Jitlal, M., Burthe, S., Freeman, S., and Daunt, F. 2017. Testing and validating metrics of change produced by population viability analysis (PVA). Scottish Marine and Freshwater Science, 8: 210.

Johnston, A., Thaxter, C.B., Austin, G.E., Cook, A.S., Humphreys, E.M., Still, D.A., Mackay, A *et al.* 2015. Modelling the abundance and distribution of marine birds accounting for uncertain species identification. Journal of Applied Ecology, 52: 150–160.

Johnston, DT, Thaxter, CB, Boersch-Supan, PH, and Humphreys, EM. 2022. Investigating avoidance and attraction responses in lesser black-backed gulls *Larus fuscus* to offshore wind farms. Marine Ecology Progress Series, 686: 187–200.

Kennedy, M., and O'Hagan, A. 2001. Bayesian calibration of computer models (with discussion). Journal of the Royal Statistical Society: Series B, 63: 425–464.

Langrock, R., King, R., Matthiopoulos, J., Thomas, L., Fortin, D., and Morales, J. M. 2012. Flexible and practical modeling of animal telemetry data: hidden Markov models and extensions. Ecology, 93: 2336–2342.

Mackenzie, M.L, Scott-Hayward, L.A.S., Oedekoven, C.S., Skov, H., Humphreys, E., and Rexstad, E. 2013. Statistical Modelling of Seabird and Cetacean Data: Guidance Document. University of St. Andrews contract for Marine Scotland SB9 (CR/2012/05), St. Andrews.

Maclean, I. M. D., Rehfisch, M. M., Skov, H., and Thaxter, C. B. 2013. Evaluating the statistical power of detecting changes in the abundance of seabirds at sea. IBIS, 155: 113–126.

Marine Management Organisation. 2014. Review of Post-Consent Offshore Wind Farm Monitoring Data Associated with Licence Conditions. A report produced for the Marine Management Organisation. MMO Project No: 1031. ISBN: 978-1-909452-24-4. 194pp. https://www.gov.uk/government/publications/review-of-environmental-data-mmo-1031. [Last accessed date: February 2023].

Marjoram, P., Molitor, J., Plagnol, V., and Tavare, S. 2003. Markov chain Monte Carlo without likelihoods. PNAS, 100: 15324–15328.

Masden, E, McCluskie, A., Owen, E., and Langston, R. 2015. Renewable energy developments in an uncertain world: the case of offshore wind and birds in the UK. Marine Policy, 51: 169–172.

Masden, E. 2015. Developing an avian collision risk model to incorporate variability and uncertainty. Scottish Marine and Freshwater Science, 6: 43.

Masden, E. A., and Cook, A. S. C. P. 2016. Avian collision risk models for wind energy impact assessments. Environmental Impact Assessment Review, 56: 43–49.

Masden, E. A., Cook, A. S.C.P., McCluskie, A., Bouten, W., Burton, N.H.K., and Thaxter, C. B.. 2021. When speed matters: The importance of flight speed in an avian collision risk model. Environmental Impact Assessment Review, 90: 106622. ISSN 0195-9255. https://doi.org/10.1016/j.eiar.2021.106622.

Matthiopoulos, J., Wakefield, E., Jeglinski, J. W. E., Furness, R. W., Trinder, M., Tyler, G., McCluskie, A. *et al.* 2022. Integrated modelling of seabird-habitat associations from multi-platform data: a review. Journal of Applied Ecology, 59: 1–12.

McGregor, R.M., King, S., Donovan, C. R., Caneco, B., and Webb, A.. 2018. A Stochastic Collision Risk Model for Seabirds in Flight. Report to Marine Scotland, https://www.gov.scot/publications/stochastic-collision-risk-model-for-seabirds-in-flight/. [Last accessed date: February 2023]

Merkel, B., Phillips, R.A., Descamps, S. *et al.* 2016. A probabilistic algorithm to process geolocation data. Movement Ecology, 4: 26.

Milner-Gulland, EJ, and Shea, K. 2017. Embracing uncertainty in applied ecology. J Appl Ecol, 54(6): 2063–2068. Epub 2017 Mar 9. PMID: 29225369; PMCID: PMC5722456. 10.1111/1365-2664.12887

Mitchell, P.I., Newton, S.F., Ratcliffe, N., and Dunn, T.E. 2004. Seabird populations of Britain and Ireland, JNCC, Peterborough, ISBN 0 7136 6901 2.

Oyebamiji, O. K., Wilkinson, D. J., Jayathilake, P. G., Curtis, T. P., Rushton, S. P., Li, B., and Guptad, P. 2017. Gaussian process emulation of an individual-based model simulation of microbial communities. Journal of Computational Science, 22: 69–84.

