Prepared by Pathways to Growth (P2G)
February 2024

Offshore Wind Industry Council

Use of evidence and data in decision-making in offshore wind farm consenting

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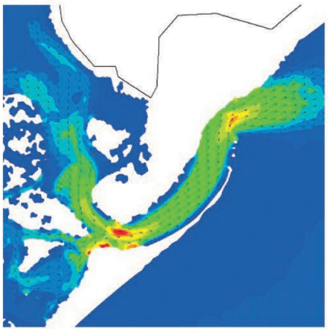


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Use of evidence and data in decision-making in offshore wind farm consenting

Lot 3

February 2024

Document Information

Document History and Authorisation		
Title	Use of evidence and data in decision-making in offshore wind farm consenting	
	Lot 3	
Commissioned by	Offshore Wind Industry Council	
Issue date	February 2024	
Document ref	R4250	
Project no	5284	
Date	**Version**	**Revision Details**
29.09.23	1	Issued for client review
09.02.24	2	Incorporating client comments

Prepared (PM)	Approved (QM)	Authorised (PD)
E R Skeate	N J Frost	C R Trigg

Suggested Citation

ABPmer, (2024). Use of evidence and data in decision-making in offshore wind farm consenting, Lot 3, ABPmer Report No. R4250. A report produced by ABPmer for Offshore Wind Industry Council, February 2024.

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Acknowledgements

We would like to acknowledge the help of the experts who inputted into the OWEER Review process. We would also like to acknowledge the input of the various stakeholders who attended the P2G Workshop on 12th July and the other members of the P2G stakeholder group and their colleagues who provided further feedback after the workshop. We would also like to thank the OWIC Developer Group for their input.

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Executive Summary

This project has been commissioned by the Offshore Wind Industry Council's Pathways to Growth Coordination Group. The Pathways to Growth workstream is part of the Sector Deal, a partnership between the Offshore Wind Sector and the UK Government which has the long-term aim of securing offshore wind as the backbone of the UK's power system.

This project looks at how evidence and data is used in decision making. It has two parts:

- **Part 1** is aimed at reviewing data to identify the most critical environmental issues constraining consent and to explore opportunities to pool data to support understanding of these key environmental issues.[1]
- **Part 2** is aimed at researching and identifying good practice in adopting evidence into consenting decision making.

Part 1

The first objective of Part 1 was to identify, agree and test with key stakeholders the 10 most critical impact evidence gaps causing the biggest delays in consenting processes by drawing on the Offshore Wind Evidence and Change Register.

This initially involved an **internal review** of the Offshore Wind Environment Evidence Register[2] by a team of experts sourced by ABPmer to identify a **long list of evidence gaps** (across all receptors) from the Offshore Wind Environment Evidence Register that were considered critical.

This list was used as the basis of a stakeholder workshop (the **external review)**, where stakeholders voted on which gaps they considered to be the most critical to produce a **short list of evidence gaps**. A list of the top 10 critical gaps was derived using the workshop scoring.

Once the gaps had been identified, a review of existing data and evidence relating to each gap was undertaken[3]. Future research that may be of potential value in accelerating understanding was also identified.

The 10 critical gaps causing the biggest delays in the consenting process were identified as:

- **Ornithology**: compensation;
- **Ornithology**: displacement;
- **Ornithology**: cumulative effects (including ecosystem effects);
- **Benthic ecology**: compensation;
- **Fish:** Essential Fish Habitat;
- **Ornithology**: collision;
- **Ornithology**: baseline understanding;
- **Marine mammals**: baseline understanding;
- **Ornithology**: mitigation; and
- **Benthic ecology**: baseline understanding.

[1]
[2] Developed through the Offshore Wind Evidence and Change programme (OWEC).
[3] This is objective 2 of Part 1 (see Table 1).

The following two evidence gaps related to floating offshore wind were also added to the list of 10 as they were seen as having the potential to inform environmental assessments of floating offshore wind as the industry scales up.

- **Fish:** Electromagnetic Field from cables suspended in the water column.
- **Marine mammals:** Potential entanglement of marine mammals in mooring infrastructure.

Review of the critical gaps indicated that there was little prospect of resolving any of themes imminently. However, the potential for relatively swift progress around mapping benthic protected features to ensure these are avoided was identified by both the ABPmer review team and the workshop and represents an area in which positive progress could be readily made, by building on the outputs of the Planning Offshore Wind Strategic Environmental Impact Decisions project.

Progression of more problematic areas was considered likely to involve both scientific research and development of supporting policy measures, such as position statements, to ensure that there are agreed pathways through consenting, appreciating that data and evidence may be lacking and may take considerable years to gather.

Following discussion with the Pathways to Growth Team it was agreed that the exercise should not duplicate outputs from projects such as Offshore Wind Environment Evidence Register and Scottish Marine Energy Research. Therefore, the output from this process, **the Critical Gaps Database,** was designed to provide key information on each gap only, which could later be used to form the basis of a position statement. **The Critical Gaps Database** therefore includes a summary of the data gap (intended as a 'stock take' of progress over the past 20 years), a list of key references relating to each data gap, and a description of possible measures to progress the gap both from research and policy perspectives.

Opportunities for pooling analysis of existing data to progress understanding were identified during this process and are provided in Section 2.5.

Further progression of this work could involve producing and testing draft position statements with key stakeholders using hypothetical consenting scenarios.

Part 2

The objectives of **Part 2** were to research and identify good practice in adopting evidence into consenting decision making through selected case studies.

These case studies included:

- Monitoring and adaptive management;
- Compensation within the ports sector;
- Consideration of climate change impacts within assessment;
- Avoiding development in areas of high ecological value; and
- Ornithological monitoring.

Key outputs from each case study are summarised below.

Monitoring and Adaptive Management

Addressing uncertainty of environmental impacts and associated compensation is a key issue within consenting of offshore wind projects. Where the potential for a significant impact exists, the adoption of adaptive management tied with suitable monitoring programmes can provide the necessary confidence to Statutory Nature Conservation Bodies to allow developments to proceed despite uncertainties. This may initially seem a risky approach to developers, as it requires complex monitoring frameworks and licence conditions. Within these conditions may be a 'stop' clause to operations or in the example of a phased development, the risk that future phases may never progress in light of the uncertainty around impacts or compensation measure efficacy. Although the risk of these difficulties cannot be eliminated, this case study demonstrates how monitoring and adaptive management has provided the mechanism to allow various differing developments within the marine sector to successfully obtain consent in otherwise challenging consenting scenarios.

Compensation within the ports sector

Compensation is a relatively new concept for offshore wind, with this case study providing an opportunity to identify transferrable knowledge from the ports sector. Experience demonstrates a clear need for sign-off procedures to be established at the project outset and for stated procedures to be agreed for when compensation may not work as anticipated. There is a need to recognise the risks associated with working with natural systems, which do not stay fixed, but may change significantly over time, and for appropriate flexibility within Environmental Management Plans. In relation to birds, monitoring needs to address whether increased bird numbers at a compensation site represents a re-distribution of birds or a genuine population increase. In situations when non like-for-like compensation is needed, it may be possible for the UK offshore wind industry to agree on a more flexible ecosystem based approach, as has been adopted in Germany within the ports sector, and which results from experience gained from earlier compensation schemes.

Consideration of climate change impacts within assessment

Although the circular relationship between species, such as Kittiwake, that are impacted by both offshore wind farms and climate change has been well-discussed, it is not currently recognized within the assessment system. Climate change means that future outcomes for most marine species are highly uncertain. Even acknowledging that offshore wind farms may have significant environmental impacts, the negative impacts of climate change on all ecosystems is a greater threat. The decarbonisation benefits of offshore windfarms to marine ecosystems needs to be incorporated within assessment alongside the impacts. It is suggested that the assessment system could be adapted to consider trade-offs between biodiversity impacts and climate change impacts to allow for more rapid and flexible decision making.

Avoiding development in areas of high ecological value

Sites of high ecological value may be leased for offshore wind farm development leading to delay, expense and even project failure. In some cases, poor baseline understanding is responsible with the presence of sensitive receptors only revealed during baseline data acquisition undertaken by the project developer. Surveys at a regional level prior to site selection could be conducted to ensure that high value are avoided. In some cases, ecology is understood and considered (albeit as a soft constraint), and decisions are made to lease the sites that are most feasible, even though these may be in ecologically important areas. However, ecological issues need to be weighted higher in the site selection system, as the difficulties, cost and delay associated with compensation is a serious constraint. Going through a longer site selection process involving a plan-level Habitats Regulation Assessment and public consultation (as undertaken in Scotland) may improve chances of success by ensuring that sites are feasible, rather than just possible. It is anticipated that outputs from Planning Offshore Wind Strategic Environmental Impact Decisions and Physics-to-Ecosystem Level Assessment of Impacts of Offshore Windfarms projects will improve planning processes although they are not yet available.

Ornithological Monitoring

At the stakeholder workshop birds were voted the most problematic receptor with 202 evidence gaps in the Offshore Wind Environment Evidence Register relating to them. This case study makes recommendations for improving ornithological monitoring programmes. Digital Aerial Surveys should be conducted using the same agreed methods so that pooled analysis of data can easily be undertaken. However, ornithological monitoring should not be limited to Digital Aerial Surveys transects only but should be more flexible so that resource can be directed towards addressing other evidence gaps. These could be tackled in a strategic manner, both in a regional and national context.

Standard monitoring programmes provide limited temporal sampling of receptors that are highly mobile and variable in their distribution and may be of limited use in providing answers to specific questions. By contrast, tailored monitoring that is site and species specific and which sets focussed research objectives, drawing on multiple techniques, are likely to provide more definite answers.

There is a need for a greater understanding of the effects of offshore wind farms on marine ecosystems, and how these may affect different receptors and the interactions between them. For seabirds, understanding prey is of central importance both in identifying key foraging areas and in safeguarding colonies through the protection of Essential Fish Habitats, which could be progressed through strategic compensation. Ornithological monitoring could usefully focus on areas which may help industry, such as monitoring 20 years on to look at habituation, radar studies to improve collision models, and more focussed work on array density and displacement, as well as studies of potentially helpful mitigation measures such as painted turbine blades. Since ornithological monitoring is expensive, outputs should be regularly reviewed with findings disseminated to key stakeholders through the Offshore Wind Evidence & Knowledge Hub.

The following more general points are drawn in conclusion:

- Use of the precautionary principle within a marine context is inherently problematic: marine ecosystems are extremely challenging to study being dynamic, constantly changing, and poorly understood, and therefore residual uncertainty is highly likely even after decades of research (as experience has demonstrated).
- Nonetheless, large-scale offshore wind farms may have negative impacts on specific receptors and ecosystems. The exclusion of ecosystem effects from the assessment system is considered untenable in view of the large volume of research being conducted within this area. It is suggested that the outputs from Physics-to-Ecosystem Level Assessment of Impacts of Offshore Windfarms should be used to start to integrate ecosystem considerations into both planning and assessment.
- Although offshore wind, like any other industry, should compensate for impacts on protected species, the time window to act on climate change to avert damage is decreasing very rapidly.

It is suggested that other mechanisms could be considered to acceptably accelerate consent of large-scale offshore wind farms in the UK. This could include:

- Collaborative identification ecological areas of low risk in which development could be accelerated through use of a more streamlined assessment system.
- Protection of areas of high ecological value (which could be part of regional compensatory measures), balanced by accelerated development of lower value areas.
- Large scale compensatory measures (e.g. closure/reduction of fisheries taking forage fish) to balance accelerated development.
- Greater flexibility within the assessment system (e.g. consideration of trade-offs) so that climate change benefits associated with offshore wind can better recognized and accommodated.
- Increased use of adaptive management as a tool to facilitate consent when there is uncertainty.
- Trial and use of mitigation measures to reduce impacts.
- Adoption of a market-based compensation system where the developer pays a government organisation to deliver compensation. Since the contribution would be financially derived, debate over use of resource would not need constrain development timescales.

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1 Project Introduction

1.1 Project Background

This project has been commissioned by the Offshore Wind Industry Council's (OWICs) Pathways to Growth (P2G) Coordination Group. The P2G workstream is part of the Sector Deal, a partnership between the Offshore Wind Sector and the UK Government which has the long-term aim of securing offshore wind as the backbone of the UK's power system.

The aims of P2G are to provide leadership, oversight and coordination to the offshore wind industry to ensure that the UK meets its offshore wind 2030 targets and is in a position to deliver net zero. P2G aims to identify and overcome strategic deployment issues in relation to consents and cumulative environmental impacts both in the marine and onshore areas and impacts on other users of sea space such as navigation and fishing.

- **Part 1** aims to carry out some initial work that could ultimately inform a detailed analysis study to look at data gathered across the UK to determine whether, by pooling data, there is sufficient understanding to close impact issues or to focus evidence and data work to more rapidly close evidence gaps.
- **Part 2** aims to research and identify good practice in adopting evidence into consenting decision making.

The Objectives and Deliverables relating to Part 1 and Part 2 are provided in Table 1. The locations of each deliverable are also indicated. It should be noted that **the Critical Gaps Database** (*supplied separately in excel)* forms the key deliverable from **Part 1**.

Deliverables for **Part 2,** a desk-based study describing specific case studies (selected and pre-agreed with the P2G Team) which describe principles that could be implemented within UK offshore wind consenting organisations, are presented within Section 3 of the current report.

1.2 Project Approach

The broad approach taken to carry out the work is illustrated in Figure 1. The work was carried out in a phased process with stakeholder engagement informing the final section of critical evidence gaps. The process was informed throughout by discussions with the P2G Team.

In addition to the original scope, ABPmer included some added value elements. These were to identify and recommend research areas relevant to each critical theme as next steps to support progress.

Table 1. Objectives and Deliverables

Objective Number	PART 1 Objective	Deliverable	Location of output
1	Identify, agree and test with key stakeholders the 10 most critical impact evidence gaps causing the biggest delays in consenting processes by drawing on the Offshore Wind Evidence and Change Register (OWEER).	A list of the 10 most critical impact evidence gaps (those causing the biggest delays in the offshore wind consenting processes), mapped against key data and evidence sources from across the UK (and potentially Europe), and how further analysis will support and add value, including any expected limitations for data analysis.	**Critical Gaps Database** *Excel file supplied separately*
		Design and delivery of a workshop with the P2G Coordination Group to inform, refine and finalise the list of critical impact evidence gaps and associated data sources.	A workshop was delivered on 12 July 2023. This is described in Section 2.2
		A written report of the P2G Coordination Group workshop documenting the discussion, agreements and follow up actions required. This report should include all ten original impact issues and clearly document which were deprioritised and why.	Provided in Section 2.2
2	Review and identify suitable data and evidence available across the UK (and if widely available also from Europe) that are relevant to each identified impact evidence gap and document these.	A list of the 10 most critical impact evidence gaps (those causing the biggest delays in the offshore wind consenting processes), mapped against key data and evidence sources from across the UK (and potentially Europe), and how further analysis will support and add value, including any expected limitations for data analysis.	Key data and evidence from UK and Europe associated with each critical gap is provided within the **Critical Gaps Database** (*Excel file supplied separately).* A table of ***Key research undertaken, underway and planned*** is presented for each critical gap.
3	Present and agree which issues are the most likely to deliver resolution or closest to resolution with the P2G Coordination Group.	High level summary of critical gaps and potential constraints and/or opportunities for resolution.	Presented in Section 2.3.

4	Identify relevant data or evidence initiatives that any further analysis of the identified data will add value to and how that can be built into the full analysis work.	A proposed approach and list of recommendations for further review and analysis of the data to inform the full analysis work that will look to address key impact issues. This should include limitations anticipated for the analysis including regional variations that might limit conclusions.	Presented in Section 2.5.
5	Define recommendations for a further analysis stage whereby the data and initiatives identified by this work can be reviewed and conclusions about current understanding/position can be presented to the P2G Coordination Group.	Recommendations made in Section 2.6.	
6	Catalogue all work undertaken within Part 1.	A final report that presents the proposed shortlisted impact evidence gaps, the data sources and evidence initiatives and approach to be taken to ensure any full review adds value to existing work. This report will also include a description of how the follow up actions have been taken forward and incorporated.	This document provides the shortlisted evidence gaps (see 2.2.2). Data sources and evidence initiatives are presented for each gap in the **Critical Gaps Database.** An approach for each gap is provided in relation to both research and policy in the **Critical Gaps Database.** An approach to developing position statements is provided in Section 2.6[4].
	PART 2 Objective		
7	To identify other sectors and countries that present good case studies for exploring how evidence has been adopted into the consenting decision-making process.	Process of identifying sectors and countries described in Section 3.	

[4] There were no specific follow up actions identified and therefore this is not included.

8	To research the agreed sectors and countries as case studies to provide some key good practice principles that could be incorporated into UK offshore wind consenting decision making processes.	A desk-based study report that describes the case studies and presents recommendations about successful principles that could be implemented by UK offshore wind consenting organisations and identifies less successful approaches to be avoided.	Provided in **Part 2.** Recommendations are presented within the conclusions of each case study.

Source: OWIC Scope of Work Lot 3, Evidence and data into decision making: Identifying good practice in adopting new evidence and exploring opportunities to pool data more widely to support understanding of key environmental issues.

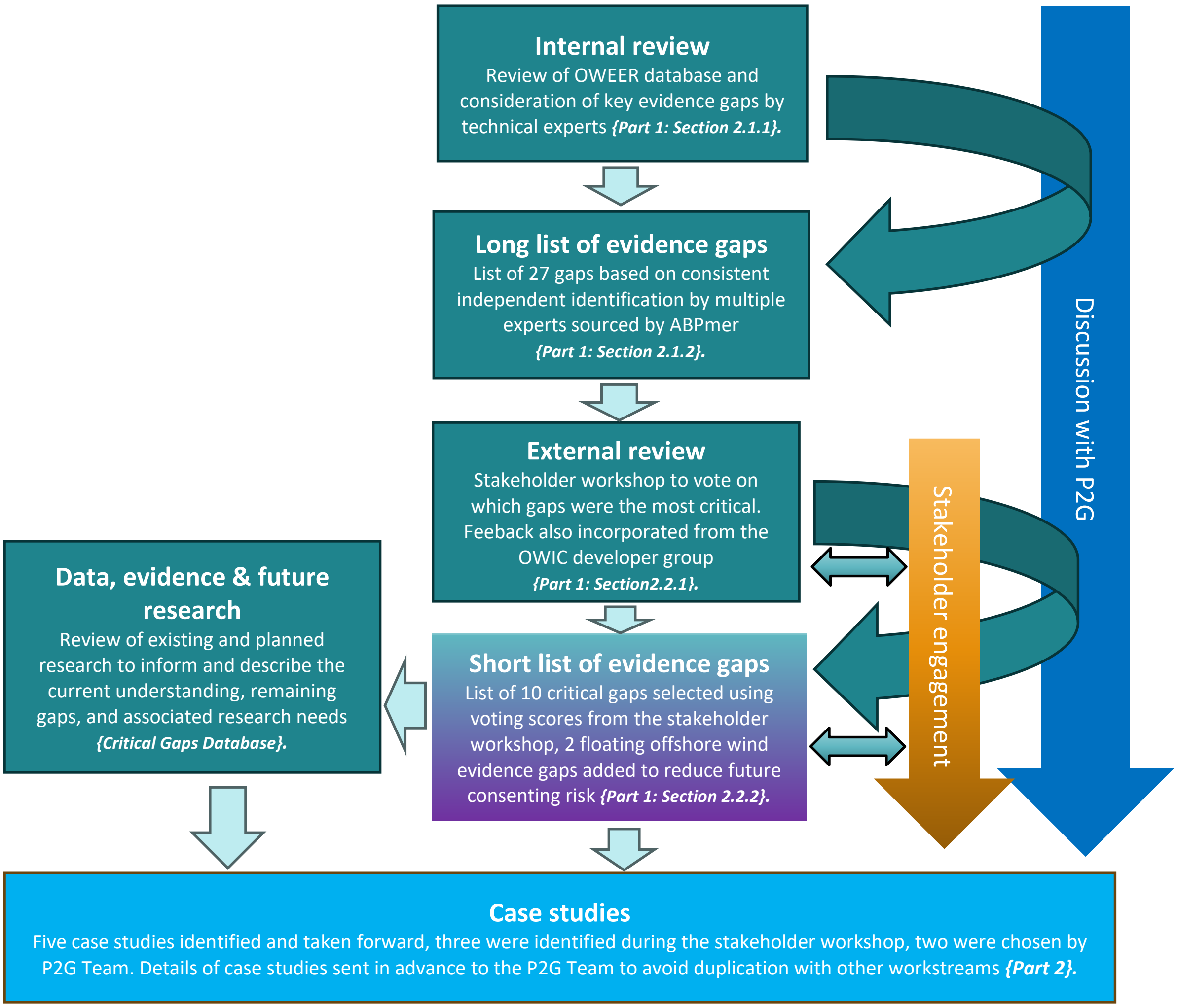

Figure 1. Project Approach and Phases.

2 Part 1: Critical Evidence Gaps

The first objective of Part 1 was to identify, agree and test with key stakeholders the 10 most critical impact evidence gaps causing the biggest delays in consenting processes by drawing on the OWEER. This was undertaken following the approach set out in Figure 1.

The first stage involved an **internal review** of the OWEER[5] by a team of experts sourced by ABPmer to identify a **long list of evidence gaps** (across all receptors) from the OWEER that were considered critical.

This list was used as the basis of a stakeholder workshop (the **external review)**, where stakeholders voted on which gaps they considered to be the most critical to produce a **short list of evidence gaps**. A list of the top 10 critical gaps was derived using the workshop scoring.

Once the gaps had been identified, a review of existing data and evidence relating to each gap was undertaken[6]. Future research that may be of potential value in accelerating understanding was also identified.

The process undertaken is described in Section 2.3 (**Data, Evidence and Future Research).** The outputs of this review are presented within the **Critical Gaps Database** *(excel spreadsheet supplied separately)***.**

In relation to the other objectives (summarised in Table 1):

- **Section 2.3** provides discussion around the issues considered most likely to deliver resolution or closest to resolution.
- **Section 2.5** identifies data or evidence initiatives where further analysis or other work (e.g. research, data gathering) may add value or accelerate progress.
- **Section 2.6** sets out recommendations for future work building on the process undertaken within this project, with a view to producing position statements summarising current understanding around each of the critical gaps.
- The **Critical Gaps Database** provides core information on each gap, which could be used and/or added to in order to draft a position statement of common understanding.

2.1 Internal Review

2.1.1 Approach

ABPmer sourced an expert team to review the OWEER (termed the internal review team). This consisted of an expert panel from a diverse array of relevant backgrounds from the UK and Europe. This included five marine environmental consultants from ABPmer, one of whom is seconded part time to Natural

5 Developed through the Offshore Wind Evidence and Change programme (OWEC).
6 This is objective 2 of Part 1 (see Table 1).

Resource Wales (NRW)'s Marine Licensing Team, and three highly published academic researchers, all of which have worked on offshore wind ecological research within the UK and Europe. Specialisms encompassed all the receptor groups represented within the OWEER.

The starting point of the internal review was for each expert to review the evidence gaps within the OWEER, relevant to their area(s) of expertise, and to identify a sub-set of those evidence gaps that were considered critical. The team reviewed the most recent iteration of the OWEER (version four, published in January 2023[7]) which contains a total of 442 evidence gaps across five topics (benthic ecology, ornithology, marine mammals, fish, and overarching). The evidence gaps within the OWEER already were prioritised (on a scale from 1 to 15). However, 54 gaps had the highest prioritisation score and therefore further prioritisation was considered necessary to identify a smaller sub-set of gaps considered the most critical to consenting.

The decision was taken to remove the OWEER prioritisation scores so that they did not influence selection choices. Experts were also asked to raise any issues not catalogued within the OWEER. This approach was adopted because it is understood that priorities shift, and also that the large volume of offshore wind farm work underway is accompanied by a rapid evolution of ideas.

While it was agreed that the evidence gaps identified by each expert should only represent those considered to be the most critical, no specific target number was set, so if multiple gaps were felt to be critical this could also be expressed by experts. Critical gaps were agreed to be those that:

- Are currently causing consenting delay; and
- Are considered likely to cause consenting delay in the future unless resolved, including horizon scanning for issues that are likely to become of greater concern.

2.1.2 Outputs

During the internal review, all reviewers independently condensed the evidence gaps by grouping related entries into themes. For example, there are multiple ornithological evidence gaps within the OWEER related to the theme ‘collision’.

It was decided to adopt this theme-based approach within the wider prioritisation exercise for two reasons:

- Both the ornithology and marine mammal tabs of the OWEER had large numbers of inter-related evidence gaps (202 and 137 entries respectively), so it was practical to group them; and
- Grouping by theme was considered more practical for discussion and voting within a workshop context (see Section 2.2).

All of the gaps associated with each theme are presented in Appendix A, with the OWEER reference number providing a means of cross referencing.

[7] 2021, JNCC, Offshore Wind Evidence and Change Programme, Offshore Wind Environmental Evidence Register | Marine Data Exchange

2.2 External Review of Critical Gaps

2.2.1 Approach

A stakeholder workshop was used to obtain input from a wide range of stakeholders. Stakeholders voted on which themes (and therefore associated gaps) they considered the most critical. The workshop was held virtually on 12 July 2023 and involved 20 attendees from 14 organisations. These organisations included the Joint Nature Conservation Committee (JNCC), The Carbon Trust, Ørsted, NatureScot, Department of Food and Rural Affairs (Defra), Department for Energy Security and Net Zero (DESNZ), Marine Scotland, Natural England (NE), Scottish Power, Welsh Government, Marine Management Organisation (MMO), Rheinisch-Westfälisches Elektrizitätswerk (RWE), National Resources Wales (NRW), and Planning Inspectorate for England (PINS).

The objectives of the workshop were:

- To refine the long list of themes identified from the internal review (see Appendix A) to generate a 'short list' of the 10 themes that were considered to be the most critical; and
- To identify relevant research planned and/underway relevant to the critical themes to ensure that it was considered within the data and evidence review (see Section 2.3).

Engagement during the workshop was facilitated using an online whiteboard tool (Jamboard), which allowed written feedback to be displayed in real-time, and which was visible to all users. Workshop attendees were initially asked which ecological receptor group contributed most to delays in the consenting processes for offshore wind. Following this, workshop attendees were asked to prioritise critical evidence gaps, selected from the internal review and pertinent to each broad ecological receptor, along with providing a justification for their inclusion. As with the internal ABPmer review, a key consideration flagged to the workshop attendees was consideration of critical gaps which could be addressed within a reasonable timeframe.

The workshop attendees were then asked if any gaps were missing and whether they were aware of any research completed, underway or planned which may help resolve a specific evidence gap. Stakeholders were also invited to suggest the type of research that could be delivered to address the gaps and how long it would take in order to establish whether there is general consensus around the timescales required to address the critical gaps, appreciating that these are often at odds with renewable energy targets.

Following the workshop, attendees were given further opportunity to comment through the online whiteboard for several weeks. Following data collation from Jamboards, summary outcomes from the workshop, the presentation and Jamboard slides were circulated to all attendees.

A separate document and online feedback form was prepared and circulated to the OWIC developer group[8] detailing the project so far and its outputs, so that their feedback could also be captured within the external review process.

[8] Companies within the OWIC developer group were SSE, BP, Corio Generation, RWE, Ocean Winds, EnBW, Equinor, EDF, Orsted, Scottish Power, and Vattenfall.

2.2.2 Outputs

Refinement of the long list (Appendix A) into a short list of 10 critical themes (Appendix B) was undertaken using the voting scores from the stakeholder workshop[9]. This was a straightforward approach to take as there was generally consensus both within the workshop and amongst the ABPmer internal review team around where the most critical gaps lay. In order of importance, the 10 critical gaps were:

1. **Ornithology**: compensation;
2. **Ornithology**: displacement;
3. **Ornithology**: cumulative effects (including ecosystem effects);
4. **Benthic ecology:** compensation;
5. **Fish:** Essential Fish Habitat (EFH);
6. **Ornithology**: collision;
7. **Ornithology**: baseline understanding;
8. **Marine mammals**: baseline understanding;
9. **Ornithology**: mitigation; and
10. **Benthic ecology**: baseline understanding.

A key outcome was the number of evidence gaps related to ornithology (*n*=six). During the workshop, there was unanimous agreement from stakeholders that ornithological receptors contribute the greatest risk of consenting delays.

Although **underwater noise mitigation** did not score enough points to be taken forward as an evidence gap, it provoked mixed reactions both within the ABPmer review and within the stakeholder workshop. It is understood that the scale of development planned means that underwater noise will be a potential consenting constraint, and mitigation will be needed to reduce underwater noise during construction. However, appreciating that policy development is underway, it was decided not to include underwater noise mitigation within this work, as it is impossible to comment on how data and evidence are being used until new policies become public. It is also relevant to acknowledge that there are thorough technical reviews of noise mitigation, which clearly specify where the relevant scientific data gaps lie (see Verfuss *et al.,* 2019). Therefore, although excluded from this review, the future importance of **underwater noise** as a constraint to consent is acknowledged.

Two additional gaps were identified relating to floating offshore wind. Although not as high scoring as the themes listed above, they were added on the grounds that if research programmes are started promptly, the data gathered would be available to inform consenting of larger floating offshore wind projects as they reach assessment. The two key areas where data and evidence were considered lacking relating to floating offshore wind were:

- **Fish:** Electromagnetic Fields (EMF) from cables suspended in the water column.
- **Marine mammals:** Potential entanglement of marine mammals in mooring infrastructure.

During the workshop discussions, policy related issues, for example the avoidance of high-risk areas, were raised. It was suggested that policy related concerns could be separated from the scientific evidence gaps and considered further within **Part 2.** Other topics where policy was considered to constrain progress (as opposed to a lack of scientific data and evidence) included the general

[9] Details of scoring is provided in Appendix A.

assessment approach (described further in Section 3.3), and ornithological monitoring. All of these items are considered within **Part 2**[10]**.**

During the workshop some specific issues were identified that were constraining consent, but which (although important for specific sites) were not considered critical in a wider strategic sense. These included impacts on Black Bream *Acanthopagrus butcheri*. Other data gaps may be very important for development in particular regions, such as data gaps around the impacts of offshore wind farms on petrels and shearwaters. The importance of these issues is not to be downplayed and they will be critical issues for some sites, although the focus of this work was to identify critical gaps that are relevant across all sites.

2.3 Status of Critical Gaps

Table 2 provides a high-level indication of the status of each critical theme, in accordance with **Objective 3** (defined in Table 1).

In all cases gathering information is expensive and time consuming. In some cases, the data gathered may increase consenting issues.

An important exception is benthic baseline understanding, where it is considered feasible that further survey work, building on the work undertaken under the Planning Offshore Wind Strategic Environmental Impact Decisions (POSEIDON) project, can provide improved information on the location of protected benthic features, which can then be avoided during the site selection process.

Otherwise, none of the critical themes are in any way considered close to resolution. Therefore, it is anticipated that progression of these problem areas will involve both research and development of supporting policy measures. This will include position statements, to ensure that there are agreed pathways through consenting, recognising that data and evidence may be lacking and may take considerable years to gather.

Table 2. The critical themes, and key reasons why each cannot easily be resolved.

Ecological Receptor	Evidence Gap	Key reason why evidence gap cannot be resolved
Ornithology	Compensation	Lack of empirical data relating to many potential compensatory measures.
	Displacement	Consequences of displacement on demographics unquantified, causes driving displacement to be poorly understood.
	Cumulative, in-combination & ecosystem effects	Cumulative effects are a result of collision and displacement impacts, and uncertainty around both means that cumulative impacts remain problematic. Ecosystem effects are likely to be complex, and it is anticipated that arriving at a full understanding may take years.

[10] Although there may be scientific data gaps relating to some of these areas, constraints were considered primarily to relate to policy rather than lack of scientific data *per se*.

Ecological Receptor	Evidence Gap	Key reason why evidence gap cannot be resolved
	Bird Collision	Not enough empirical data gathered.
	Baseline understanding	Although there has been substantial progress, a greater level of understanding is required to identify suitable compensatory measures.
	Mitigation	Little or no empirical data available in relation to virtually all mitigation options.
Marine Mammals	Baseline understanding	Many areas unsurveyed (particularly further offshore). Small Cetaceans in European Atlantic waters and the North Sea (SCANS) surveys limited to a single sampling occasion.
	Floating Offshore Wind (FLOW): entanglement in mooring infrastructure	Not many large FLOW sites yet, therefore difficulties in understanding response of marine mammals (entanglement, displacement etc) which often occur at low density.
Benthic	Baseline understanding	Uncertainty regarding the distribution of protected habitats and species.
	Compensation	Difficulties in compensating for potential impacts on Marine Protected Area (MPA) sandbank features.
Fish	EFH (baseline mapping)	Currently assessment relies on data gathered >10 years ago, although some work is now underway further data gathering is needed to produce comprehensive reliable UK wide datasets.
	EMF (FLOW)	Data lacking in understanding of marine species sensitivity to EMF, especially pelagic fish species.

2.4 Data, Evidence and Future Research

2.4.1 Approach

Data and Evidence

Once the critical themes were identified, a database was compiled to collate research undertaken, underway and planned that related to each critical evidence gap (**Objective 2 in Table 1**). It was originally anticipated that this would involve assembling data from a range of sources:

- Research entries from the OWEER, both entries that are associated with the evidence gaps, and also searches of the research tabs by keyword;
- Entries from the Scottish Marine Energy Research (ScotMER) evidence maps;
- Information on research in planning from the stakeholder workshop (see Section 2.2);
- Information on work underway (both within the UK and Europe) from the ABPmer review team.
- Other searches, e.g. Tethys, Google Scholar etc.; and
- Other key work that might not be within the OWEER, e.g. pre-2020 references (understanding that the OWEER only contains work undertaken since 2020).

It was expected that the OWEER would be the key tool used to undertake this process, understanding that it also contains all of the ScotMER entries, and was updated recently.

However, problems were encountered with a number of entries regarding, for example, uncertainty around referencing of a particular project, how and if initiatives were actually being progressed and/or the specific content of respective deliverables. Examples of the types of issues encountered included:

- RE.OR.55: Measuring mortality of kittiwake and other seabirds from collisions by monitoring turbines. *Possibly has become the PredicTor project?*
- RE.OR.56: Camera-based ornithological monitoring at offshore wind farms. *Possibly has become Aberdeen Bay study?*
- RE.OR.54: Monitoring bird behaviour across multiple offshore wind farms. *Is this part of Defra's strategic monitoring?*
- RE.OR.29. Digital Aerial Survey (DAS) - statistical and modelling expert input to the development of a best practice position/guidance. *Unclear why this has not progressed – understood that NE now planning similar work.*
- RE.OR.30: Delivering compensation for ecological impacts of offshore renewables: a framework to achieve acceptable conservation, social, and economic outcomes. *Should have been produced in 2021, but no evidence of this online – unclear if never undertaken or being delivered late?*
- RE.OR.32: Roadmap of actions to address evidence gaps identified in the Scotland's draft Sectoral Marine Plan (SMP) for Offshore Wind and development of a framework to evaluate ornithological compensatory measures. *This is available, but does not contain any information on compensation, so scope of work has been adjusted.*

Since it was outside of the scope of work to check all of the relevant entries within the OWEER and appreciating that the process as a whole was resulting in large databases (when the original aim had been to prioritise a large database), an alternative approach was adopted.

The ABPmer expert panel selected key references in relation to each theme, with the intention that it could be used later to produce a position statement (**objective 5 in Table 1**).

Tables of key references for each theme are presented within the **Critical Gaps Database.** These tables include, where relevant, work undertaken/planned in other countries and other industries. They also include academic publications and pre-2020 reports (not included within the OWEER). The aim was to select the most relevant references rather than a comprehensive set of references. The outputs are not intended to be exhaustive, but to provide a starting point for the production of position statements.

Future Research

As a part of the added value offered by ABPmer, experts suggested research that could be undertaken to progress specific evidence gaps. This is included within the **Critical Gaps Database** and Appendix C. The limitations of potential research options were also considered and presented, along with justification for recommendations.

Supporting information

Understanding that the desired end point was the production of position statements, supporting information was provided to facilitate interpretation of the data tables, and to ensure that the outputs provided would support Objective 5 (see Table 1). The following contextual information was added to the database with the aim that the **Critical Gaps Database** could be used to write position statements in relation to each critical theme:

- **Summary:** A definition and explanation of the theme. A 'stock-take' of progress summarising what is and is not known about the topic, in many cases summarising how understanding has evolved over the past 20 years of offshore wind research.
- **Key Research Undertaken, Underway or Planned:** A table detailing key research relating to the topic area that has either been undertaken in the past, is underway or is in planning.
- **Potential Future Research & Limitations:** Recommendations for where future research could usefully focus, including a description of potential limitations.
- **Policy and Practice:** Areas where policy and science are separated, or where policy-based solutions may be of benefit.
- **Stakeholder Consultation:** Stakeholder consultation is recommended when there is a large project either underway or in planning, where the outputs may significantly influence progress (but are not yet in the public domain).

2.4.2 Outputs

All outputs are summarised within the **Critical Gaps Database.** A summary of key research undertaken, underway and planned is also provided in Appendix C. A summary of research recommended by the expert team is provided in Appendix D.

2.5 Opportunities for progress and/or added value

During the creation of the **Critical Gaps Database** experts also identified where relevant data or evidence initiatives might be used together or added to in order to accelerate progress (**Objective 4 in Table 1**).

The following opportunities for further analysis work were identified:

- **Marine mammals – baseline understanding:** the potential for pooled analysis of Passive Acoustic Monitoring (PAM) data gathered from different arrays was identified, although further consultation with Sea Mammal Research Unit (SMRU) would be required to assess feasibility.
- **Ornithology – collision:** the potential to improve understanding of bird collisions through analysis of camera footage collected by curtailment systems such as DT Bird was suggested.
- **Ornithology – displacement:** the potential for meta-analysis of existing datasets to establish whether there are identifiable factors that affect displacement, with an end goal of improving characterisation of displacement impacts within the assessment system was proposed.
- **Ornithology – mitigation:** it was considered possible that bird tracks from wind farm radar studies could be analysed collectively to establish principles around how birds navigate around and through offshore wind farms, to ultimately build an evidence base for bird friendly design principles and produce best practice guidance around minimizing impacts at the site design stage[11].

During this review process, ABPmer identified the European Wendy project (Network of Interest – WENDY (wendy-kep.eu) as being of potential interest to P2G and the Offshore Wind Evidence & Knowledge Hub (OWEKH) as one of its aims it to establish knowledge hubs to facilitate knowledge sharing between stakeholders.

[11] The Norwegian start up company Spoor has been looking at bird friendly design concepts using 3d camera tracklines.

2.6 Next Steps

In accordance with **Objective 5** in **Table 1**, the following recommendations for next steps were made around how this work could be taken forward, which include:

- An expert/expert panel could draft the background information, which could be reviewed by Statutory Nature Conservation Bodies (SNCBs) and a wider stakeholder group to establish whether there is consensus around the key issues, and if not, where disagreements lie.
- The expert/expert panel could suggest methods for dealing with problem issues that typically arise at assessment, using a workshop/stakeholder feedback process to establish preferred approaches.
- A draft position statement could be sent to a range of stakeholders for further comment and tested using hypothetical scenarios.

3 Part 2: Case Studies

The purpose of Part 2 of this project is to identify principles that could be adopted more widely in consent decision making, drawing on case studies from other countries and/or other industries. The case studies aim not only to identify when a particular approach has been successful, but also when there have been problems, so that relevant knowledge may be transferred to offshore wind consenting.

Ideas for potential case studies were discussed with the P2G Team. Two obvious areas were identified where case studies would be beneficial. These were:

- **Monitoring and adaptive management** – this was considered highly relevant to all the critical themes, as it is the primary mechanism available to facilitate consent in the face of uncertainty. The case study discusses a range of marine projects including the Morlais tidal energy project and various port expansion projects where monitoring and adaptive management have successfully been used to facilitate consent. Discussion of projects where outcomes have been less successful and the reasons behind this are also considered.
- **Compensation within the ports sector** – although a relatively recent requirement for offshore wind, and as such a major bottleneck in consenting, other sectors, such as port development have been designing and implementing compensation measures for a number of years. This case study compares how data and evidence have been used in consenting and delivery of compensation for port expansion projects, examining casework from the UK and Germany, and identifying where lessons have been learned that would be transferrable to offshore wind. The case study also identifies issues that are distinct to offshore wind, and which will require dedicated effort to resolve.

Several discussions from the workshop were considered worthy of further consideration within this project, although these areas were related specifically to offshore wind and differ from the two case studies identified above. Although other countries and industries are discussed, there is perhaps less potential for transferrable learning, understanding that the UK has more offshore wind installed than any other European country. These case studies are:

- **Consideration of climate change impacts within assessment**. Climate change means that future outcomes for most marine species are highly uncertain, and this is not captured within the current assessment system, which assumes that without the development populations would persist at their current level. Whilst many seabird species are projected to decline with warming climates (therefore increasing concerns over other potential stressors such as offshore wind farms), conversely the outcomes for these species (and whole ecosystems) will be worse without decarbonisation of the UK economy[12]. This aspect of climate change is not captured within the current assessment process. The case study considers whether consideration of these trade-offs could be incorporated within the current assessment process.

- **Avoidance of high-risk areas.** Avoidance of impacts represents the first step of the mitigation hierarchy, and the need to avoid areas of high ecological value at the site selection stage is clear. Ecological marine survey work is time consuming, expensive, and residual uncertainty may still be a problem even once additional work has been completed. In a worst-case scenario, a dedicated survey programme may reveal high usage of a potential development area by a protected species, and ultimately lead to project failure. In other scenarios monitoring costs may escalate, and expensive compensatory measures may be required to achieve consent. Therefore, avoiding areas of high ecological value at the site selection stage benefits all. This case study investigates the how the site selection process considers ecological receptors in England, Scotland and in Europe.
- **Ornithological monitoring.** The value of current ornithological monitoring programmes was raised by the P2G Team and has been discussed on various occasions over the past decade without any fundamental changes made to standard survey transect-based programmes. The case study draws on the types of ornithological data that can be gathered and looks at how use of multiple techniques can reduce uncertainty with reference to ornithological offshore wind farm monitoring carried out both in the UK and in Germany.

3.1 Monitoring & Adaptive Management

Many of the delays in consenting are a direct result of uncertainties and the burden on developers to demonstrate, through supporting evidence, that the impact predictions (and mitigation) are acceptable and can be confidently relied upon.

3.1.1 Introduction

Adaptive management is an iterative process that allows actions to be taken under uncertain conditions based on the best available science. Detailed monitoring and ongoing evaluation of the data outputs are then used to increase the evidence base, inform decisions, and if required, take actions.

Common to all the critical evidence gaps identified (see Table 2) is the uncertainty of the potential environmental impacts from offshore wind development and the efficacy of mitigation and compensation measures for reducing/offsetting significant impacts. The impact uncertainty (its occurrence and/or magnitude) has a critical role in the assessment and therefore consenting process. Consequently, many of the delays in consenting are a direct result of uncertainties and the burden on developers to demonstrate, through supporting evidence, that the impact predictions (and mitigation) are acceptable and can be confidently relied upon. Similarly, as the effectiveness of compensation measures is often uncertain, highly precautionary measures can be required to be put in place. Even then a successful outcome is not certain.