Parton, A., and Blackwell, P. G. 2017. Bayesian inference for multistate 'step and turn' animal movement in continuous time. Journal of Agricultural, Biological, and Environmental Statistics, 22: 373–392.

Patterson, T. A., Thomas, L., Wilcox, C., Ovaskainen, O., and Matthiopoulos, J. 2008. State–space models of individual animal movement. Trends in Ecology and Evolution, 23: 87–94.

Peschko, V., Mendel, B., Mercker, M., Dierschke, J., and Garthe, S. 2021. Northern gannets (*Morus bassanus*) are strongly affected by operating offshore wind farms during the breeding season. Journal of Environmental Management, 279: 111509.

Peschko, V., Mendel, B., Müller, S., Markones, N., Mercker, M., and Garthe, S. 2020b. Effects of offshore windfarms on seabird abundance: strong effects in spring and in the breeding season. Marine Environmental Research, 162: 105157.

Peschko, V., Mercker, M., and Garthe, S. 2020a. Telemetry reveals strong effects of offshore wind farms on behaviour and habitat use of common guillemots (*Uria aalge*) during the breeding season. Marine Biology, 167: 1–13.

Peschko, V., Mercker, M., and Garthe, S.. 2020. Telemetry reveals strong effects of offshore wind farms on behaviour and habitat use of common guillemots (Uria aalge) during the breeding season. Mar Biol, 167: 118. https://doi.org/10.1007/s00227-020-03735-5. [Last accessed date: February 2023].

Pietzsch, B., Fiedler, S., Mertens, K. G., Richter, M., Scherer, C., Widyastuti, K., Wimmler, M.-C. *et al.* 2020. Metamodels for evaluating, calibrating and applying agent-based models: a review. The Journal of Academic Social Science Studies, 23: 9.

Regular, P. M., Hedd, A., Montevecchi, W. A., Robertson, G. J., Storey, A. E., and Walsh, C. J. 2014. Why timing is everything: energetic costs and reproductive consequences of resource mismatch for a chick-rearing seabird. Ecosphere, 5: art155.

RSPB. 2019. Application by Norfolk Vanguard Limited for an Order Granting Development Consent for the Norfolk Vanguard Offshore Wind Farm'; RSPB response to the Applicant's Deadline 8 submission 'Precaution in ornithological assessment for offshore wind farms' (2019).

Rush, G. P., Clarke, L. E., Stone, M., and Wood, M. J. 2018. Can drones count gulls? Minimal disturbance and semiautomated image processing with an unmanned aerial vehicle for colony-nesting seabirds. Ecology and Evolution, 8: 12322–12334.

Sansom, A., Wilson, L. J., Caldow, R. W. G., and Bolton, M. 2018. Comparing marine distribution maps for seabirds during the breeding season derived from different survey and analysis methods. PLoS One, 13: 1–17.

Schaub, M., and Kery, M. 2021. Integrated Population Models: Theory and Ecological Applications with R and JAGS. Academic Press, Massachusetts, MA.

Searle, K R, Butler, A, Mobbs, D, Trinder, M, McGregor, R, Cook, A, McCluskie, A *et al.* 2022a. Study to examine how seabird collision risk, displacement and barrier effects could be integrated for assessment of offshore wind developments. Report for Marine Science Scotland, ISBN 9781804352205. https://www.gov.scot/publications/study-examine-seabird-collision-risk-displacement-barrier-effects-integrated-assessment-offshore-wind-developments/. [Last accessed date: February 2023].

Searle, K R, Mobbs, D C, Butler, A, Furness, R W, Trinder, M N, and Daunt, F. 2018. Finding out the fate of displaced birds. Scottish Marine and Freshwater Science, 9 (8): 149.https://doi.org/10.7489/12118-1

Searle, K. R., Jones, E. L., Bogdanova, M. I., Wilson, L, Bolton, M., Elston, D., Fang, Z. *et al.* 2022a. Study to examine the feasibility of extending SeabORD to the entire breeding season. Marine Scotland Report, ISBN: 978-1-80435-226-7. https://www.gov.scot/publications/study-examine-feasibility-extending-seabord-entire-breeding-season/. [Last accessed date: February 2023].

Searle, K., Mobbs, D., Butler, A., Bogdanova, M., Freeman, S., Wanless, S., and Daunt, F. 2014. Population consequences of displacement from proposed offshore wind energy developments for seabirds breeding at Scottish SPAs (CR/2012/03). Scottish Marine and Freshwater Science, 5: 147.