There is also an increasing requirement for offshore wind developments to provide effective compensation packages (e.g. Berwick Bank Wind Farm). However, given the lack of evidence to date surrounding the success of marine compensation[13], the efficacy of compensation needs to be evidenced

[12] Although it is acknowledged that decarbonisation must ultimately also be a global commitment.
[13] Best practice guidance for developing compensatory measures in relation to Marine Protected Areas: consultation document (defra.gov.uk)

through location specific monitoring programmes. An adaptive management approach allows developers to potentially rationalise compensation packages dependent on monitoring outputs and demonstration of effectiveness. Currently, it is accepted that any compensation package should realistically and confidently be able to deliver a ratio of greater than 1:1[14]. In many cases, delivering and demonstrating that the measures put forward are providing the required degree of compensation is extremely challenging. However, where the potential risks and impacts are medium or long term and will occur slowly, if at all, adaptive management provides a proportionate approach for managing the risk i.e. applying measures as they are required.

On top of this, there are significant and ongoing environmental changes which need to be acknowledged (e.g. climate change, avian influenza). Even though these wider changes are impacting directly or indirectly upon features, there is often considerable uncertainty around the degree of impact. Through adaptive management approaches, re-evaluation of management and monitoring decisions can be carried out, as required, in response to new data and evidence.

Within the consenting process, monitoring and adaptive management are therefore critical tools for managing and reducing uncertainty, potentially allowing projects to proceed but also to develop the evidence base in the medium to long term.

3.1.2 Use of data and evidence to inform adaptive management

Morlais Tidal Stream Project

The Morlais Project (the project) was awarded consent in 2021. It is located off the west coast of Anglesey, within one of several marine energy demonstration zones located around the UK coast. The project provides a consented tidal technology demonstration zone, specifically designed for the installation and commercial demonstration of multiple arrays of tidal energy devices, with a generating capacity of up to 240 MW.

A key element to this project is that the installation of tidal stream devices will be phased to ensure that the development does not negatively impact marine wildlife. This approach was primarily a result of the uncertainty of collision impacts with the turbines, in particular the potential risk of marine mammal collisions but also the potential for underwater noise disturbance on harbour porpoise.

While in over 15 years of tidal stream operation in the UK there have been no records of marine mammal collisions with tidal turbines, considerable uncertainty exists surrounding current population estimates and trends (e.g. SCANS III) of marine mammals and their potential for turbine avoidance. Although predictive collision modelling was carried out by the applicant to support the assessments, due to the lack of suitable empirical data for this emerging renewable technology, there was not enough certainty to validate the modelling.

Therefore, under the full proposal (240 MW) it was not possible to conclude no adverse effect on site integrity (nAEOI), in relation to harbour porpoise, bottlenose dolphin, grey seal or harbour seal features without the application of suitable mitigation and management measures.

An outline Environmental Mitigation and Monitoring Plan (oEMMP) was produced by Morlais to demonstrate how the potential effects of the project on marine mammals, diving birds and migratory fish could be mitigated, monitored and managed. The oEMMP encompasses an Adaptive Management Plan and through discussions with NRW and evolution of the document, provides realistic mechanisms to prevent an Adverse Event of Specific Interest (AEOSI). The oEMMP considers appropriate mitigation

[14] ibid

and monitoring methods (both real time and recorded) for the collection of environmental management data during the deployment and operation of arrays of tidal devices. As a condition of consent, the oEMMP will be developed in agreement with regulators into a detailed Environmental Mitigation and Monitoring Plan (EMMP) post consent.

The EMMP identifies specific approaches and details conditions appropriate to maintaining the conservation objectives, in this case population viability, in relation to ecological features including harbour porpoise, bottlenose dolphin, grey seal and harbour seal. It allows deployment and operation to occur at a scale that is acceptable with sufficient confidence that operational activities will not lead to an AEOSI on Annex II and Annex IV species. Trigger levels for each marine mammal species, as detailed within the EMMP, will lead to a mitigation cascade that will maintain the continued viability of the population, thus ensuring that AEOSI does not occur.

Commitments by the applicant to measures within the EMMP are required to provide enough confidence that AEOSI would be avoided. These include but are not limited to:

- The applicant's commitment to phase deployment and installation of devices, with the number and scale of each phase of deployment linked to the outcomes of the EMMP. As stated in paragraph seven of the oEMMP[15] 'device deployments in all Phases including Phase 1 will only be allowed at scales at which Regulators agree that the best available scientific understanding does not predict adverse impacts upon marine mammals or upon non-Special Protected Area (SPA) populations of diving seabirds from local colonies.'
- The commitment to the implementation of mitigation, monitoring and management measures as agreed with regulators and overseen by an independent Advisory Group.
- The commitment to the implementation of 'back stop' mitigation in the form of an immediate 'stop' clause (cessation of turbine operation) if monitoring measures indicate potential for AEOSI.

An illustration of the EMMP process, as outlined in v9 of the outline EMMP (MMC447(3) MOR-RHDHV-DOC-0072 (09))[16] is shown in Figure 2.

While there are inherent uncertainties about the potential for an impact, there is enough confidence that an AEOSI can be avoided by applying the measures within the EMMP. As the project was consented for full scale (240 MW), there also must be enough confidence that AEOSI would be avoided at that scale.

Consideration was given to the monitoring technology and mitigation measures. Despite adequate monitoring technology to discern different marine mammal collisions being currently unavailable at the time of the application, given their different trigger thresholds for the mitigation cascade. It was considered realistic that this technology could be developed within a reasonable timeframe and applied to the proposal. To overcome this limitation, particularly early on (e.g. Phase 1) as technology is still being developed, assumptions are made within the EMMP which apply a worst-case scenario i.e. that any collision event recorded would be assumed as occurring upon the marine mammal with the lowest collision limit. At this point in time, the worst case would assume a bottlenose dolphin collision. Furthermore, unless it can be confidently discerned, any collision must be assumed as leading to mortality of the individual.

Essentially the oEMMP encompasses a survey, deploy and monitor (including real-time monitoring) approach with regular reviews of the data. These data inform the next steps of the process and when

[15] 160919 Morlais TWAO Application Documents - Dropbox
[16] 160919 Morlais TWAO Application Documents - Dropbox

the next phases of deployment should take place, if at all, and at what scale. As noted, the oEMMP is not limited to collision risk on marine mammals. It also encompasses measures to monitor and model underwater noise (Section 1.3.4 of the oEMMP) to ensure there is no potential disturbance to marine mammals. Each phasing of deployments only being allowed to begin if monitoring (and modelling prior to Phase 1) indicates that the next phase of deployment could begin without an adverse effect on marine mammals or birds.

The application of the monitoring and adaptive management measures set out in the oEMMP allowed the development to be consented despite the scientific uncertainties. This has included the commitment to appropriate mitigation for the realistic worst-case scenario which can be secured and is feasible with a high chance of success. Furthermore, to comply with the Habitats Directive (Article 6(3)), clear actions are included within the EMMP to be taken before a significant adverse effect upon a feature of a European Protected Site can occur.

3.1.3 Examples from other industries or countries

Adaptive management is a commonly used approach to demonstrate and secure compensatory measures. Implementation of a suitable monitoring framework allows both the degree of impact and the efficacy of compensation to be managed. Adaptive steps are then taken to manage the outcomes from these two areas of uncertainty to avoid unacceptable affects. This may result in the evolution of the methodology and/or adoption of additional compensation measures to ensure they adequately compensate the impacts. Conversely, the monitoring outputs (impacts and compensation efficacy) may indicate a point post-consent that compensation is no longer required.

The next two examples consider successful applications of adaptive management in relation to compensation. The final example considers how adaptive management is currently being relied upon for offshore wind.

Wightlink Lymington Ferries

Wightlink Ltd operates an established and regular cross-Solent ferry service that connects Lymington in Hampshire with Yarmouth on the Isle of Wight. In 2007, Wightlink put forward proposals to upgrade the vessels operating this service. The existing 'C-Class' vessels were reaching the end of their safe operational life and needed to be replaced. To accompany this vessel upgrade there was a need to modify the existing ship berths (to accommodate the proposed new generation of 'W-Class' vessels) and also to improve the passenger ramps and link span bridge at Lymington and Yarmouth.

The key concern for NE, and for a number of other stakeholders (including some members of the local community), was that the regular navigation of larger ferries through the 1 km Lymington approach channel would change the wash/drawdown conditions around the vessels and that this, in turn, would exacerbate the ongoing erosion of the intertidal habitats that lie alongside the channel. These intertidal habitats lie within the Southampton Water SPA and Ramsar sites as well as the Solent Maritime Special Area of Conservation (SAC). The subtidal area is also part of the SPA and Ramsar sites.

The primary challenge for this project centred upon the indirect (and relatively 'intangible') nature of the potential wash/drawdown effects and the difficulties of measuring or predicting such effects. There was uncertainty both about what might happen physically to the habitats and what that would mean for the integrity of the Solent Maritime European Marine Site in an environment which is itself subject to progressive ongoing erosion.

In the final agreements made between NE and Wightlink Ltd, NE noted that these effects would be uncertain, small and dwarfed by natural processes but that further measures would be required to be assured that the project would have no adverse effect on the integrity of the Natura 2000 and Ramsar sites. The offsetting measure in this case consisted of the implementation of an adaptive management strategy. This strategy involved carrying out practical habitat restoration measures linked to monitoring work which was designed to evaluate the effects of the ferries and the effectiveness of restoration work. This programme was overseen by an Environmental Management Plan (EMP) made of key stakeholders (including NE) and competent authorities.

The implementation of this adaptive management strategy was underpinned by condition 3.2.9 of the marine licence as follows:

"*Condition* 3.2.9 *The Licence Holder must ensure that agreements set out within the Section 106 planning permission to, "carry out Habitat Works for the protection, restoration and regeneration of an area of saltmarsh at Pylewell Bank and shore works at Lymington Pier," are adhered to.*

Reason: To ensure that agreements made between NE and Wightlink are adhered to."

The adaptive approach was designed to achieve an increased level of mudflat and saltmarsh 'habitat persistence' by delaying the loss of intertidal habitat to ensure that there is no adverse effect on the integrity of the European Sites by reference to the Conservation Objectives. Like the predicted impact itself there were, initially, some uncertainties associated with the potential effectiveness of the restoration measures. However, the crucial consideration here is that there was flexibility in approach.

The recharge campaigns would be altered in scale (area and volume of sediment used) and frequency (number of years over which they are carried out) as required. The ferry speeds could also be changed and there was also further consideration that the UK Government could impose a Special Nature Conservation Order (SNCO) (as a provision in the UK Habitat Regulations) to stop damaging activities.

The EMP oversees this process and considers findings from this work to make judgements about the effectiveness of the recharge against the effects of the ferry to confirm that there is no adverse effect and, if there is any risk of such an effect, what intervention measures might be required.

In 2012 and 2013 Wightlink Ltd carried out two annual programmes of dredge sediment recharge. At that time the EMP advised that no further recharge work was required and there was progressive reduction in monitoring over time, as lessons were learned during the programme. At the end of 2020, the project was signed off as having delivered the requisite mitigation by an environmental panel overseeing the work. No further restoration campaigns were therefore required[17].

Pagham Spit Intervention

The local community at Pagham (West Sussex) proposed to undertake a managed breach of the shingle spit at the mouth of Pagham Harbour. The main aims of this shoreline adjustment were to move the coastline towards a more sustainable morphology and address the coastal erosion, amenity and human health problems being experienced along the adjacent Pagham Beach. The planning and marine licence applications for this novel coastal management intervention project were submitted to the relevant licensing authorities in September 2015.

The project represented a 'soft' solution to these problems because it sought to mimic a process (i.e. breaching of the spit) that has happened naturally in the past and is likely to occur in the future anyway (although the timing of this was uncertain). The aim of the managed breach was to do this in a

[17] 142 - Boiler Marsh Lymington (omreg.net)

predictable and controlled way that addresses immediate problems, anticipates future needs, and provides time for the ongoing adaptive management of this coastline.

The proposed breach was within an area of high nature conservation importance. It was within the Pagham Harbour Site of Special Scientific Interest (SSSI), SPA and Ramsar areas. Based on advice from NE it was recognised from an early stage in the development of this project that it would not be possible to conclude with certainty that there would be nAEOI of the European sites. The compensation to offset the predicted impact in this case was the creation of a shingle island.

The planning and marine licence applications for this novel coastal management intervention project were submitted to the relevant licensing authorities in September 2015 and permissions secured in September 2017. By that time a breach in the spit had occurred anyway and thus the permissions had to be secured again in October 2021.

Adaptive management was adopted to address the issue of uncertainty, especially in respect of the effects of the project on the Pagham Harbour SPA interest features and the effectiveness of the compensation measures in addressing this effect. Therefore, an adaptive management plan was produced. The requirements for the applicant (the local community) to produce this adaptive management plan, which included compensatory measures, was underpinned by the following marine licence conditions:

"*Condition 5.2.14 The licence holder must ensure that the breach of the shingle spit continues to be managed and monitored according to the proposed adaptive 'Traffic Light System' approach*[18] *set out in schedule 2 of this marine licence (and with oversight from the stakeholder group) to ensure that it does not close up after the works. This must be managed for five years after the works commence.*

Reason: To ensure effective tidal exchange between the harbour and coast is maintained.

Condition 5.2.15 Evidence of the breach monitoring (referred to in condition 5.2.14) and details of decisions reached must be submitted to the MMO annually, by 31 December each year, from the start of works for five years. The breach must be monitored based on the "Traffic Light" warning system as described in schedule 2 of this licence.

Reason: To ensure effective tidal exchange between the harbour and coast is maintained."

In light of the evidence assembled, the compensatory measures were considered to meet the requirements under the Habitats Regulation Assessment (HRA) guidance (Defra, 2012) of being: technically feasible, clearly planned, close to the site of potential impact, appropriately timed to achieve the required quality (within the context of the dynamism of the existing environment and the nature of the changes that have been and will be experienced on the site) and technically proven. They were also in-keeping with the requirements of important case-law guidance (e.g. Briels Case[19] [20]).

Berwick Bank Offshore Wind Farm

At the time of writing, the SSE Renewables (SSER) proposal for Berwick Bank Offshore Wind Farm is going through the determination phase. Located in the North Sea, in the outer Firth of Forth, Berwick Bank Offshore Wind Farm has the potential to deliver up to 4.1 GW of installed capacity, making it one of the largest offshore opportunities in the world.

[18] C.R.Scott, E.Harris, and I.H.Townend. 2020. Lessons in applying adaptive management on a dynamic coastline: a case study at the inlet to Pagham Harbour, UK. *Anthropocene Coasts*. **3**(1): 86-115. https://doi.org/10.1139/anc-2019-0002
[19] EUR-Lex - 62012CJ0521 - EN - EUR-Lex (europa.eu)
[20] CJEU case law update: Hilde Orleans & Others v Vlaams Gewest - Freeths

Given the scale of the proposal and the potential for significant effects on bird receptors (including Kittiwake and Guillemot), proposals for a comprehensive compensation package were submitted with the marine licence application. To support the implementation of compensation, stakeholders requested that SSER provide an outline framework for the suggested compensation measures, indicating how monitoring would inform management decisions and feedback through an adaptive process.

SSER have stated how data from the compensatory measures and new evidence from wider monitoring activities will be analysed, and management actions implemented in a timely manner, including contingency compensatory measures to ensure that the compensation delivered is always sufficient to offset impacts from the proposal[21].

3.1.4 Conclusion

The aim of adaptive management is to avoid unacceptable effects through a systematic and iterative approach of "learning by doing and adapting as you learn".

The above examples of consented projects highlight how the successful application of monitoring and adaptive management have been used, or in the case of Berwick Bank, is intended to be used, to address uncertainty and allow projects to proceed through the consenting process. Key learning outcomes are summarised in the box below.

Box 1: Monitoring and Adaptive Management

Key learning outcomes and value of this approach:

- Addressing uncertainty of environmental impacts is often the main issue within consenting of offshore wind projects.
- Where the potential for a significant impact exists, the adoption of adaptive management tied with suitable monitoring programmes can allow developments to proceed despite uncertainties.
- Provided suitable and realistic monitoring programmes can be implemented, then it may be possible to avoid a conclusion of AEOI under the Habitats Regulations if measures within the adaptive management will prevent the impact from ever reaching an agreed threshold.
- Monitoring and adaptive management can provide the necessary confidence to SNCB's that implemented compensation measures will offset development[1] impacts.
- Compensation measures can be adapted based on monitoring outcomes.

Adaptive management may initially seem a risky approach to developers, as it requires complex monitoring frameworks and licence conditions. As highlighted with the Morlais Tidal Stream project, within these conditions may be a 'stop' clause to operations or in the example of a phased development, the risk that future phases may never progress in light of the uncertainty around impacts or compensation measure efficacy. However, it is the regulator's responsibility to only progress developments that have a reasonable degree of success i.e. that the uncertainty is not insurmountable to address within realistic timescales. While there are examples where marine renewable projects have not progressed to their originally intended scale (e.g. London Array) or pace of deployment (e.g. MeyGen), in many instances, without adopting an adaptive management then these projects would not have secured consent for the initial phase(s).

In the case of offshore wind, the uncertainties around the impacts on seabird populations (collision, displacement, disturbance) are unlikely to be addressed within the short term (see Section 3.4). To

[21] aei02 - addendum to the derogation case - section 3 - implementation monitoring.pdf (marine.gov.scot)

enable these developments to proceed, especially within an increasingly busier marine space, monitoring and adaptive management provides a necessary tool.

Provided unacceptable impacts are not likely to occur over short timescales, the application of monitoring measures and adaptive management will potentially enable the regulator to have enough confidence that the project (or plan) will not have significant adverse effects (e.g. AEOI) on sensitive environmental receptors. When carrying out an Appropriate Assessment (AA) under the Habitats Regulations, it is often the perception that there is a need to demonstrate without uncertainty that a development would not lead to an AEOI. However, even where uncertainty exists it is possible to conclude no AEOI provided that the competent authority puts in place a legally enforceable framework to prevent risks from materialising (e.g. Advocate General Kokott's preliminary ruling on the Waddenzee case[22]; Morlais Tidal Stream development).

As previously noted, the application of monitoring and adaptive management is likely to become increasingly necessary to support delivery of offshore wind compensation. The requirement to adopt a realistic worst-case scenario within the assessment process, can result in impact conclusions that while credible, may also be unlikely. Where this requires compensation to offset and balance the predicted impacts, the measures will be accordingly aligned to these worst-case assessment scenarios. Despite the uncertainty around the potential medium/long term impacts (e.g. collision risk to birds), the full compensation package will have to provide regulators with sufficient confidence that under the worst case predictions, the affected features would be fully offset. However, given that predicted significant impacts on these features (e.g. collision impacts on bird populations) may not (under the worst-case scenario predictions) manifest for a number of years, adaptive management can be used to limit the initial amount of compensation that is implemented while at the same time gathering additional monitoring data to inform a better understanding of potential impacts.

Applying monitoring and adaptive management in this manner, allows compensation to be more responsive. Thus, compensation measures can be implemented and adapted based on an ever-increasing evidence base.

Essentially, key environmental risks to offshore wind development may become manageable and acceptable if the impact uncertainty has potential to be addressed through monitoring programmes. From the developer's perspective, offshore wind projects may then proceed on the basis that operational monitoring data will demonstrate that the full compensation package or prohibitive mitigation requirements (e.g. cessation of turbine operation) may be acceptably unlikely to be required.

[22] eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:62002CC0127

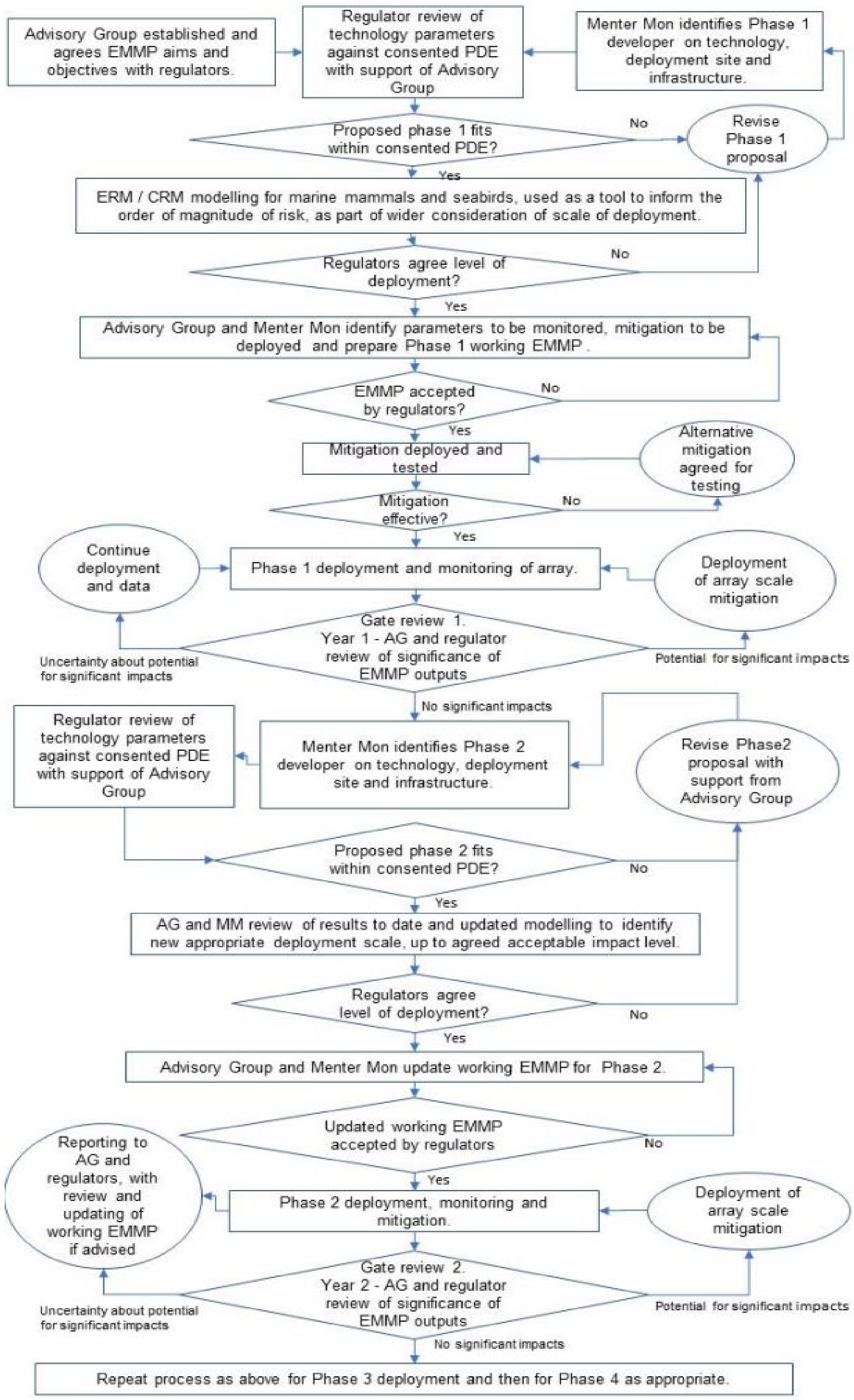

Figure 2: Illustration of proposed EMMP process for initial deployment and repowering. Taken from Plate 2-1 of the outline EMMP (v9)[23].

[23] 160919 Morlais TWAO Application Documents - Dropbox

3.2 Compensation within the ports sector

There is a lack of robust scientific data relating to the likely efficacy of potential compensatory measures, and a lack of clear guidance over which measures are likely to be acceptable and which are not, with approaches differing between regions, compounded by a delay in the delivery of strategic compensation. There is also a fundamental need for acceptance around the use of non like-for-like compensation when like-for-like compensation is problematic.

3.2.1 Introduction

The level of uncertainty associated with many proposed compensatory measures for offshore wind results in significant delays to consenting decisions. This case study explores how data and evidence have been used in decision-making around consenting of port developments where compensation is required. It uses comparative casework from the UK and Germany and identifies where learning may be transferrable to offshore wind, but also identifying where offshore wind faces challenges which are distinct from other developments. Port developments have been selected for this case study because similarities can be drawn in terms of setting targets (which can in some situations relate to specific numbers of birds), uncertainty around the potential efficacy of habitat creation, and also the need for adaptive management as a delivery mechanism for large complex projects (see Section 3.1).

To date, the development of compensatory measures for offshore wind has been developer-led, with suggestions for compensation made on a project-by-project basis. Evidence reviews on compensatory measures have been carried out, such as Furness *et al*. (2013) and McGregor *et al*. (2022), which provide a starting point in terms of which options may be effective for particular species. However, uncertainty around how much compensation might be delivered by a particular measure has delayed consenting decisions, although the Ecosystem Change, Offshore, Wind, Net Gain and Seabirds (ECOWINGs) project is currently working to fill data gaps over the scale of compensation that might be provided from different measures. Within the P2G workshop held on 12 July, the primary reason for delay was suggested to be conflict over scale. However, questions over efficacy (and therefore the scale of what may be achieved) are also very relevant.

One of the defining principles associated with compensation is the end goal, which is to have certainty that once implemented there will be nAEOI from the development. Simmonds *et al*. (2019) pointed out that one potential pitfall of target-based compensation is that developers may set the bar low in terms of targets. However, since there is a need to demonstrate that there will be no AEOI, the process for ports involves an element of negotiation between both parties to reach an acceptable agreement.

For offshore wind, the target numbers for compensation are an output from the assessment process. However, uncertainty over the true scale of collision impacts and the consequences of displacement (in terms of effects on survival and productivity) are poorly understood. For this reason, precautionary approaches are recommended in assessment, with disagreements on the levels of precaution that should be applied and often high compensation scenarios being implemented. It is simply not understood whether or not this is the case, and it is argued by the Royal Society for the Protection of Birds (RSPB) highlight that precaution is due to uncertainty, and that the solution is to reduce uncertainty rather than precaution (McCluskie, 2018). However, there remains a mismatch between the quantity of compensation that developers perceive is needed and the quantity that is expected by SNCBs, with uncertainty over the efficacy of proposed measures constraining resolution.

In spite of a general agreement that prey availability is a key driver of seabird productivity, with compensatory measures to address this providing the greatest level of benefit (McGregor *et al*. 2022), fisheries management measures can only be implemented by the government, and may be politically contentious for many reasons. As a result, very few offshore wind farm sites have suggested compensatory measures relating to restriction of fisheries. However, it is hoped that strategic compensation may offer a way of overcoming these constraints, although the scale of the challenge is acknowledged.

3.2.2 Use of data and evidence to inform compensatory measures for port developments

Port compensation typically involves replacing habitats lost to development on a like-for-like basis. However, it has some similarities with offshore wind compensation in that benefits may take time to achieve, outcomes are not guaranteed, and compensation targets may, in some situations, relate to target numbers of birds.

Although compensation targets for offshore wind farm sites are quantified through the assessment process, ratios for port compensation are set on a case-by-case basis with the extent of compensatory habitat required determined by the quantitative and qualitative aspects inherent to the elements of integrity i.e. including structure and functionality and their role in the overall coherence of the UK National Sites Network. As a general principle, it is assumed that a minimum compensation ratio of 1:1 is required, although uncertainty and delayed timescales typically result in a need for increased ratios.

In cases where there is uncertainty as to whether the compensation benefits will balance predicted impacts, an environmental management planning approach has been undertaken and underpinned by a legal agreement, which (in a number of cases) has enabled the SNCBs to withdraw objections[24]. This approach would involve producing an EMP which sets out how the impacts of the project will be monitored and how these will be tackled through mitigation and/or compensation, specifying how the project may be adjusted to ensure environmental impacts are minimized.

The securing of such adaptive processes within legal agreements has been increasingly used for large-scale projects. An example is Bristol Port Company's (TBPC) Steart Habitat Creation Scheme, which was undertaken to create new mudflat and saltmarsh habitats in compensation for impacts on designated mudflats resulting from the proposed construction of a new deep water container terminal at Avonmouth (near Bristol). In summary, the objectives for TBPC were to carry out the compensation scheme, so far as reasonably practicable to:

- Deliver the required compensatory habitat (particularly 20 ha of intertidal habitat, including at least 20 ha of longer-term mudflat) in advance of the predicted damage to the designated habitats at Avonmouth during construction;
- Support around 3,000 water birds in the winter (together with the Avonmouth intertidal area);
- Be of sufficient quality to qualify for designation as an extension to the Severn Estuary European Marine Sites within ten years of becoming fully functional; and
- Require minimum future intervention and be sustainable in the long term.

The securing of adaptive processes within legal agreements has been increasingly used for large-scale projects as a route through planning (see 3.1 Monitoring & Adaptive Management), with objectives then regularly reviewed through monitoring.

[24] Examples include Immingham Outer Harbour Environment Monitoring and Management Plan on the Humber, Seaforth River Terminal Monitoring and Mitigation Plan on the Mersey, Ipswich Ro-Ro berth, Harwich Channel Deepening, Trinity Terminal Extension at Felixstowe and London Gateway Port.

For many port compensation sites with specific objectives, sign-off procedures have been unclear, with many sites having no official sign-off procedure in place from the outset making it difficult to predict what would happen at the end of the defined review period. With regards to ABP's managed realignment sites on the Humber Estuary, which were undertaken to offset the impacts of multiple ABP developments, data was collected annually and reviewed against objectives at six monthly Environmental Steering Group (ESG) meetings. The potential for the boundaries of designated sites to be extended to include the managed realignment sites on the Humber Estuary has also been discussed at the six-monthly meetings. NE advised, however, that the mechanism whereby this is achieved is relatively complex and can take several years. However, it is notable that (unlike SACs, and Marine Conservation Zones (MCZs)) SPAs cannot be extended in this way as Under Article 4 of the Birds Directive, Member states are already required to classify suitable territories as SPAs.

With port developments, compensatory habitat should be provided as close to the adverse effect as possible to provide an alternative habitat that can be used by the impacted population. If this cannot be undertaken, higher compensation ratios are likely to be required and a full audit trail needed. This may cause problems when there are a lack of sites for habitat creation or enhancement measures within or near any given designated site.

Similar problems are encountered with offshore wind, although advice over the location of compensatory measures for offshore wind is also confused, which leads to debate around whether the compensation should be local to the site or at another location. Concerningly, for seabirds, if offshore wind farm compensation is not applied at a local colony level, then this may put a particular colony at risk, unless compensation can be implemented at a nearby location, and connectivity can be demonstrated. However, conversely, there may be opposition to enhancing habitat near an offshore wind farm, as it could be considered to pull birds to an area where they are at greater risk of collision. As offshore wind farms are built and in planning in many locations within UK waters, greater consideration is needed to satisfactorily address this issue, with protection of specific areas for birds (without wind farms) worthy of serious consideration at a wider marine spatial planning (MSP) scale.

Problems encountered in the delivery of port compensation programmes include situations when habitats evolve rather than having fixed sustainable features. This is also very relevant to marine ecosystems, many of which are changing rapidly due to climate change. For example, the potential benefits of sandeel fishery closures may be temporally limited as sandeel distributions shift northwards (see Section 3.3).

A further issue raised by SNCBs at Wallasea Island, which now supports large numbers of birds and is generally viewed as an example of best practice, is that it is not possible to establish to what extent populations have increased or whether birds have simply re-distributed themselves along the estuary (Blake *et al.* 2021). This point is also relevant to offshore wind seabird compensation, where the number of breeding pairs of seabirds on an island may increase suddenly when rats are removed because the quality of the breeding habitat is much improved. An initial increase in the number of adult pairs is not an increase *per se* but rather a re-distribution of birds. Therefore, greater effort is required to monitor both bird populations over time[25], but also other measures such as productivity (i.e. the number of chicks fledged per pair) so that number of chicks recruited into the colony each year can be compared before and after compensatory measures are implemented. However, disentangling the impacts and benefits of wind farm construction and compensation from wider population trends will be highly challenging.

[25] However, understanding that populations of many species may also be impacted by events occurring within wintering areas.

3.2.3 Examples from other industries and other countries

In Germany, early port compensation projects involved a complex planning process, with objectives set out before the project commenced and constituting part of the overall legally binding agreement. Some German sites have had specific bird targets, most notable the Hahnöfer Sand compensation site in the Elbe Estuary, which failed to attract the required roosting Shoveler numbers by a factor of 20 (some 50 pairs as opposed to the 1,000 anticipated). However, no corrective action has been requested by the regulators, as they had been involved in the design of the measure and had signed it off as appropriate. This demonstrates the value of stakeholder engagement, and it is recommended that all projects should have an ESG that involves regulators and/or SNCBs.

Another German scheme in the Weser Estuary (Kleinensieler Plate) also failed to meet its objectives within a few years of implementation. Here the implementers took corrective measures including the dredging of a lagoon that had accreted more rapidly than expected. They had to convince regulators it would work, although it did prove successful (Halcrow *et al*. 2012).

More recent German compensation projects such as Bremenports (Weser Estuary) kept objectives deliberately general in recognition that it had previously proven difficult to predict objectives a long way in advance, and in general Germany has moved towards a more flexible ecosystem-based approach as a result of experience gained from earlier schemes. There is a clear need for offshore wind compensation to consider measures to strengthen ecosystems when like-for-like compensation may not be achievable[26]. Lack of clear direction around problematic compensation scenarios is a key reason why consenting is delayed. However, measures such as planting seagrass meadows as a compensation measure for seabird impacts[27] is not currently accepted in the UK. Although this measure is likely to be beneficial at an ecosystem level[28] the evidence base is currently poor, with the only way forward being to gather scientific data on efficacy.

In both the UK and Germany monitoring outputs are reviewed by an ESG. The issues described above with sign-off have also occurred in Germany, although typically monitoring programmes are longer (~15 years), although reviews are held less frequently, every 2-3 years. Whilst targets set for port compensation are sometimes not achieved, other sites do achieve targets within a longer timescale than initially anticipated, with monitoring often extended until targets are reached. However, there is less certainty around how bird populations may respond to differing compensatory measures, with monitoring (particularly anything involving offshore surveys) being particularly costly. These issues are further complicated by the need for long-term datasets to tease out what are likely to be relatively small wind farm impacts from other major population drivers such as avian influenza. Therefore, the difficulty and expense involved in offshore wind farm compensation has the potential to result in significant cost to offshore wind, but conversely needs to be robust to enable consent to be granted. Therefore, the need to avoid sites of high ecological value is considered of high importance (see Section 3.4)

3.2.4 Issues specific to offshore wind compensation

Issue 1: Fundamental flaws in the types of targets being set

Although there is learning that can be transferred from the ports sector, there are several ways in which compensation for offshore wind differs. Firstly, the impact pathways associated with both developments are different, particularly for birds. Port expansion results in habitat loss, whilst offshore wind results in

[26] With this being of specific relevance to Annex 1 sandbank features.
[27] Understanding that these inshore habitats may be used as nursery areas for herring, which are then later prey for pelagic seabirds offshore.
[28] Even if in a worst case scenario the use of seagrass meadows by herring may be less than anticipated.

mortality of birds (from collision and displacement). Whilst both port development and offshore wind farms may result in the displacement of birds, this is dealt with differently in assessment. In port development there is usually habitat lost to the development, which is replaced at a compensation site. However, in offshore wind farm assessment, the potential mortality due to displacement is added to mortality predicted through collision risk modelling to create a total number of birds that are predicted to die every year due to the development.

Therefore, ports are required to implement compensation to create habitats, whilst wind farms are required to implement compensation that will lead to a population increase in specific seabird species. As a starting point the requirement to produce a defined number of additional birds per year of a species which may be in decline and under pressure from a range of threats[29] (including long term historic over-exploitation of fisheries), may be fundamentally flawed, and may assign an impossible level of responsibility to the offshore wind industry for issues that are well beyond those of the project. Nonetheless, the loss of even a few birds from some populations may result in decline and risk of extinction for some species, following losses due to avian influenza. Even the best compensatory measures available may only slow a trend of decline, especially if prey species are being impacted by climate change and warming seas. Therefore, care is needed to agree appropriate wording and agree what is deliverable and what may not be deliverable at the project outset. This process would benefit from a market-based approach, i.e. transparent discussion around what cost can reasonably be allocated to compensation, with joint decisions made over how this resource can best be used.

Another solution in cases where population decline is underway, may be to look towards 'maintenance' compensation. As a concept maintenance compensation is based around implementing compensation that prevents future loss and is considered valid in other industries (see Simmonds *et al*. 2019). Another clear way forward would be to push large scale 'no-regrets' ecosystem measures such as fisheries closures as a solution whilst negotiating more flexible targets, appreciating the high level of ecosystem benefits these measures would deliver across multiple receptors.

Issue 2: Fundamental flaws in the calculation of compensation benefits

Proposed compensatory measures are variable, with varying levels of data and evidence associated with them. This means that targets set are also of variable quality. For example, whilst removing rats from a seabird island will improve productivity, the level of benefit achieved through rat removal is often calculated by counting the number of nesting sites available on the island (see GoBe, 2022). Although these assumptions are stated, they are not sensible, and represent a maximum benefit. Therefore, if these values are used within the licensing process as compensation targets, then there is a risk that the developer may be held responsible for delivering them, when this was always unlikely[30], [31]. Population modelling of the benefits likely to be achieved through different compensation measures for seabirds (informed by either data or expert elicitation) undertaken under ECOWINGs will help fill this data gap, although this not currently available to benefit projects currently going through the planning process. Therefore, care is needed to ensure that projects negotiating compensation at the current time are aware of these issues, and that some flexibility is agreed in licences and EMPs, rather than straight numerical targets.

[29] Including losses sustained on overwintering grounds for some species.

[30] In this case, collective analysis of productivity data from wardens reports from all islands where rat removal has been undertaken could potentially fill data gaps and improve calculations of compensation benefit and the types of targets being set.

[31] Understanding ports have been required to extend monitoring programmes of compensation sites until targets have been met.

Issue 3: Monitoring compensation benefits

Against a backdrop of climate change, avian influenza and other major population drivers, monitoring to detect the much smaller impacts and compensation benefits of offshore wind farms will be problematic, appreciating the high natural variability in offshore seabird abundance and distributions. Therefore, there is a risk that developers spend large sums of money attempting to demonstrate that their compensation has worked, and/or that the actual impacts of the offshore wind farm development are lower than predicted within the Environmental Impact Assessment (EIA) (with the aim of reducing compensation requirements). Whilst the need for better empirical data on both impacts and compensation are much needed, both are risky for a developer to undertake at a project level as there are inevitably many complicating factors, and teasing out the influence of each is problematic, especially where compensation to benefit birds is indirect[32]. It is suggested that empirical data gaps around both impacts and compensation are filled at a strategic level, with certain sites addressing specific issues. Monitoring also needs to be undertaken over the longer term, using a thorough and more holistic monitoring approach, adopting multiple techniques and ensuring that the resulting data addresses specific research questions (see Section 3.5). It is not that compensation should not be monitored – indeed it should, and there may be cases where compensation is implemented at a particular colony, and land-based monitoring may be readily achievable. It is rather that care is needed in the design of large-scale costly offshore monitoring packages to ensure that they have adequate statistical power to detect change (now considered within standard guidance, but still of concern), and that there will be a defined method of separating out the influence of other major driving factors in as best a way as is possible (see Section 3.5).

3.2.5 Conclusion

There are some similarities but various distinct differences between compensatory measures and procedures for offshore wind and for ports. Therefore, there will be a significant quantity of work needed to resolve the issues specific to offshore wind. These are summarised in Box 2.

Given the scientific and political complexity of these issues, resolution will not be quick, and interim guidance and/or a position statement is clearly needed, as a large number of sites are in early planning stages. The difficulties finding information on decision-making relating to port compensation was identified in NE's review of UK compensation (Blake *et al*., 2021). Equally, there has been little dissemination of information on what is currently happening around wind farm compensation. Poor dissemination of information may prevent learning both from the ports sector and within the offshore wind farm industry. It is hoped that the new OWEKH will be well-placed to ensure that this is issue is remedied.

It is also hoped that strategic compensation may offer a solution that enables timely consenting of offshore wind and deliver improved environmental outcomes through compensation schemes applied in a strategic manner, although the underlying scientific uncertainties will remain until data gaps can be filled. One solution may be to manage compensation across a particular region so that several differing compensatory measures are implemented (understanding that some smaller scale measures may be more reliable in delivering benefits). This may de-risk the process in case one compensation project does not perform as anticipated. Compensation measures could also be designed to be additive: for example, seabird colonies may be exposed to multiple pressures, and if key pressures are correctly identified and tackled together strategically compensation benefits may be maximized. Since pressures vary between sites and species, these should be identified carefully to ensure the compensation

[32] Fisheries based measures are an example of indirect compensation - by reducing harvesting of fish there is a knock-on benefit to birds through improved prey availability, the scale of which is difficult to calculate due to the number of fish taken by other predators as well as birds. Ideally this should be monitored, but this is technically challenging. By contrast, direct measures (such as predator control) have a direct benefit on the survival of the bird and in this aspect are easier to monitor and comprehend.

implemented will be effective at the location where it is being deployed. So, although the deployment of compensation is strategic, it should always be underpinned by a thorough understanding of the local pressures affecting different species at each SPA within a particular region.

Understanding the difficulties with quantitative targets there is a need to consider large scale 'no regrets' measures to improve marine ecosystems when like-for-like compensation is proving problematic. This would reduce the need to use data and evidence to 'oversell' the efficacy of compensation and would encourage more open dialogue. It would also allow for changing distribution of seabirds due to climate change (see Section 3.3).

Such measures could include:

- Reducing/closing fisheries that target forage fish.
- Purchasing undesignated seabird islands and managing and safeguarding them for nature conservation.
- Restoring seagrass meadows, which may act as nursery areas for larval clupeids, which later feed pelagic seabird species offshore.
- Protection of EFH for forage fish.
- Protection of other known ecologically important offshore areas, such as fronts, upwellings etc)[33].
- Tackling marine plastics[34].

Opening up compensation to also include maintenance measures may also improve the number of options available. Much standard conservation management is based around maintenance of habitats, this could include vegetation management, such as the removal of tree mallow and nettles to improve access to Puffin burrows or could include funding seabird biosecurity work to keep seabird islands rodent free. Maintenance of favourable breeding space for seabirds could also consider (where acceptable) predator control, or reduction of human disturbance through wardening.

[33] Understanding that the location of these features is not static, but may vary within a locally defined region.
[34] Although likely to be of less appeal, there is robust scientific data demonstrating that plastic ingestion is of a level to result in starvation for a number of key seabird species

Box 2: Compensation within the ports sector

Learning that can be transferred from the ports sector includes:

- Using monitoring and adaptive management to improve SNCB confidence that the compensation will balance the impacts of the development[1].
- Use of an ESG (including regulators) to review monitoring outputs and, if possible, collectively agree on actions.
- The need for sign-off procedures to be established at the project outset.
- The need for stated procedures when compensation is not working.
- The need to recognise risks associated with working with natural systems, which do not stay fixed, but may change significantly over time, and the need for appropriate flexibility in EMPs.
- The need to understand whether increased bird numbers at a compensation site represents a re-distribution of birds or a genuine population increase. This could be tackled by monitoring productivity at SPA colonies expected to benefit from compensation. However, many factors influence productivity, which naturally varies hugely from year to year, and long-term datasets will be needed to identify trends.
- When non like-for-like compensation is needed, it may be possible to adopt a more flexible ecosystems based approach. This approach has been progressed in Germany as a result of experience gained from earlier compensation schemes and could be adapted to suit the UK offshore wind farm industry.