Searle, K.R., Butler, A., Mobbs, D., Trinder, M., Waggitt, J., Evans, P., and Daunt, F. 2020. Scottish Waters East Region Regional Sectoral Marine Plan Strategic Ornithology Study: final report (Report No. NEC07184). Report by Natural Environment Research Council (NERC). Report for Marine Scotland Science. https://www.gov.scot/publications/scottish-waters-east-region-regional-sectoral-marine-plan-strategic-ornithology-study-final-report/. [Last accessed date: February 2023].

Searle, KR, Butler, A, Waggitt, JJ, and Evans, PGH. 2022b. Potential climate-driven changes to seabird demography: implications for assessments of marine renewable energy development. Mar Ecol Prog Ser, 690: 185–200. https://doi.org/10.3354/meps14045. [Last accessed date: February 2023].

Sisson, S. A., Fan, Y., and Tanaka, M. M. 2007. Sequential Monte Carlo without likelihoods. PNAS, 104: 1760–1765.

Skov, H, Heinänen, S, Thaxter, CB, Williams, AE, Lohier, S, and Banks, AN. 2016. Real-time species distribution models for conservation and management of natural resources in marine environments. Marine Ecology Progress Series, 542: 221–234.

Skov, H., Heinänen, S., Norman, T., Ward, R., Méndez-Roldán, S., and Ellis, I. 2018. ORJIP bird collision and avoidance study. Final report—April 2018. The Carbon Trust, 248pp.

M. E. Soulé (Ed). 1986. Conservation Biology. The Science of Scarcity and Diversity. Sinauer Associates, Inc., Sunderland, MA. 584pp. ISBN 0-87893-795-1.

Suryan, R. M., Irons, D. B., Brown, E. D., Jodice, P. G. R., and Roby, D. D. 2006. Site-specific effects on productivity of an upper trophic-level marine predator: bottom–up, top–down, and mismatch effects on reproduction in a colonial seabird. Progress in Oceanography, 68: 303–328.

Thaxter, C. B., Ross-Smith, V. H., Bouten, W., Clark, N. A., Conway, G. J., Rehfisch, M. M., and Burton, N. H.K. 2015. Seabird–wind farm interactions during the breeding season vary within and between years: a case study of lesser black-backed gull *Larus fuscus* in the UK. Biological Conservation, 186: 347–358.

Thaxter, C. B., Ross-Smith, V. H., Bouten, W., Masden, E. A., Clark, N. A., Conway, G. J., and Burton, N. H. K. 2018. Dodging the blades: new insights into three-dimensional area use of offshore wind farms by lesser black-backed gulls *Larus fuscus*. Marine Ecology Progress Series, 587: 247–253.

Tremblay, Y., Bertrand, S., Henry, R. W., Kappes, M. A., Costa, D. P., and Shaffer, S. A. 2009. Analytical approaches to investigating seabird-environment interactions: a review. Marine Ecology Progress Series, 391: 153–163.

Vanermen, N., Onkelinx, T., Courtens, W., Van de walle, M., Verstraete, H., and Stienen, E. W. M. 2015. Seabird avoidance and attraction at an offshore wind farm in the Belgian part of the North Sea. Hydrobiologia, 756: 51–61.

Waggitt, J. J., Cazenave, P. W., Howarth, L. M., Evans, P. G. H., van der Kooij, J., and Hiddink, J. G. 2018. Combined measurements of prey availability explain habitat selection in foraging seabirds. Biology Letters, 14:20180348. http://doi.org/10.1098/rsbl.2018.0348.

Waggitt, JJ, Evans, PGH, Andrade, J, Banks, AN, Boisseau, O, Bolton, M, Bradbury, G, *et al.* 2020. Distribution maps of cetacean and seabird populations in the north-east Atlantic. Journal of Applied Ecology. 57: 253–269.

Wakefield, E. D., Owen, E., Baer, J., Carroll, M. J., Daunt, F., Dodd, S. G., Bolton, M. *et al.* 2017. Breeding density, fine-scale tracking, and large-scale modeling reveal the regional distribution of four seabird species. Ecological Applications, 27: 2074–2091.

Welcker, J, and Nehls, G. 2016. Displacement of seabirds by an offshore wind farm in the North Sea. Marine Ecology Progress Series, 554: 173–182.

Woodward, I., Thaxter, C.B., Owen, E., and Cook, A.S.C.P. 2019. Desk-based revision of seabird foraging ranges used for HRA screening. BTO Research Report Number 724. https://www.marinedataexchange.co.uk/details/1716/2019-2020-the-crown-estate-round-4-habitats-regulations-assessment-hra-front-loading-projects/packages/6190?directory=%2F. [Last accessed date: February 2023].

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