Distinct challenges facing offshore wind are:

- Fundamental flaws in the types of targets being set – for example, delivering a specified number of additional birds of a declining species may be impossible, as the causes of decline may relate to climate change and historic over-exploitation. In such circumstances, the best compensation may only result in a reduced rate of decline, and this needs to be recognised within EMPs. Alternatively in specific circumstances, non like-for-like compensation, including 'no regrets' ecosystem based measures could be investigated.
- Fundamental flaws in the calculations of compensation benefits, which may then be used as compensation targets. Proposed compensatory measures are variable, with varying levels data and evidence associated with them. The need to provide evidence of compensation benefits to obtain consent for a site means that predictions at the maximum end of the scale may be presented within planning documents. However, this will cause major problems in the delivery phase of these compensation schemes, especially if monitoring programmes are extended until compensation targets are achieved, as has been requested (and delivered) in relation to several port compensation schemes.
- There are distinct difficulties in monitoring compensation benefits, due to the inherent difficulties in surveying for mobile species at sea coupled with the complex nature of some of the work. Against a backdrop of climate change, avian influenza and other major population drivers, monitoring to successfully detect and tease out the much smaller impacts and compensation benefits of offshore wind farms will be expensive and difficult. It is suggested that offshore monitoring is strategic, carefully designed, sets clear objectives and utilises multiple techniques.

3.3 Consideration of climate change impacts within assessment

Climate change means that future outcomes for most marine species are highly uncertain, and this is not captured within the current assessment system.

3.3.1 Introduction

Climate change means that future outcomes for most marine species are highly uncertain, and this is not captured within the current assessment system. Within the current system there is a conflict between large scale development of offshore wind farms and the attainment of biodiversity targets. However, this needs to be taken into context with the greater threat to all ecosystems posed by climate change. As a species, the Kittiwake is the embodiment of this conflict. Warming seas mean that their sandeel prey is declining, and there is little that can be done to fix this, but even the loss of a small number of birds may precipitate a population level decline, and they remain a major consenting concern for offshore wind with 49 evidence gaps in the OWEER referring to them.

Consideration also needs to be given as to how to approach other large-scale drivers of change in assessment, especially those that relate to climate change e.g. marine heat waves, sandeel failures, avian flu and other impacts related to severe weather. Although direct comparisons between industries are problematic, as impacts and responsibilities differ, P2G have identified proportionate EIA as one of their key barriers to consenting, with offshore wind farm EIAs typically numbering many thousands of pages.

This case study will investigate whether other countries and /or industries consider climate change within assessment, and if so, whether principles could be transferrable to a UK context.

3.3.2 Use of data and evidence to inform assessment approach to climate change

The accelerating impacts of climate change on ecosystems is well-documented within the Intergovernmental Plan on Climate Change (IPCC) Sixth Assessment Report (IPCC, 2022). Within the marine environment the effects of climate change are particularly apparent:

We see a growing number of scientific studies that present multiple lines of evidence showing climate change impacts…Examples include the timing of fish spawning and plankton blooms that fish larvae depend on for food, and insect availability at the time when birds are breeding…Approximately half of the many thousands of species studied on land and in the ocean already show corresponding responses, leading to climate-caused local population extinctions and shifts in vegetation zones. In the ocean, marine plants and animals including entire communities have shifted their distributions poleward at an average speed of 59 km per decade due to increasing water temperatures. Ocean acidification and decreasing oxygen in the water also play a part. Together all three processes have caused a reorganisation of biodiversity over the past 50 years, especially at the ocean surface. Those species that cannot adjust or move fast enough are at high risk of becoming extinct[35].

Focussing on seabirds in the North East Atlantic, Hakkinen *et al*. (2022) use a species distribution model considering changes in temperature, precipitation, salinity, distance from the sea and marine chlorophyll concentration, as well as several species-specific variables to predict the proportions of habitat that will remain suitable and become more suitable between 2070-2100. Positive impacts of climate change are also predicted when considered likely. However, for all but a few species, the impacts are negative with total breeding habitat considered suitable decreasing by ~60% for Kittiwake, 61% for Gannet, 63% for Guillemot and 78% for Razorbill. Similarly, Pearce-Higgins 2021 identifies that 14 UK seabird species are at risk from climate change impacts, with an 89% decline predicted for Puffin by 2050. The same report also identifies marine renewables as recommended climate change mitigation to reduce impacts on birds, whilst acknowledging the difficulties with species such as Kittiwake, which is vulnerable to both climate change impacts and potential wind farm impacts.

The OWEER (EG.OR.122-124) identifies that '*assessments are often based on no impact population forecasts, but these forecasts currently ignore large scale drivers of change. Effects of climate change on kittiwake have been predicted to be particularly relevant*.' The research suggested to fill this evidence gap is to '*produce a predictive population model that accounts for climate change scenarios.*'

This process has been started by Searle *et al.* (2022), which models relationships between distribution, demographic rates and climate to forecast future projected change in at-sea distributions, productivity, adult survival and population growth rates within the North Sea. As would be expected, species are predicted to move northwards, associated with widespread declines for many. Declines are especially severe for Puffin and Kittiwake. Guillemot, Herring Gull and Razorbill are predicted to decline during the summer, whilst Razorbill and Great Black-backed Gull are predicted to decline in the winter. However, Razorbill is predicted to increase in the winter, and Gannet is predicted to increase in the summer and the winter. This directional shift in habitat use, from south to north will mean that the number and source of populations of individual birds interacting with specific offshore wind farm footprints will vary over time. If, as recommended, assessments should consider multiple impact scenarios, then presumably so should the development of compensatory measures.

What has not been investigated or included within assessment processes is the acknowledgement that populations of species such as Kittiwake are in decline due to climate change, and that without decarbonisation of the UK economy, overall long-term impacts on both Kittiwake and wider marine ecosystems will be far more severe (without measures to halt climate change). Although it is appreciated that on a global scale the UK's contribution to global climate change may be small relative to those of larger countries, the overriding need for all countries to collaborate in reducing carbon emissions collectively has long been acknowledged.

The current assessment system operates based on the assumption that there is a choice over whether or not to develop a particular offshore wind farm site, and that if it is decided not to develop, the hypothetical Kittiwake population will remain as it is. However, this assumption is flawed for several reasons. Firstly, many pelagic seabird species occur to some extent in most UK waters, and therefore (unless building particularly near a breeding colony) locating the site elsewhere may not alleviate the problem. Secondly, even if the site was not built, the Kittiwake population may still continue to decline. The mitigation needed to slow climate change impacts and the decline in Kittiwake populations is in fact the wind farm site. Whilst this circular relationship has been much discussed, it is nonetheless not accommodated anywhere within the assessment system, presumably on the grounds that any sort of quantification of this issue would be technically challenging.

A wind farm may, in a worst-case scenario, have a negative impact on a local Kittiwake colony, but if countries decarbonise, outcomes across all marine ecosystems will be very significantly improved.

Climate change is already resulting in relatively severe population level impacts on a number of seabird species. For example, the sandeel failures between ~2004-2008 (associated with warm sea surface temperatures) in the UK led to a rapid decline in seabird numbers, particularly in the north of Scotland[36]. Although sandeels are affected by other issues, such as overfishing, the loss of seabirds at many Scottish colonies during these years was very marked. For example, Kittiwake numbers decreased by >80% between 2000 and 2015-19 at all major seabird colonies located in the far north e.g. Fair Isle, Shetland, Orkney, St Kilda etc[37].

Although avian influenza was a known risk, the current mutation's ability to persist through spring and summer appears to be climate change related. It is not understood how many more wild birds will die before population level immunity is established. However, there has been a globally significant impact on Gannet and Great Skua populations[38],[39]. as well as very serious declines in other groups such as terns.

In 2014, the US suffered a severe marine heat wave. This event resulted in huge loss of marine life from tunicates to whales (Jones *et al*., 2018; Wild *et al.,* 2019; Osborne *et al*., 2020; Suryan *et al*., 2021, Schoen *et al.,* 2022). In terms of seabird, impacts were particularly severe in relation to Cassin's auklet *Ptychoramphus aleuticus* (see Jones *et al.,* 2018).

Although scientists thought that the UK would not suffer impacts of marine heat waves, a Category four heatwave occurred in the summer of 2023. Although significant ecological damage does not seem to have occurred, research is currently underway to improve understanding around why some marine heat waves are more damaging than others[40].

By contrast, although empirical data is still lacking, there is general agreement that seabird collision with wind turbines is low, with avoidance rates exceeding 99% for many species (Cook *et al.,* 2014, 2018). Equally, there is uncertainty over the energetic consequences of displacement and their potential impacts on seabird survival and productivity. Although the issue of cumulative ecosystem impacts, particularly at a regional scale, is of considerable concern and should be addressed, even these effects are localised and are not likely to come close to the scale of climate change impacts.

3.3.3 Examples from other countries and other industries

The current Ecological Impact Assessment guidelines (CIEEM, 2018) do not provide guidance on how to assess the impacts (positive or negative) of a proposed development on climate change, although consideration of how ecological features may change in relation to changing climate is considered. The legislation within the UK that deals with protection of wildlife, and renewable energy targets, operate independently of each other. This is the same within Europe, although it is of relevance to note that the paperwork burden is less, with the Hollanse Kust Nord Environmental Statement (ES) numbering 381 pages for a 759 MW development. This offshore wind farm is a similar size to East Anglia One, although the Ornithology Chapter for East Anglia One alone is a similar length suggesting that the planning process in the UK is certainly more cumbersome than elsewhere in Europe.

[36] sma2020_-_seabirds_-_healthy_and_biologically_diverse.pdf (marine.gov.scot)
[37] Black-legged kittiwake (Rissa tridactyla) | JNCC - Adviser to Government on Nature Conservation
[38] Although colonies are still being counted and data being collated, Bass Rock has lost ~20259 AON (see: Bass Rock gannet colony down by quarter after bird flu - BBC News) and Grassholm has lost 18,009 AON (see Largest Welsh gannet colony suffers population crash - BirdGuides) suggesting that around 6.5% of the global population has been lost from just these two colonies alone.
[39] Concern at reduced bird numbers in wake of avian flu outbreak - BBC News
[40] Home (marineheatwaves.org)

However, in comparison with the rest of Europe, the UK has developed offshore wind very rapidly[41]., with assessment requirements increasing as the industry has grown. As a country, the UK is unique within Europe in having such an extensive coastline and potential wind resource, and in terms of its focus on offshore wind farm development. When looking at the five largest wind farm developments currently under construction in Europe, only one of them is an offshore wind farm, the others are onshore sites. Equally, Great Britain and Ireland are also unique in terms of seabird interest, supporting a quarter of Europe's breeding seabirds, almost eight million individuals across 25 species[42]. Both the UK's value for offshore wind and seabirds are linked to a large coastline and cool climate, with many UK seabird species being dependent on cold water forage fish.

Offshore renewables are unusual in that they represent development that may impact both negatively on marine biodiversity whilst also providing benefits through alleviating climate change impacts. However, there are parallels with large-scale solar arrays, which may impact negatively on wildlife though displacement and habitat fragmentation, although the species that may be impacted are very location specific. However, the processes used for assessment are similar to those used for offshore wind. On this basis it does not appear as though there are lessons that can be drawn directly from other countries and industries.

A key problem within the current assessment system lies in accurately quantifying the impacts of both large-scale offshore wind farm developments, particularly cumulative impacts on ecosystems, and of climate change, and in comparing these to establish what level of responsibility may reasonably be assigned to offshore wind. For example, aviation is not required to compensate for bird strikes although the species impacted are often large gulls, geese etc. Average bird strike rates of between 2.83-8.19 birds per 10,000 aircraft movements were reported in civil aviation (Metz *et al*., 2020), therefore assuming 1,000,000passenger aircraft flights (based on 2019 figures) then this is in the region of 213-819 birds per year. Assuming (rightly or wrongly) a similar level of collision to that observed at Thanet, and a total of 2,652 offshore wind turbines in UK waters, a total of 1,989 bird collisions may occur per year. Although there is much uncertainty associated with both sets of numbers, aviation is not required to compensate for losses of birds. This is because offshore wind may impact on SPA species, and although aviation may also impact on SPA species, losses cannot be assigned to a specific colony. There are calls for offshore wind to understand (and presumably ultimately compensate for) impacts on birds in the non-breeding season. However, similar requests are not being made in relation to aviation, even though attempts could be made to apportion birds when these are protected species in a similar manner to the processes undertaken in offshore wind EIA[43].

Therefore, in some respects the level of responsibility being allocated to offshore wind does appear disproportionate and application of the precautionary principle appears inconsistent across industries. Similar analogies can be made in respect to other behaviours that impact negatively on birds that are not regulated such as bird strike with glass buildings, collision of vulnerable species with power lines, consumption of birds by cats, and continual and severe disturbance of breeding/feeding birds by people and dogs. Noting that it is acknowledged that these may not directly impact on the suite of offshore pelagic species typically present at UK offshore wind farm sites.

Whilst a wind farm may generate negative impacts on particular sensitive receptors, the contribution of offshore wind farms to decarbonisation is not captured within the assessment system, and therefore the value of these developments in averting, or at least slowing, the climate crisis is not recognised and they are treated similarly to developments that may contribute to climate change. , Direct comparisons with other developments are problematic, as the nature of the developments and the impact pathways differ.

[41] Although it is relevant to note that numbers of onshore turbines in many European countries are higher than in the UK.
[42] Understanding the impacts of climate change on seabirds | BTO - British Trust for Ornithology
[43] Understanding that the majority of bird strikes occur during take-off and landing.

However, it is clear that there is an increasing quantity of ecological research conducted relating to offshore wind, with an ever-increasing list of research gaps (captured by the OWEER and ScotMER). The number of assessment tools also increases with each EIA as do the list of potential issues requiring consideration. The number of institutions undertaking work in this area, and the speed at which work is undertaken now means there is a need for a knowledge hub, the OWEKH. It is undeniable that offshore wind has funded a multitude of marine datasets, a number of which have resulted in the designation of sites (e.g. the Red-throated diver SPAs in the Greater Wash, Outer Thames Estuary and Liverpool Bay, Shell Flat and Lune Deep SAC, and the Irish Sea Front SPA). It is clear that the offshore wind industry is funding a large body of marine survey work that is filling gaps in our understanding of marine ecology in UK waters.

3.3.4 Conclusion

Key points from the discussion are summarised within Box 3.

Decarbonisation of the economy is the only means of reducing the impacts of climate change. The UK has reduced its Carbon dioxide (CO2) emissions by 40% since 1990. Although this statistic may be contested, the reason for this drop is due to the reduction in emissions from coal-fired electricity production replaced with generation from low carbon sources. Collectively the UK's wind farms provided 24% of the UK's electricity supply in 2020. Of this 24%, offshore wind supplied 13% (2,652 turbines at 43 farms) and onshore wind 11% (8,827 turbines at 2,604 farms)[40]. Thus, offshore wind provides the main source of renewable energy in the UK.

Current issues with the assessment system relate back to uncertainty around quantification of impacts and therefore the scale of compensation required. The standard approach to work around these issues is through the default application of the precautionary principle. Although the precautionary principle is generally viewed to be effective in preventing harm to the environment, its limitations are acknowledged. For example, it has been criticized on the basis that it can impose excessive burdens on development and inconsistency in its application is also a recognized problem[44],[45].

However, guidance around use of the precautionary principle could be more flexible, potentially incorporating an analysis of pros and cons of action versus inaction, and a discussion of trade-offs. SNCBs could advise such approaches within guidance documents as much decision making is based on guidance. A precedent for this type of more flexible decision making is proposed in the UK government's position statement relating to unexploded ordnance, in which a risk-based approach considering the environment, safety and economic implications is provided[46].

Climate change impacts are likely to be orders of magnitude larger than the impacts of offshore wind. Whilst it is not clear whether the offshore wind farms installed to date have had population level impacts, population level impacts have certainly occurred due to sandeel failures, marine heatwaves and avian influenza. Therefore, the additional wind farm effect needs to be taken into context with larger scale climate change impacts to ensure that responsibility and therefore compensation requirements are apportioned to the offshore wind industry in a proportionate and achievable manner.

Although the scale and severity of climate change impacts strongly shows that offshore wind development should not be constrained, there is nonetheless a duty of care to understand the impacts of large-scale offshore wind farm development on ecosystems and to inform development plans using best practice guidelines. As a fundamental starting point, understanding how ecosystems may change

[44] The precautionary principle: Definitions, applications and governance | Think Tank | European Parliament (europa.eu)
[45] still-one-earth-precautionary-principle.pdf (iisd.org)
[46] However, it is fully acknowledged that the differences between these issues are very significant.

with climate change and large-scale wind farm developments together in future years is a major research priority. This understanding is also required in order to implement compensatory measures that may be successful in strengthening ecosystems.

Furthermore, if relevant agreed procedures are developed and agreed to avoid developing in high-risk areas (see section 3.4), then increased flexibility around decision making could be considered in areas of lower ecological value to accelerate development through deployment of more flexible guidelines. This could be progressed using best practice planning tools (such as being promised by PELAgIO) to ensure that trade-offs are understood and accepted at project outset to accelerate planning processes.

At this stage of climate breakdown, and excessive use of the precautionary principle is potentially damaging, particularly in relation to consenting delay. The precautionary principle is embedded in national and international legislation, and is applied if evidence is conflicting, complicated, uncertain or inconclusive. Marine ecosystems are extremely challenging to study being dynamic, constantly changing, and poorly understood, and therefore residual uncertainty is highly likely even after decades of research (as experience has demonstrated). Therefore, more flexible approaches should be considered, using monitoring and adaptive management as a path through consenting (see Section 3.1). Stakeholder engagement and transparency will always be central to resolving conflict between offshore wind farm development and biodiversity. Therefore, increasing flexibility within the assessment process also goes hand in hand with developing best practice guidelines for the avoidance of high-risk areas.

Box 3: Consideration of Climate Change impacts within Assessment

Although other industries and countries were considered, there was no specific learning that could be identified and transferred. However, the key issues are summarised as follows:

- Climate change means that future outcomes for most marine species are highly uncertain, and this is not captured within the current assessment system.
- The assessment system assumes that without development, a population will remain in its current state, but many protected species are declining due to climate change with decarbonisation being the primary mitigation required to halt this trend.
- Although this circular relationship has been much discussed, there is no recognition of it within the current assessment system.
- Even acknowledging that offshore wind farms may have significant environmental impacts, the negative impacts of climate change on all ecosystems is a greater threat.
- The decarbonisation benefits of offshore wind farms to marine ecosystems needs to be incorporated within assessment alongside the impacts.
- The assessment system could be adapted to consider trade-offs between biodiversity impacts and climate change impacts to allow for more rapid and flexible decision making.

3.4 Avoiding development in areas of high ecological value

Sites of high ecological value may be leased for offshore wind farm development leading to delay, expense and even project failure. In some cases, poor baseline understanding is responsible with the presence of sensitive receptors only revealed during baseline data acquisition by the project developer. In others, ecology is understood and considered (albeit as a soft constraint), and decisions are made to lease the sites that are most feasible, even though these may be in ecologically important areas.

3.4.1 Introduction

The need to avoid areas of high ecological value for wind farm development was an issue raised and discussed both by the internal review and during the workshop. Developing in ecologically sensitive areas involves significant additional expense, delay and even project failure.

Lack of baseline understanding regarding use of potential development areas by sensitive receptors is one reason why high-risk areas may be selected, with the presence of sensitive receptors revealed during baseline data acquisition undertaken by the developer. Example of projects affected by this type of issue include Shell Flats, where surveys revealed the site as a key foraging area for large numbers of Common Scoter *Melanitta nigra*. The development was abandoned due to issues with radar, although the RSPB also objected to the proposed wind farm.

The advent of DAS revealed high densities of overwintering Red-throated Divers *Gavia stellata* in several locations around the UK, including the Greater Wash, The Outer Thames Estuary and Liverpool Bay. This proved highly problematic at London Array, which was consented as a phased build. However, only the first phase was completed due to issues with displacement of Red-throated Diver.

Within the Greater Wash Round 2 strategic development area, it was initially assumed that Sandwich Tern *Thalasseus sandvicensis* foraged only inshore. However, surveys demonstrated that this species was capable of foraging across the whole Greater Wash area. Consent for Docking Shoal (in the Greater Wash) was refused following a three-year decision-making process due to the predicted impact of the project on Sandwich Tern populations (Broadbent & Nixon, 2019). Therefore, it is clear that attempting to develop within ecologically sensitive areas may have serious repercussions.

3.4.2 Use of data and evidence in site selection

Offshore wind development rounds have typically been informed by Strategic Environmental Assessments (SEAs), although initially environmental limitations were not raised. For example, the 2009 Offshore Energy SEA concluded that '*at a strategic level there were no overriding environmental considerations to prevent achievement of deployment of 33 GW of offshore wind*' (DECC, 2009). However, the selection of high-risk areas for development has without doubt led to considerable difficulties, and over time the site selection process has evolved to consider a range of aspects.

Other countries include consideration of ecosystems within marine spatial planning (MSP). For example, this has happened in Germany, although there are still concerns that the system has not worked well, and there is still no solution as to how to resolve conflict between biodiversity preservation and large-scale offshore wind development (Saloman, 2023). In Germany, the conflict between biodiversity and offshore wind has constrained development, and since they are now falling behind with renewable energy targets, Germany has recently issued a new area development plan to address this. However, conflict over biodiversity is of concern. For example, the Nature and Biodiversity Conservation Union (NABU) have filed several lawsuits against the construction and operation of the Butendiek Offshore Wind Farm on the basis that Red and Black-throated Divers have lost at least 265 km^2 of designated protected area. Although the Federal Administrative Court ruled out temporary shutdown[47], the conflict continues both in Germany and in the UK, where the highly sensitive Red-throated Diver also overwinter in numbers, and where recently it was ruled that the construction of London Array Offshore Wind Farm had resulted in adverse impacts on the condition of the Outer Thames Estuary SPA protected for this species.

Other European countries have rejected offshore wind farm developments when surveys indicate ecological sensitivities. For example, the Swedish government rejected Vattenfall's bid to develop Stora Middelgrund offshore wind farm based on ecological grounds (as well as impacts on shipping). However, it is clear that not building offshore wind is not a viable option if renewable energy targets are to be met. In summary, whilst European approaches have been successful in identifying issues early, there are no easy routes to resolution, although it is notable that the Dutch Government intends to develop Hollandse Kust West VI in harmony with nature, with minimal impact on birds, bats and marine mammals, and with a thriving underwater world. The aim is to enable offshore wind farms to have a net positive impact in the near future. This is a key condition for eventually achieving the ambition of 70 GW of offshore wind energy by 2050 without exceeding the ecological limits of the North Sea.

Other countries, such as the US, are looking at how harvesting the wind is likely to affect upwellings and drive overall regional change prior to development (Raghukumar *et al.*, 2023). This approach is not yet underway in the UK, although it is hoped that the planning tools under development within the PELAgIO project may enable these factors to be incorporated within planning systems.

This case study considers the process used by The Crown Estate to select sites for the Celtic Sea Offshore Wind Leasing Round 5 from wider Areas of Search (AOS) [48], and compares this with the leasing process conducted under the Scottish Sectoral Marine Plan (SMP).

The Celtic Sea R5 Offshore Wind Leasing Round 5

The site selection process was based on the following steps, and is illustrated in Figure 3:

1. Key Resource Areas were identified based on water depth, metocean conditions and geology.
2. An Exclusion Model was then applied to remove areas which could not be developed. Areas removed included:
    a. Hard constraints - *existing infrastructure, safety (shipping, oil and gas safety zones) and existing rights to the seabed.*
    b. Soft constraints – t*hese were incorporated using a Restrictions Model containing various spatial criteria which are structured and weighted in terms of the risk that development may present on the represented activity or sensitivity. This category includes data on environmental designations, navigation, fisheries and visibility from landscape designations.*
3. Soft constraints are weighted by Tier. Tier 1 represents the highest-level themes (Economic, Social, Environment), Tier 2 represents sub-themes that accommodate the large number of criteria that fall within each theme, and Tier 3 includes a wide range of other restrictions.

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[47] https://www.4coffshore.com/windfarms/germany/butendiek-germany-de08.html
[48] 2022-floating-wind-site-selection-methodology-report.pdf (thecrownestate.co.uk)

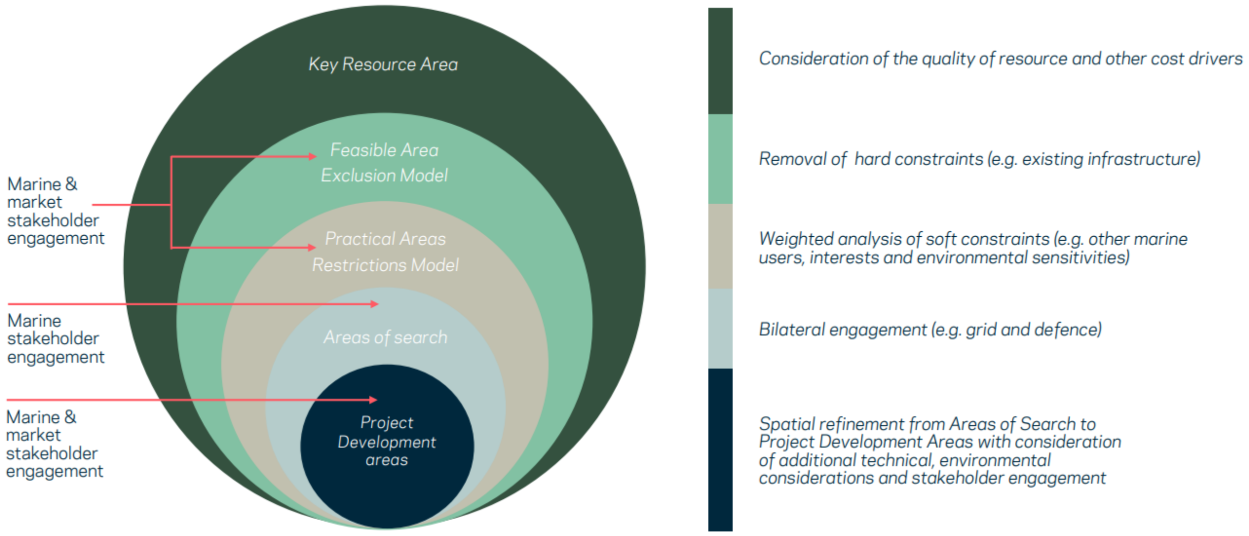

Figure 3: High-level stages of spatial assessment showing decreasing spatial footprint at each stage. Reproduced in full from: 2022-floating-wind-site-selection-methodology-report.pdf (thecrownestate.co.uk)

Although this system appears to incorporate environmental designations, analysis at this stage is based on geographic overlap of protected areas with the development footprint (and buffers) and does not incorporate an assessment of mobile receptors, although arguably it could do.

A mobile species sub-theme was discussed at a marine stakeholder workshop during the site selection process. However, there was concern about weighting individual species above, or below one another and confidence about effectively modelling their spatial distribution was considered low. There are, however, many sources of information on the abundance and spatial distribution of mobile receptors within UK offshore waters that could be used to inform such an approach. For marine mammals these include SCANS surveys[49] and for birds it is possible to plot mean maximum foraging ranges using the data from Woodward *et al.* (2019) and there are other datasets such as Waggitt *et al.* (2019), and Evans and Waggitt (2023).

The sub-theme was removed from the tiered hierarchy, and instead it was suggested that mobile species should be considered through plan-level (HRA). Therefore, by the point that a plan level HRA is conducted, the path forwards in terms of dealing with effects may only be achieved through derogation and compensation and not through adjustment to site design. This may not be appropriate: for example, the Celtic Sea supports >50% of the global population of Manx Shearwater, so generating enough compensation may be difficult to achieve in practical terms. Appreciating the issues with compensation, it is beneficial to consider whether sites could be more actively designed to minimize impacts from the

[49] See: Microsoft Word - SCANS-III design-based estimates 2021-05-26 (tiho-hannover.de)

start of the leasing process so that they are designed to support features such as flight corridors for birds, and that size and orientation considers the location of key colonies (to reduce barrier effects). Whilst this type of mitigation typically falls within the remit of the developer, a lack of uptake of these measures so far in the UK suggests that some of these decisions could be more effectively taken at a regional scale earlier in the process of site selection.

Leasing under the Scottish Sectoral Marine Plan (SMP) process

It is worth noting the slight differences in the current leasing process between Scotland and the rest of the UK. The Time Charter Equivalent model used in England and Wales calculates a relative constraint scope based on multiple soft constraints, such that the importance of individual constraints can be lost. By contrast the approach used in Scotland to identify potential development areas, retains the granularity of individual constraints (such as seabirds) to better inform decision making.

Particularly relevant to the avoidance of high-risk areas is the timing of the plan level HRA and how this in turn, may inform offshore wind developers. Under the Scottish SMP process, marine planning activities have, for the most part, been carried out before the leasing round opens. The areas identified for offshore wind development have been refined following plan-level HRA and public consultation (e.g. SMP for OWEC, 2020[50]). This approach has been welcomed by stakeholders for the greater certainty it offers developers. Thus, developers can select/bid for areas being put forward during a ScotWind leasing round with the knowledge that consideration has already been given to environmental issues. This approach is perceived to direct developers to where potential wind farms are *feasible*, rather than just possible.

Conversely, carrying out the plan level HRA after the bidding process places a greater risk on the developer. If an adverse effect on the integrity of the site is identified within a lease area, the developer will potentially have to demonstrate how strategic compensation will be delivered to offset the effect. It may also be necessary to have these compensation measures in place before consent can be granted, potentially adding time to the overall consenting process.

Within the current R5 Celtic Sea leasing area, the plan level HRA is being conducted alongside the tender process, and developers will be able to account for the outcomes of the HRA in their bidding strategies, thus adjusting what they are prepared to pay for a lease, considering the outputs of the HRA[51].

3.4.3 Examples from other industries and other countries

Although other industries such as aggregates, shipping, and oil and gas extraction also have environmental impacts, they differ from the impacts of offshore wind. For example, aggregates extraction takes place over a limited time window and limited area. Seismic exploration for oil and gas does have similar impacts to the geophysics surveys conducted in advance of offshore wind farm development and is dealt with in a similar manner using the JNCC Marine Mammal Mitigation (JNCC, 2017). However, in general EIA's for oil and gas are far less extensive and survey requirements are much reduced relative to offshore wind, with the focus being on impacts on fish and benthos. Impact pathways for birds relate to oil spills only, and no dedicated bird survey work is required. Since offshore wind farms have a relatively large development footprint, extensive surveys are required to characterize the environment. Surveys for birds are particularly robust, with two years of monthly data collection required. During this data acquisition, it is inevitable that regional or national thresholds for particular

[50] Sectoral Marine Plan for Offshore Wind Energy (www.gov.scot)
[51] Round 5 latest update | The Crown Estate

species will be exceeded, and now, following 20 years of development, cumulative impacts on pelagic species that occur at multiple sites are very hard to avoid.

Whilst a crude measure, the EIA for Rosebank numbers 401 pages and three Appendices, offshore wind farm EIAs typically number thousands of pages, and usually >70 technical appendices covering a wide range of topic areas, but many relating to sensitive receptors such as birds and marine mammals. For example, the recent Berwick Bank EIA when printed numbered 13,000 A4 pages (19 folders of information). Whilst the nature of the impacts associated with offshore wind and oil and gas differ significantly, the need for proportionate EIA has been identified as one of P2G’s barriers to consent.

3.4.4 Conclusions

Key points from the discussion are summarised within Box 4.

Mobile receptors do not fit well into standard MSP approaches because they may use a range of offshore areas other than those where they are protected, and avoiding a protected area and buffer zone may not be an adequate approach. However, protecting larger areas, such as the Red-throated Diver SPAs, is also problematic as activities must be regulated across a wide area, inside of which development will be restricted. Improved baseline understanding is needed within regions where development is planned to ensure that development is not located in areas that are well used by protected species and to ensure that decisions are based on evidence rather than assuming a lack of use. This could be rectified by conducting surveys prior to site selection.

Lack of baseline understanding is particularly relevant for marine mammals as, apart from seals, tagging is extremely challenging. Therefore, in areas where marine mammals are more abundant, survey work in advance of site selection would be a sensible method for de-risking potential development areas, particularly when baseline understanding of an area or species is known to be weak or lacking.

The nature of the data and evidence used to make site selection decisions will be improved once the outputs from the POSEIDON project are available. POSEIDON aims to provide mapping and modelling outputs including updated spatial models for key species and habitats that are most vulnerable to offshore wind impact. It will also provide environmental risk and opportunity maps to help guide future offshore wind development and feed into wider marine planning. Although these outputs will be available in future years, the project is currently in the data gathering phase. The OneBenthic tool will support the benthic outputs from POSEIDON, is already open access and available for use: OneBenthic Baseline Tool (cefas.co.uk). Similarly, data relating to previous work in a specific geographic area is available from Marine Environmental Data and Information Network (MEDIN).

The PELAgIO project will support the development of evidence-based policy and marine management through interdisciplinary research that explores the consequences of offshore wind development on marine environments, marine wildlife, and wider ecosystem structures. By observing and modelling over a large range of physical and biological scales, using a combination of autonomous platforms and ocean robots, research vessels and satellite observations, PELAgIO will build an ecosystem-level understanding of projected changes. Relevant to planning, it will also produce tools to assess trade-offs to inform policy and minimise negative impacts on marine life whilst tackling climate change. The project is also underway, and therefore outputs are not yet available. When available these planning tools could be incorporated into SEAs.

In the meantime, there are spatial datasets that can be used. Tagging data for seabirds is available to view on the Seabird Tracking Database[52]. The Seabird Mapping and Sensitivity Tool (SeaMAST) outputs could also be used in policy to set out 'no go' areas of high ecological value where development should not take place, and conversely areas of lower value where it can (although understanding that even these areas are likely to have some issues in cumulative impact assessment)[53]. Although the SeaMAST outputs need updating in view of new foraging range evidence, nonetheless use of an imperfect dataset, with outputs sense-checked may still help in avoidance of high-risk areas until mapping outputs from POSEIDON become available. There could also be agreed zones where wind farms can be developed but with specific monitoring/mitigation measures. These zoning shapefiles (once tested using existing sites and data to establish whether the classification system works) could then be incorporated into the Site Selection process described above within Soft Criteria – Tier 1. This would be achievable for seabirds, and it is also suggested that marine mammals could be addressed in a similar way using outputs such as Waggitt *et al.* (2019) and Russell *et al.* (2017).

[52] Home - Seabird Tracking Database

[53] Data layers from this work are available to use on Natural England's Magic Map Application . These relate to combined collision and displacement impacts for breeding SPA species.

Box 4: Avoiding development in areas of high ecological value.

Although other industries and countries were considered, there was little specific learning that could easily be identified and transferred. However, the key issues are summarised as follows:

- Sites of high ecological value may be leased for offshore wind farm development leading to delay, expense and even project failure.
- In some cases, poor baseline understanding is responsible with the presence of sensitive receptors only revealed during baseline data acquisition undertaken by the project developer. Surveys at a regional level prior to site selection could be conducted to ensure that high value areas are avoided.
- In some cases, ecology is understood and considered (albeit as a soft constraint), and decisions are made to lease the sites that are most feasible, even though these may be in ecologically important areas. However, ecological issues need to be weighted higher in the site selection system, as the difficulties, cost and delay associated with compensation is a serious constraint.
- Going through a longer site selection process involving a plan-level HRA and public consultation (as undertaken in Scotland) may improve chances of success by ensuring that sites are feasible, rather than just possible.
- It is anticipated that outputs from POSEISON and PELAgIO projects will improve planning processes although they are not yet available.

3.5 Ornithological Monitoring

Currently, ornithological monitoring employs differing methodological approaches between contractors, while results are not fully published or shared. This reduces adaptive learning and constrains progress and future development of the industry.

3.5.1 Introduction

Making better use of standard monitoring data in a coordinated way could considerably improve understanding around key issues. Poor monitoring design is a primary reason why understanding of collision rates and the details of displacement offshore are still limited.

Currently, in the UK, standard ornithological monitoring is based on transect surveys carried out before, during and after construction. These are now undertaken by aircraft taking digital aerial footage (either video or stills). Once the camera footage has been collected, birds and marine mammals[54] are identified at a later stage by technical specialists[55] There are differences in approaches between contractors relating to the use of video footage versus still photos, relating to the calculation of density (which one contractor calculates by transect and another calculates through multiple sampling stations), and there are also differences in camera specification, and how the lenses are orientated. There are further differences in the criteria used to make positive identifications of particular species leading to differing identification rates. To use data gathered by different contractors together, then the data needs to go through an alignment process (which can only be carried out by one of the contractors). To further complicate issues, historic data was gathered from boats, and the densities from these surveys are not directly comparable with DAS. Therefore, whilst numbers and densities of birds are published within the relevant EIA chapters for sites, differences in methodology remain problematic and in general constrain data sharing, opportunities for pooled analyses and general learning[56].

Although standard monitoring using DAS is a requirement, in some cases developers fund additional ornithological work, such as seabird tagging, to answer questions around the relative value and usage of potential wind farm sites by key receptors.

This case study looks at different monitoring approaches and monitoring programmes both from the UK and Europe and evaluates their effectiveness, how they have been designed, and how they have contributed to adaptive learning and whether they offer key principles that could be adopted.

[54] Although this case study is focussed on birds, the same dataset is used for marine mammal EIA chapters, although in some cases developers may also employ passive acoustic monitoring.
[55] Although at some point in the future this may be done using AI.
[56] Whilst data is now provided on MEDIN, which represents a significant improvement, there is often a time lag in this occurring.

3.5.2 Use of data and evidence to inform Ornithological Monitoring

Vanerman and Stienen (2019) state that '*when aiming to monitor overall seabird responses to offshore wind farms, there is not one method undeniably better than the other…In the end, the chosen method is likely to be a compromise between the study goals and the budget and logistics available to meet those goals*'. As a principle, there is no perfect technology and use of multiple techniques is favoured as a way of reducing risk and improving understanding, although this increases cost.

Typically, ornithological monitoring programmes for offshore wind consist of transect surveys, originally conducted by boat, but now conducted by aircraft using DAS techniques. Two years of monthly surveys are typically required to establish baseline usage of an area, with surveys continuing during and post construction. Although in the UK surveys are now conducted using DAS as sites have become larger and are located further offshore, although in other countries (e.g. Ireland, Norway, Belgium) boats are still used.

There are limitations associated with both boat-based surveys and DAS, both of which are based fundamentally on transect surveys conducted once a month. For example, large gulls and Fulmar are typically attracted to vessels, whilst species such as divers avoid them. DAS is typically flown over a brief time window around the middle of the day (to reduce glare which affects imagery) and therefore sampling is undertaken over a brief time window when birds are less active (with most species exhibiting most activity around dawn and dusk). The brief nature of DAS surveys (a few hours) means that opportunities for detection of birds may be limited, and therefore densities derived from DAS are much lower than from boat-based surveys (acknowledging that the attraction of some species to boats also affects this).

However, DAS provides a means of surveying large areas offshore which would be challenging on a boat. Although it was difficult to identify many birds to species level from DAS during earlier surveys, improvements in camera technology have largely resolved this issue, although there are still difficulties in identification of smaller birds, such as terns, to species level. There are also concerns around detection of small dark species such as Storm Petrel which may at times be difficult to see against a dark sea.

In some cases, a control area is monitored, enabling a Before After Control Impact (BACI)[57] analysis to be undertaken. However, as some studies have shown rather large displacement effects on Red-throated Diver, a BACI approach may be hampered by the difficulty of finding a reference area that is similar in depth, seabed conditions, tidal flow patterns, prey density, distance to a colony etc to the impact area (Webb & Nehls, 2019).

An alternative to BACI is the Before-after Gradient (BAG) design in which the wind farm is located in the middle of a much larger survey area. In this approach, any differences between pre- and post-construction are assumed to be a function of distance from the wind farm, and that effects would be roughly the same in all directions (Vaneman & Stienen, 2019). A significant before-after change that declines with distance from the wind farm provides compelling evidence that the wind farm is the cause of any change (Webb & Nehls, 2019).

Although these methods were introduced 20 years ago to ensure that data collection was standardised, and so that data could be compared easily between sites (see Camphuysen *et al.,* 2004)[58], one key problem is that they do not provide a means of measuring bird collisions. Although it may have originally been anticipated that collisions would be observed whilst surveys were underway, this has not

[57] Before After Control Analysis
[58] tethys.pnnl.gov/sites/default/files/publications/Camphuysen-et-al-2004-COWRIE.pdf

been the case and to date there are no reported bird collisions from any post-construction transect-based monitoring.

This issue was not addressed during monitoring reviews (see MMO, 2014). Whilst the issue was recognised, the suggested solution was the Offshore Renewables Joint Industry Programme (ORJIP) study (at that point in early planning stages). However, more work is needed: the ORJIP study only recorded radar data over a small area of the site (see Skov *et al.,* 2018), and the more recent Aberdeen Bay Bird Collision Avoidance Study also only recorded data from two turbines over two years during the daytime only (see Tjørnløv *et al*., 2023). Even a small number of collisions (as observed at Thanet) would be of concern in relation to Kittiwake populations, when scaled up to account for the numbers of turbines in UK waters. Since collision and displacement are co-dependent, with one directly related to the other, it is considered possible that collision rates (like displacement) may be site and season specific

Other reviews have recommended that post-construction monitoring could involve the use of five multisensor systems to monitor collision, one at each corner of the site and one in the middle (see Molis *et al.,* 2019). Although expensive, this could be progressed at selected sites where collision impacts are predicted to be significant resulting in the need for costly compensation, with the results of the monitoring used to adjust compensatory requirements[59]. This type of monitoring and adaptive management approach to the delivery of compensation is carried out in other countries (see New *et al*., (2015) for an example of this from an onshore wind site in the US.

Although standard monitoring has demonstrated that many species are displaced from offshore wind farms (see Dierschke *et al.,* 2016), unfortunately displacement distances can vary between sites. In general, displacement during the non-breeding season is greater, presumably because birds are not tied to a nest and are free to exploit other areas. However, there may be other factors which influence displacement, for example, displacement may relate not to visual effects but to ecosystem change, and changes in the location of upwellings and therefore prey distributions. Transect-based survey data does not allow us to properly investigate the mechanisms behind displacement, but improved understanding of the influential factors and accounting for these within the predictions made in EIA would help improve the quality of assessments. This knowledge would be of fundamental help in selecting sites that may be developed with the least impact on birds.

Transect surveys were originally instated 20 years ago as a means of monitoring the impacts of offshore wind farms. At that time there was very little data on how seabirds used offshore areas. However, since then the understanding of how seabirds forage at sea has been transformed through tagging studies, and there is now a large volume of data available. Instead, answers are lacking to other questions: a more precise quantification of collision is needed to understand the mechanisms that drive and influence displacement, and to be able to quantify population level consequences. Further pooled analysis of data is needed to establish which factors influence displacement, and why displacement can be so variable between sites. A complete lack of data on habituation of birds to offshore wind farm sites, is another data gap that urgently needs filling. Further data on the different prey items taken by different species at different seabird colonies would also be of great help in designing compensation and protecting EFH for key forage fish.

Since transect-based surveys, whether carried out by boat or by aircraft, are expensive, capacity to fund additional research at a developer level beyond standard monitoring is limited, even though this research may be of benefit to the industry. Furthermore, potentially promising ornithological mitigation options, such as painted turbine blades, remain unstudied and untested in the offshore environment.

A more strategic approach to answering key questions needs to be adopted, but to do so it may be necessary to reduce some of the transect-based survey work and direct funding towards some of these key data gaps[60]. Ornithological work could be funded collectively by developers in a particular region, with some sites continuing with transect surveys and others conducting collision monitoring or addressing other research gaps. At a P2G workshop on Strategic Monitoring held 4 May 2023, a system based on the Regional Advisory Group (RAG) was voted by stakeholders as being a popular way of implementing strategic monitoring within a UK context (HMC, 2023). The RAG system has been successfully used in Scotland to ensure that appropriate and effective monitoring of the impacts of the developments are undertaken to satisfy the requirements of the section 36 consent and marine licence conditions. The RAG also encourages collaboration between developers working in a particular region to ensure monitoring programmes provide more strategic outputs and are aligned with relevant areas identified through ScotMER. Prior to establishing the Forth and Tay Regional Advisory Group (FTRAG) a regional developer group collectively funded research on seabirds (specifically tagging studies). This approach may provide a means of accelerating understanding around a range of other aspects, which otherwise would not be progressed.

Collaboratively funded strategic research[61] would also be of great value to progress ornithological data gaps, where there is currently no mechanism to investigate them. However, which evidence gaps are prioritised would need to be administered centrally to avoid undesirable duplication[62], potentially through the SNCBs and through the OWEKH (with decisions made with reference to the OWEER).

3.5.3 Examples from other industries or countries, and non-standard monitoring conducted in the UK

As discussed in Section 3.2.4, other offshore industries are not required to carry out the same level of bird monitoring as offshore wind, so onshore wind is the only other industry with similar issues with which offshore wind can be easily compared. However, many of the issues identified for offshore wind also apply onshore. The number of onshore developments has been limited in the UK, due to restrictive planning laws and therefore offshore wind is ahead in relation to ornithological studies[63].

Other countries have adopted different approaches to ornithological monitoring programmes. Additionally, some UK offshore wind farm sites have carried out bespoke monitoring when there has been a licensing requirement to do so. Examples which will be discussed in this section include:

- Scroby Sands (UK);
- Sheringham Shoal (UK).
- Alpha Ventus (Germany);
- Wozep (Holland);

A further section is included that summarises other monitoring options that are not included within the case studies.

Scroby Sands

Scroby Sands was one of the first offshore wind farms to be built in UK waters, with baseline monitoring undertaken in 2002 and 2003, construction monitoring in 2004 and operational monitoring in 2005 and 2006. The site is 2-5 km offshore of Great Yarmouth, 2 km from what was formerly the largest colony of

[60] Please see the **Critical Gaps Database** for more information on the ornithological data gaps that need filling.
[61] For example, funded by developers along with other parties such as The Crown Estate, ORJIP, UK Government etc,
[62] Understanding that some work may need to be trialled at several sites in order to understand site-specific differences.
[6363] Appreciating that there are also significant differences in both ornithological survey methods and issues.

Little Terns *sternula albifrons* in the UK. The AA concluded that the impacts of the offshore wind farm on Little Terns would be of moderate significance, but the decision was taken to carry out monitoring to validate the conclusions made in the AA. The project was awarded consent and developed on the basis that comprehensive monitoring would be undertaken to generate understanding to feed into future offshore wind farm assessments. The following work packages were developed by NE and Defra in consultation with the RSPB:

- **Prey studies** – spatial and temporal distribution of prey offshore;
- **Radio-tracking** - to gather data on the offshore spatial and temporal distribution of foraging birds offshore;
- **Breeding colony studies** – focussing on chick provisioning rates; and
- **Bird strike studies** – comprised of collision risk modelling after an understanding of the wind farm had been gained.

Although this monitoring programme was focussed on a single species, significant progress in understanding was achieved through these work packages both in relation to the ecology of Little Terns and in relation to the impacts of the wind farm:

- **Prey studies** revealed that Little Tern in this region depended on young-of-the-year larval herring *Clupea harengus,* with a reduction of prey in 2004 found to occur after pile driving which was undertaken during the winter, coincident with the herring spawning period (Perrow *et al*., 2011).
- **Radio-tracking** data showed that offshore foraging behaviour was heavily influenced by the abundance of prey offshore, with birds travelling further than previously understood and utilising the wind farm area (Perrow *et al*., 2006).
- **Breeding colony studies** confirmed that provisioning rates[64] varied depending on the abundance of prey offshore (ECON, 2006).
- **Bird strike studies.** Collision risk was calculated from the telemetry data using the Band model (ECON, 2006). It was concluded that assuming an avoidance rate of 99% the number of potential collisions would be relatively small (tens of individuals).

This work was undertaken before standard bird monitoring was introduced (Camphuysen *et al.,* 2004), and although this approach has not been repeated, this project posed and answered specific questions about a single species demonstrating that setting focussed research objectives and putting in place a series of work packages to address them ensures that the questions are more likely to be answered.

The holistic nature of the monitoring programme meant that data was gathered that encompassed both offshore and onshore monitoring, leading to both increased knowledge around the bird's ecology and a clearer understanding around potential wind farm impacts. This style of approach could usefully be adopted (and improved), at sites where there is likely to be an issue with a particular protected species. A more detailed species- and site-specific understanding could also be of value in developing appropriate compensatory measures.

Sheringham Shoal

Sheringham Shoal is another UK offshore wind farm where a consent condition to validate the predicted mortality of Sandwich Tern *Sterna sandvicensis* from collision modelling was applied. Visual tracking was used to follow birds transiting through the wind farm area. Monitoring was carried out before, during and after construction to investigate collision risk and avoidance behaviour. This work contributed to

[64] That is, the number and biomass of fish (and other prey) per hour delivered to the nest.

both an improved understanding of the ecology of Sandwich Tern (see Perrow *et al*., 2017) and of the impacts of the wind farm (Harwood *et al.,* 2018). Although no collisions were recorded, the study provided valuable insights into variations in avoidance behaviour, successfully monitoring this at macro, meso and micro scales.

It is of interest that at Sheringham Shoal, Sandwich Terns often cut off the corner of the site as it took a long time for birds to fly along the southern extent of the site (to fly round it). Had the site been long and thin instead of square it could have been a lot easier for the birds to navigate around. The consideration of size and orientation of the site relative to any coastal seabird colonies could be considered at the site selection of offshore wind farms to minimize potential displacement impacts.

Alpha Ventus

Alpha Ventus was the first offshore wind farm in Germany, and on this basis was accompanied by several research projects sponsored by the Federal Ministry for Environment (BMU), which extended across multiple disciplines with the research undertaken related to meteorological, ecological, geological and oceanographic questions. The work conducted under this monitoring programme is presented in full in BSH and BMU (2014). Alpha Ventus is unusual in that extensive studies were carried out across trophic levels and in-depth studies of benthic species, pelagic fish, seabirds, marine mammals (including static acoustic monitoring) and construction and operational noise were incorporated. Ornithological studies were varied and included:

- Joint evaluation of research data, data from monitoring programmes and EIA studies as a holistic approach to ecological effect monitoring in the *alpha ventus* test site.
- Test site research on bird migration in the areas of the *alpha ventus* test site.
- Evaluation of bird migration data recorded continuously at the FINO1 research platform (2008-2012).
- Assessment of collision risk of migratory birds using the VARS camera system.
- Monitoring if evasive movements of migratory birds using the Bird Scan Method (fixed pencil beam radar).
- Joint Evaluation of seabird data for ecological effect monitoring in the *alpha ventus* test site.
- Studies on possible habitat loss and behavioural changes in seabirds at the *alpha ventus* offshore test site.

This work was undertaken between 2008-2013, with the wind farm becoming operational in 2010. Although this case study relates to ornithology only, the variety of monitoring work undertaken across different receptors (and including oceanographic data[65]) is particularly notable. This type of monitoring could be considered (using updated techniques) to better understand not just ornithology but trophic linkages[66], particularly predator-prey relationships. Further study in this area is much needed and should also build on the output from the PrePARED project.[67] Although other similar work is now underway, the Alpha Ventus study was the first wind farm site where the impact of the development on Ekman dynamics and the locations of upwellings and downwellings was identified, and the potential effects of this on the marine environment were considered (see Broström *et al*., 2019).

Although fish monitoring programmes in the UK have been minimal, there is a clear need for ecosystem understanding and more comprehensive fish monitoring (Gill *et al.,* 2020). The number and type of fish surveys conducted at Alpha Ventus and the thoroughness of the analysis which even looks at details such as the stomach contents of mackerel (and other species) inside and outside of the wind farm is

[66] This type of approach has been recently adopted by the Dutch Wozep programme (see case study below).
[67] PrePARED – An offshore renewables science project (owecprepared.org)

notable. Recommendations to use static hydroacoustic monitoring as a (non-destructive) sampling technique to gather better data on pelagic fish is a worthwhile recommendation that would help improve understanding of how pelagic fish (and therefore their seabird predators) may respond to offshore wind farms[68][69]. For example, it is possible that small shoaling pelagic species may be deterred if offshore wind farms provide habitat for larger predatory fish such as cod.

The focus of Alpha Ventus on migratory species is due to its location on a known migration route, as a number of species are known to pass through the German Bight from breeding sites in Scandinavia to wintering sites within the southern Hemisphere. Although not specifically studied in the UK, there are cases in which UK sites may also benefit from undertaking this type of study -for example, the English Channel is part of this same important migratory route.

In summary, it is not just the ornithological work that is notable, but the range of ecological and environmental data collected appreciating that Alpha Ventus is only 12 turbines. Also notable was the effort made to advance novel techniques (radar, hydroacoustics) and to work collaboratively across disciplines as part of holistic approach to ecological monitoring.

Although there are many state-of-the art research organisations in the UK working collaboratively on interdisciplinary research, this is generally beyond what is delivered through standard monitoring, which is viewed separately. However, there is no reason why funding for monitoring cannot be similarly directed towards specific data gaps to accelerate understanding around key issues and species.

Wozep

Wozep is a long-term research programme initiated by the Dutch Government which is anticipated to extend until 2030. It aims to expand knowledge about how offshore wind farms affect protected species. There are three objectives for monitoring and research in Wozep:

- The reduction in levels of uncertainty relating to knowledge gaps and assumptions in the cumulative effect assessment, EIA, and AA.
- The reduction of levels of uncertainty about knowledge gaps and assumptions relating to the long-term impacts and upscaling of offshore wind farms.
- The determination of the effectiveness of mitigation measures.

In addition to species-based research, Wozep will look at the possible, more long-term, ecosystem impact of the development of large areas with offshore wind farms. The effects on physical and hydrodynamic processes are being studied, as is the possible effect on the lower trophic groups. From the outset, Wozep has focused on understanding cause-effect relations, assessing impacts, and efforts to formulate and to evaluate mitigation measures. The Dutch government is committed to developing offshore wind in Dutch waters with a net positive gain on the environment. The recently announced Hollandse Kust (west) VI wind farm (being developed by Ecowende) will have a focus on ecology and will entail work to investigate the efficacy of various nature-inclusive scour-protection designs and help carry out research into biogenic reefs[70]. It also involves the use of multiple techniques including tagging Great Black-backed Gulls in Norway, demonstrating a transboundary approach to birds that use the waters around multiple counties.

[69] Although appreciating that hydroacoustics, like any technique has strengths and weaknesses – so this would need looking at on a project specific basis.

In terms of ornithology, it is understood that work will focus on assessing the efficacy of different bird radar systems, long-range cameras and curtailment systems. The focus on migration is different to the UK, where impacts on migratory species are considered less of a concern, with the focus at assessment generally being on SPA breeding species. Migration typically occurs at night, with much of it at height (well above the height of wind farms).

However, Dutch research using avian radar showed that there was a regular peak of activity during the autumn period, where birds flew through a wind farm site, a reasonable proportion of which were at potential collision risk height (Leemans *et al.,* 2022). The results of this work were then used to design a method for detecting this mass migration movement in advance to inform temporary shut-down[71]. It is understood that high numbers of migratory birds may occur at sites where migration activity is concentrated, such as straits. It is not clear whether this type of work could be of value in the UK[72], although the issue is of migration now being considered more seriously and this type of work is worthy of further investigation[73]. Although curtailment devices that involve continuous stopping and starting of the turbine would be of concern to engineers due to additional wear, in this case shut down took roughly 24 hours, and would only need to happen once per year. If a developer was able to demonstrate that this type of mitigation would significantly reduce bird collisions at their site then there could be merit in adopting this type of measure, even as an alternative to compensation.

Other monitoring options

Centrica Irish Sea Zone: Water sampling for salinity and chlorophyll *a* was undertaken concurrently with boat-based bird surveys covering Centrica's Irish Sea zone. Correlation of salinity (a feature of tidal mixing fronts) and Manx Shearwater densities was in part responsible for the designation of the Irish Sea Front SPA[74]. Whilst SPA designation was not an intention of the work, this approach was no doubt effective in identifying ecologically significant areas. Although DAS does not provide the same opportunities for concurrent sampling, it is cheaper and more practical at large sites located further offshore. Nonetheless analysis of DAS data with environmental covariates from other datasets could be undertaken as standard practice. Alternatively boat-based surveys could be used to gather information on a range of receptors concurrently e.g. undertaking bird survey work, towing a hydrophone, benthic sampling, and water samples (for analysis of salinity, chlorophyll *a*, eDNA etc). Fish marks on the echosounder could also be recorded. A movement towards a more integrated ecosystem-based approach within the UK would help in addressing many of the data gaps within the OWEER, a number of which relate to trophic interactions. It would also move monitoring and research closer together allowing for greater synergies between the two and greater overall progress in relation to data gaps.

Bird observers. Whilst use of AI to identify birds from video footage may in time be accepted, with high resolution satellite imagery maybe even replacing DAS in years to come, there is at the same time a need to understand the fine resolution flight behaviour of birds in wind farms, which could equally be enhanced through the use of simpler monitoring methods. Typically, numerous vessels transit to and from wind farms before during and after construction. Floating hotels are installed during the construction process, and therefore opportunities to send out ornithologists on vessels chartered for other purposes should not be forgotten. Many aspects of ornithological monitoring and survey design have become increasingly complex as original methods have been criticised and now complex statistical power analysis is a necessary step in commissioning any sort of offshore survey work for birds. There is

[71] Netherlands Tests Offshore Wind Farm Shutdown to Protect Birds (maritime-executive.com)
[72] If successful and appropriate for the site, this type of mitigation could help in reducing collision risk and therefore the need for compensation.
[73] strategic-study-collision-risk-birds-migration-further-development-stochastic-collision-risk-modelling-tool-work-package-1-strategic-review-birds-migration-scottish-waters.pdf (www.gov.scot)
[74] Irish Sea Front SPA | JNCC - Adviser to Government on Nature Conservation

a great reliance on remote monitoring and technology whether it be GPS tags or multisensor systems. All of these increase project expense. However, it should not be forgotten that one of the easiest and most effective means of understanding birds and how they behave in offshore wind farms is to simply go and look[75].

Conclusion

The outputs of the case study are summarised in Box 5.

The term 'monitoring' refers to the systematic gathering and analysis of information. On this basis, monitoring should be targeted towards filling specific evidence gaps in a strategic manner, both in a regional and national context. However, aligning with industry standard methodologies can constrain progress, with current guidance offering a very prescriptive approach to ornithological monitoring (see Parker *et al.,* 2022a).

The Office for Environmental Regulation recently published a report reviewing EIA, SEA and HRA processes, in acknowledgement that these are often not operating as they should[76]. Root causes were identified relating to data accessibility, post-decision monitoring, evaluation, and reporting, all of which are relevant to this case study.

Ornithological monitoring is a substantial topic, and this review should certainly not be considered exhaustive. Rather, it is intended to prompt further discussion on this topic, providing data and evidence to support trialling different approaches to ornithological monitoring at offshore wind farm sites in the future.

[75] Leopold & Mardik (2018) provide a methodology that could be utilised/adapted for taking behavioural observations of birds within wind farms from a fixed platform.
[76] https://www.theoep.org.uk/report/environmental-assessments-are-not-effective-they-should-be-due-practical-barriers

Box 5: Ornithological monitoring

A range of ornithological monitoring programmes both within the UK and Europe were compared, and the following conclusions drawn:

- At the stakeholder workshop birds were voted the most problematic receptor with 202 evidence gaps in the OWEER relating to them. The case study makes recommendations for improving ornithological monitoring programmes.
- Standard DAS should be conducted using the same agreed methods so that pooled analyses of data can be easily undertaken.
- Ornithological monitoring should not be limited to standard DAS but should be more flexible so that resource can be directed towards addressing other evidence gaps. These could be tackled in a strategic manner, both in a regional and national context.
- Standard monitoring programmes provide limited temporal sampling of receptors that are highly mobile and variable in their distribution and may be of limited use in providing answers to specific questions. By contrast, tailored monitoring that is site and species specific and which sets focussed research objectives, drawing on multiple techniques, are likely to provide more definite answers.
- There is a need for a greater understanding of the effects of offshore wind farm on marine ecosystems, and how these may affect different receptors and the interactions between them. For seabirds, understanding prey is of central importance both in identifying key foraging areas and in safeguarding colonies through the protection of EFH, which could be progressed through strategic compensation.
- As a principle, there is no perfect technology and use of multiple techniques is favoured as a way of reducing risk and improving understanding, although this increases cost. Lower cost monitoring opportunities, such as adding observers to other survey vessels should not be forgotten, although it is acknowledged that the use of artificial intelligence may also provide cost saving solutions.
- Ornithological monitoring could usefully focus on areas which may help industry, such as monitoring 20 years on to look at habituation, radar studies to improve collision models, more focussed work on turbine spacing and displacement, and studies of potentially helpful mitigation measures such as painted turbine blades.
- Since ornithological monitoring is expensive, outputs should be regularly reviewed with findings disseminated to key stakeholders through the OWEKH.

4 Discussion

4.1 Part 1

Twenty years of research into the effects of offshore wind farms on marine ecosystems has yielded results that are positive and negative. It is notable that significant data gaps such as seabird collision and displacement are still unresolved, in spite of considerable resource and effort directed towards progressing understanding.

One of the widely held views within the research community is that there have not been enough studies to make categorical statements about benefits and disbenefits of offshore wind farms on specific receptors as impacts are also often site-specific. For example, Russell *et al.* (2014) shows that both Grey and Harbour seals forage around turbine bases. Although similar data is available from Alpha Ventus, two studies is not a sufficient basis on which to conclude that wind farm development will benefit seals Increased use of offshore wind farms by seals is likely due to increased prey abundance, and in different localities seals will focus on different prey species. Therefore, a similar study elsewhere may have a different outcome.

These types of concern present considerable challenges to being able to 'close' evidence gaps, and instead it is suggested that instead prioritisation should be the focus of bodies such as OWEKH, who would have a strategic overview on the work being undertaken. Research programmes typically identify other evidence gaps, therefore the more research that is carried out, the greater the number of gaps. Gaps are rarely fully closed out, although the priority assigned to them may vary over time as understanding progresses. However, a continual process of reviewing and reprioritising gaps and associated research is considered highly beneficial given the scale of offshore wind farm development planned.

There may also be very tangible benefits of offshore wind farm development that are currently not captured within the assessment system. Fisheries exclusion zones turn some sites into effective 'no-take' zones, which may have great value as refuge areas. Conversely in other sites there is known to have been an increase in fishing activity post-construction. For example, post-construction Sheringham Shoal appears to support a thriving lobster and crab fishery, although there has been no official monitoring undertaken. Whether wind farms result in a net increase in numbers of crustaceans, or simply affect their distribution is also unclear (Gill & Wilhelmsson, 2019).

The need for a better understanding of how marine ecosystems respond to offshore wind farm development at both a local and regional level are fully recognized by the research community, with various projects underway to further understanding[77]. However, it was of notable concern, particularly to the non-UK based researchers involved in the ABPmer's review process that ecosystem effects are not currently considered in assessment. It is argued that ecosystem effects should be considered, with the planning outputs from PELAgIO (when available) providing a means of enabling this to happen.

Concerns were also raised over the lack of critical gaps relating to marine mammals, as only one gap related to marine mammals was voted into the top 10 (baseline understanding). Mobile receptors do not fit well into standard MSP approaches, and the challenges for marine mammals, many of which often occur at low density, are particularly difficult[78]. Therefore, monitoring requirements for marine mammals have not been very stringent, appreciating that many developments have been built in areas of low value for marine mammals. However, it is considered likely that locating sites further offshore may involve a greater consideration of marine mammals and it is possible that the impacts of FLOW could differ significantly to those resulting from fixed-based sites.

However, in summary, this prioritisation exercise showed relatively high agreement over where the critical evidence gaps were. Although some gaps, such as EFH, may not relate directly to consenting, they relate to a wider appreciation of the need to better understand marine ecosystems to ensure that development can progress alongside nature conservation and biodiversity targets. This is part of a growing acceptance that a more holistic approach is needed to develop sites, with an increasingly in-depth understanding of the marine environment required to navigate pathways through consenting.

4.2 Part 2

The case study on **monitoring and adaptive management** demonstrates that complex consenting scenarios can be successfully navigated if developers are prepared to engage with this approach. Although this may seem a risky strategy, it has enabled other large scale marine projects to obtain

[77] Examples include PELAgIO, PrePARED, EcoWIND ACCELERATE, SHEAR
[78] With the exception of pinnipeds, which haul out and can therefore be counted, and also tagged.

consent, even when there was significant uncertainty over impacts. Whilst high profile cases such as London Array will be of concern to developers, it is hoped that this case study provides reassurance that there are also many more projects that have achieved successful outcomes through this route.

Use of **monitoring and adaptive management** in the delivery of **compensation of ports** has also been standard practice. Although there is transferrable learning from the ports sector of relevance to offshore wind, it is also of concern that there are some fundamental flaws in how compensation is being progressed in relation to offshore wind. Since **compensation** is undoubtedly a complex and expensive problem, there is a need to ensure that future offshore wind farm sites **are not located in areas of high ecological value**. Whilst site selection is a highly complex process, it is argued that the delay and cost involved with dealing with ecological issues does justify increased consideration at an early stage[79],

However, even though some impacts can be minimized through avoidance there remains an urgent need to rapidly install large scale offshore wind farms to decarbonise the UK economy. Therefore, **there needs to be a mechanism to account for the larger impacts of climate change on seabird and marine ecosystems** within the assessment system to allow consenting to continue. Although offshore wind should still compensate and be accountable for its impacts, planning delay is in itself damaging. Use of the precautionary principle within a marine context is inherently problematic: marine ecosystems are extremely challenging to study being dynamic, constantly changing, and poorly understood, and therefore residual uncertainty is highly likely even after decades of research (as experience has demonstrated). Conversely, there is a high degree of certainty in relation to the impacts of climate change on all species. Therefore, it is suggested that the assessment system could consider trade-offs of these factors within the assessment process.

5 Conclusion

The review of the OWEER and workshop indicated that there was a relatively high level of consensus around the most critical gaps, which are identified in Section 2.2.2. Information on each gap is presented within the **Critical Gaps Database**.

However, there was little prospect of closing any of these gaps in the short term due to the quantity of work needed, the time and cost it required to achieve this work, and the general scale and complexity of the issues involved (see Table 2). A few opportunities for pooled analysis of data were identified (see Section 2.5), although in general there is a need for much more targeted research around the critical gaps identified (see Appendix D and the **Critical Gaps Database**.).

The case studies demonstrate key areas around which progress could focus, with key outputs summarised in **Boxes 1-5.**

The following more general points are also drawn in conclusion:

- The environmental impacts of offshore wind farms across receptors are well documented, with publications such as the *Wind Farms and Wildlife* series providing comprehensive expert summaries of key topics in relation to impacts, monitoring and mitigation.
- Large-scale offshore wind farms may have positive and negative impacts on specific receptors and even ecosystems. The exclusion of ecosystem effects from the assessment system is untenable in view of the large volume of research being conducted within this area. It is

[79] Acknowledging that avoidance of ecological issues is the first step of the mitigation hierarchy.

suggested that the outputs from PELAgIO should be used to start to integrate ecosystem considerations into both planning and assessment.

- However, use of the precautionary principle within a marine context is inherently problematic: marine ecosystems are extremely challenging to study being dynamic, constantly changing, and poorly understood, and therefore residual uncertainty is highly likely even after decades of research (as experience has demonstrated).
- Although offshore wind, like any other industry, should compensate for impacts on protected species, the time window to act on climate change to avert damage is decreasing rapidly. It is suggested that other mechanisms could be considered to acceptably accelerate consent of large-scale offshore wind farms in the UK. This could include investigation of:

    - Collaborative identification of ecological areas of low risk in which development could be accelerated through use of a more streamlined assessment system.
    - Protection of areas of high ecological value (which could be part of regional compensatory measures), balanced by accelerated development of lower value areas.
    - Large scale compensatory measures (e.g. closure/reduction of fisheries taking forage fish) to balance accelerated development.
    - Greater flexibility within the assessment system (e.g. consideration of trade-offs) so that climate change benefits associated with offshore wind can better recognized and accommodated.
    - Increased use of adaptive management as a tool to facilitate consent when there is uncertainty.
    - Trial and use of mitigation measures to reduce impacts.
    - Adoption of a market-based compensation system where the developer pays a government organisation to deliver compensation. Since the contribution would be financially derived, debate over use of resource would not need to constrain development timescales.

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7 Abbreviations/Acronyms

AA	Appropriate Assessment
ABP	Associated British Ports
AEOI	Adverse Effect on Site Integrity
AEOSI	Adverse Event of Specific Interest
AG	Advisory Group
AI	Artificial Intelligence
AOS	Areas of Search
APEM	Environmental Consultancy
BACI	Before After Control Impact
BAG	Before-after Gradient
BioSS	Biomathematics and Statistics Scotland
BMU	Federal Ministry for Environment
BSH	Bundesamt für Seeschiffahry und Hydrographie (German Federal Office for Maritime Navigation and Hydrography).
BTO	British Trust for Ornithology
CATT	Cetacean Acoustic Trend Tracking Project
CEFAS	Centre for Environment, fisheries and Aquaculture Science
CEH	Centre for Ecology and Hydrology
CFA	Cornwall FLOW Accelerator
CIEEM	Chartered Institute for Ecology and Environmental Management
CO2	Carbon dioxide
COMPASS	Collaborative Oceanography and Monitoring for Protected Areas and Species
COWSC	Collaboration on Offshore Wind Strategic Compensation
CS	Celtic Sea
CSP	Celtic Sea Power
DAS	Digital Aerial Survey
DC	Direct Current
DECC	Department of Energy and Climate Change
DEFRA	Department of Food and Rural Affairs
DESNZ	Department for Energy Security and Net Zero
DisNBS	Designing studies to assess consequences of displacement
ECOMASS	East Coast Marine Mammal Acoustic Study
ECON	Environmental Consultancy
ECO-WIND	Ecological Consequences of Offshore Wind
ECOWINGs	Ecosystem Change, Offshore, Wind, Net Gain and Seabird
EFH	Essential Fish Habitat
EIA	Environmental Impact Assessment
EMF	Electromagnetic fields
EMMP	Environmental Mitigation and Monitoring Plan
EMP	Environmental Management Plan
EOWDC	European Offshore Wind Deployment Centre
ES	Environmental Statement

ESG	Environmental Steering Group
FLOW	Floating Offshore Wind
FTRAG	Forth and Tay Regional Advisory Group
GIS	Geographic Information System
GPS	Global Positioning System
GW	Gigawatt
HMC	Howell Marine Consulting
HRA	Habitats Regulation Assessment
HVDC	High Voltage Direct Current
IPCC	Intergovernmental Plan on Climate Change
JNCC	Joint Nature Conservation Committee
MARCIS	Norwegian project looking at marine spatial planning and cumulative impacts of blue growth on seabirds
MEDIN	Marine Environmental Data and Information Network
MFED	Marine Fish Ecology Database
MMO	Marine Management Organisation
MOTUS	Motus automated radio telemetry network
MPA	Marine Protected Area
MSP	Marine Spatial Planning
MW	Megawatt
NABU	Nature and Biodiversity Conservation Union
nAEOI	No Adverse Effect on Site Integrity
NE	Natural England
NEST	Natural England Sensitivity Tool
NIRS	Near-Infrared Spectroscopy
NRW	Natural Resource Wales
oEMMP	Outline Environmental Mitigation and Monitoring Plan
ORJIP	Offshore Renewables Joint Industry Programme
OWEC	Offshore Wind Evidence and Change
OWEER	Offshore Wind Evidence and Change Register
OWEKH	Offshore Wind Evidence & Knowledge Hub
OWIC	Offshore Wind Industry Council
P2G	Pathways to Growth
PAM	Passive Acoustic Monitoring
PDE	Project Design Envelope
PELAgIO	Physics-to-Ecosystem Level Assessment of Impacts of Offshore Windfarms
PINS	Planning Inspectorate for England
POSEIDON	Planning Offshore Wind Strategic Environmental Impact Decisions
PrePARED	Predators and Prey around Renewable Energy Developments
RAG	Regional Advisory Group
RPS	Environmental Consultancy
RSPB	Royal Society for the Protection of Birds
RWE	Rheinisch-Westfälisches Elektrizitätswerk
SAC	Special Area of Conservation
SCANS	Small Cetaceans in European Atlantic waters and the North Sea

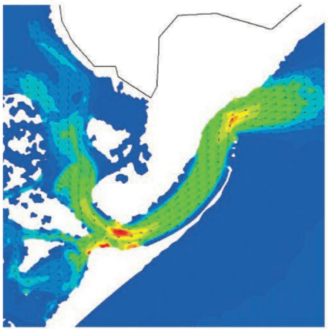
ScotMER	Scottish Marine Energy Research
SEA	Strategic Environmental Assessment
SeaBORD	Seabird Offshore Renewable Development
SeaMaST	Seabird Mapping and Sensitivity Tool
SMP	Sectoral Marine Plan
SMRU	Sea Mammal Research Unit
SNCB	Statutory Nature Conservation Body
SNCO	Special Nature Conservation Order
SPA	Special Protected Area
SSER	SSE Renewables
SSSI	Site of Special Scientific Interest
TBPC	Bristol's Port Company
TCE	The Crown Estate
UK	United Kingdom
UXO	Unexploded Ordnance

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Appendices




Innovative Thinking - Sustainable Solutions

A Long List of Evidence Gaps

Receptor	Theme	OWEER reference	Search criteria
Ornithology	Collision	EG.OR.1-17, 34, 49-52, 75, 78-80, 99-104, 128-130, 133, 136, 138, 141, 143, 148, 153, 155, 160, 161, 174, 176, 202	1. Keyword = collision; or 2. Target activity, impact or consenting risk = collision; or 3. Evidence Gap = collision
	Displacement	EG.OR.38-48, 76, 77, 105-112, 128, 129, 139, 144, 147, 149, 150, 154, 159, 166, 171-174, 176, 177, 182	1. Keyword = displacement; or 2. Target activity, impact or consenting risk = displacement; or 3. Evidence Gap = displacement
	Mitigation	EG.OR.141, 143, 144, 168, 169, 202	1. Keyword = mitigation; or 2. Target activity, impact or consenting risk = mitigation; or 3. Evidence Gap = mitigation
	Monitoring	EG.OR.1, 30-33, 52, 53, 86-90, 105, 106, 132, 134, 135, 167, 176, 179, 180, 183-200	1. Keyword = monitoring; or 2. Target activity, impact or consenting risk = monitoring; or 3. Evidence Gap = monitoring
	Cumulative and in-combination	EG.OR.73-75, 126-128, 137, 167, 181	1. Keyword = cumulative; or 2. Target activity, impact or consenting risk = cumulative; or 3. Evidence Gap = cumulative
	Compensation	EG.OR.142, 144, 163, 178	1. Keyword = compensation; or 2. Target activity, impact or consenting risk = compensation; or 3. Evidence Gap = compensation, compensatory
	Assessment approach	EG.OR.25, 122 - EG.OR.125, 137, 146, 197, 199	1. Keyword = assessment, climate; or 2. Target activity, impact or consenting risk = assessment; or 3. Evidence Gap = climate
	Baseline understanding	EG.OR.30-32, 66, 86-94, 132, 134, 135, 140, 180, 191-200	1. Keyword = baseline; or 2. Target activity, impact or consenting risk = baseline; or 3. Evidence Gap = baseline
	Ecosystem effects	EG.OR.18-29, 50, 51, 144, 164, 199, 201	1. Keyword = ecosystem; or 2. Target activity, impact or consenting risk = ecosystem; or 3. Evidence Gap = ecosystem, forage, foraging, dynamic
Marine Mammals	Baseline understanding	EG.MM.1-4, 14, 15, 35, 46-47, 51-53, 74, 93, 115, 131-132, 135.	1. Keyword = baseline, abundance, distribution; or 2. Target activity, impact or consenting risk = baseline; or 3. Evidence Gap = baseline
	Displacement	EG.MM.134	1. Keyword = displacement; or 2. Target activity, impact or consenting risk = displacement; or 3. Evidence Gap = displacement

Receptor	Theme	OWEER reference	Search criteria
	Underwater noise mitigation	EG.MM.6–33, 49, 57-61, 63-65, 67, 72, 73, 75, 76, 78, 79, 81-84, 86-88, 91, 92, 94, 96, 98-112, 114, 116, 117–21, 129, 131, 133, 137, 139[80]	1. Keyword = underwater noise; or 2. Target activity, impact or consenting risk = underwater noise, impulse noise, UXO; or 3. Evidence Gap = noise
	Entanglement	EG.MM.50, 80	1. Keyword = entanglement; or 2. Target activity, impact or consenting risk = entanglement; or 3. Evidence Gap = entanglement
	Ecosystem effects	EG.MM.51-53, 61, 69, 137	1. Keyword = forage, foraging, dynamic, ecosystem; or 2. Target activity, impact or consenting risk = ecosystem; or 3. Evidence Gap = ecosystem
	Cumulative assessment	EG.MM.54-56, 63, 100, 112, 138	1. Keyword = cumulative, combination; or 2. Target activity, impact or consenting risk = cumulative, combination; or 3. Evidence Gap = cumulative, combination
Benthic	Baseline understanding	EG.BE.3, 36	1. Keyword = baseline; or 2. Target activity, impact or consenting risk = baseline; or 3. Evidence Gap = baseline
	Coastal Processes	EG.BE.2, 5, 6, 25, 26, 38, 48, 49	1. Keyword = coastal ,process, sand, reef; or 2. Target activity, impact or consenting risk = coastal, process; or 3. Evidence Gap = coastal, process, sand, reef
	Ecosystem effects	EG.BE.24-26, 47	1. Keyword = forage, foraging, ecosystem; or 2. Target activity, impact or consenting risk = ecosystem, forage, foraging; or 3. Evidence Gap = ecosystem, forage, foraging
Fish	Essential Fish Habitat baseline mapping	EG.Fi.13-15, 21	1. Keyword = essential; or 2. Target activity, impact or consenting risk = essential; or 3. Evidence Gap = essential
	Monitoring	EG.Fi.1, 2, 4 - 8, 10, 12, 14, 15, 18-20, 26, 28-32, 34, 36, 39	1. Keyword = monitoring; or 2. Target activity, impact or consenting risk = monitoring; or 3. Evidence Gap = monitoring 4. Topic filter = monitoring ticked
	EMF	EG.Fi.1-4	1. Keyword = EMF, electro; or 2. Target activity, impact or consenting risk = EMF, electro; or 3. Evidence Gap = EMF, electro

[80] *NOTE: "noise" and "underwater noise" is used for filtering, not "noise mitigation". As such it is likely that references may relate to noise generally and not the mitigation for noise.*

Receptor	Theme	OWEER reference	Search criteria
Overarching	Baseline understanding	EG.OA.08 EG.OA.05	1. Keyword = baseline; or 2. Target activity, impact or consenting risk = baseline; or 3. Evidence Gap = baseline
	Ecosystem effects	EG.OA.06 EG.OA.10	1. Keyword = ecosystem; or 2. Target activity, impact or consenting risk = ecosystem; or 3. Evidence Gap = ecosystem
	Compensation	None	1. Keyword = compensation; or 2. Target activity, impact or consenting risk = compensation; or 3. Evidence Gap = compensation 4. Topic filter = compensation ticked
	Cumulative assessment	EG.OA.04, 07, 09	1. Keyword = cumulative; or 2. Target activity, impact or consenting risk = cumulative; or 3. Evidence Gap = cumulative
	Nature positive design options	EG.OA.01	1. Evidence Gap = nature, positive, design
	Assessment approach	EG.OA.08, 09	1. Keyword = assessment; or 2. Target activity, impact or consenting risk = assessment; or 3. Evidence Gap = assessment, approach

B Short list of Evidence Gaps

Receptor	Theme	Score[81]	Justification for inclusion	Related OWEER evidence gaps	Search Criteria used within OWEER
Ornithology	Compensation	31	Agreement between ABPmer review and stakeholders, scored as highest priority by stakeholders. Recent projects delayed due to uncertainty surrounding potential efficacy of compensatory measures.	EG.OR.142, 144, 163, 178	1. Keyword = compensation; 2. Target activity, impact or consenting risk = compensation; 3. Evidence Gap = compensation, compensatory
Ornithology	Displacement	27	Agreement between ABPmer review and stakeholders, scored as second highest priority by stakeholders. Scale of compensation determined by impacts; displacement is a major impact pathway.	EG.OR.38-48, 76, 77, 105-112, 128, 129, 139, 144, 147, 149, 150, 154, 159, 166, 171-174, 176, 177, 182	1. Keyword = displacement; or 2. Target activity, impact or consenting risk = displacement; or 3. Evidence Gap = displacement
Ornithology	Cumulative effects[82]	20	Agreement between ABPmer review and stakeholders, scored as third highest priority by stakeholders. Ecosystem effects incorporated within cumulative effects as inter-linked. Many offshore wind farm sites affect the same key pelagic seabird species, which is a fundamental problem.	EG.OR.18-29, 50, 51, 73-75, 126-128, 137, 144, 164, 167, 181, 199, .201	1. Keyword = cumulative; or 2. Target activity, impact or consenting risk = cumulative; or 3. Evidence Gap = cumulative
Benthic	Compensation	18	Highest scoring benthic evidence gap from the workshop due to the requirement to fulfil MPA targets, whilst acknowledging the technical challenge of compensating for the loss of Annex I Sandbank habitats.	EG.BE.37	1. Keyword = cumulative; or 2. Target activity, impact or consenting risk = cumulative; or 3. Evidence Gap = cumulative
Fish	Essential Fish Habitat (EFH)	11	Highest scoring critical evidence gap for fish. Also relevant to seabird compensation and marine net gain (horizon scanning). Identifying EFH would builds a fuller understanding ecosystem function, potentially improving quality of assessments.	EG.FI.13-15, 21	1. Keyword = essential; or 2. Target activity, impact or consenting risk = essential; 3. Evidence Gap = essential
Ornithology	Bird Collision	10	It remains important (yet challenging) to quantify collision mortality, due to the sensitivity of some seabird populations to even relatively small losses.	EG.OR.1-17, 34, 49-52, 75, 78-80, 99-104, 128-130, 133, 136, 138, 141, 143, 148, 153, 155, 160, 161, 174, 176, 202	1. Keyword = collision; or 2. Target activity, impact or consenting risk = collision; or 3. Evidence Gap = collision

[81] Generated from voting within the workshop, with high priority items assigned the highest number of points (i.e. the gaps considered most critical score the highest).
[82] Including ecosystem effects.

Ornithology	Baseline understanding	9	Although the data gathered both through survey work and tagging has improved understanding of at-sea distributions considerably, data gaps remain. Data gaps are varied and relate to specific species, localities, and behaviour of SPA species outside of breeding/overwintering periods. Improving understanding of seabird diet and also EFH of forage fish may also benefit development of effective compensatory measures.	EG.OR.30-32, 66, 86-94, 132, 134, 135, 140, 180, 191-200	1. Keyword = baseline; or 2. Target activity, impact or consenting risk = baseline; or 3. Evidence Gap = baseline
Marine mammals	Baseline understanding	9	Agreement between workshop scoring and ABPmer review that poor baseline understanding is a critical evidence gap in relation to marine mammals as many cetacean species are particularly challenging to study.	EG.MM.1-4, 14, 15, 35, 46-47, 51-53, 74, 93, 115, 131-132, 135.	1. Keyword = baseline, abundance, distribution; or 2. Target activity, impact or consenting risk = baseline; or 3. Evidence Gap = baseline
Ornithology	Mitigation	7	Many potential ornithological mitigation measures are untested and consequently not routinely adopted. Trials of potential mitigation measures such as curtailment systems, painting turbine blades, leaving flight corridors, and even increasing the air-blade gap are needed to establish which are effective and to quantify potential benefits.	EG.OR.141, 143, 144, 168, 169, 202	1. Keyword = mitigation; or 2. Target activity, impact or consenting risk = mitigation; or 3. Evidence Gap = mitigation
Benthic	Baseline understanding	7	Potential to utilise the outputs from POSEIDON to more precisely map/identify locations of sensitive features to ensure that development is not planned in these areas. Results considered achievable in the short term.	EG.BE.3, 36	1. Keyword = coastal ,process, sand, reef; or 2. Target activity, impact or consenting risk = coastal, process; or 3. Evidence Gap = coastal, process, sand, reef

C Key Research Undertaken, Underway and Planned

Receptor	Theme	Project	Source and/or organisation funding body	Description
Ornithology	Compensation	ECOWINGS	UK Centre for Ecology & Hydrology[83]	This project aims to establish pathways for strategic compensation on key species based on the cumulative effects of offshore wind farms.
Ornithology/Benthic	Compensation	COWSC	TCE / OWIC[84]	A collaborative project that brings together stakeholders to deliver offshore wind compensation pilot projects.
Ornithology	Cumulative and in-combination	Cumulative Effects Framework	UK Centre for Ecology & Hydrology[85]	A tool that calculates cumulative ornithological effects of a proposed development.
Ornithology	Compensation	Strategic Scale Compensation Measures in Scotland.	RSPB	An assessment of potential options for strategic scale, rather than project-specific, compensation measures in Scotland.
Ornithology	Compensation	Assessment of compensatory measures for impacts of offshore windfarms on seabirds (NECR431).	Natural England[86]	A study to identify recommended methods for compensation relating to nine qualifying features of eight SPAs in England.

83 https://ecowind.uk/projects/ecowings/
84 https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2023-the-crown-estate-and-offshore-wind-industry-council-launch-35m-project-to-test-effectiveness-of-strategic-environmental-compensation-measures-around-offshore-wind-developments/
85 https://www.ceh.ac.uk/our-science/projects/cef-workshops
86 McGregor, R., Trinder, M. and Goodship, N. 2022. Assessment of compensatory measures for impacts of offshore windfarms on seabirds. A report for Natural England. Natural England Commissioned Reports. Report number NECR431.

Receptor	Theme	Project	Source and/or organisation funding body	Description
Ornithology/Benthic	Compensation	Offshore Wind Farms Enabling Actions: A review of the use of compensatory measures and applicability to UK offshore developments (ME6032).	Centre for Environment, fisheries and Aquaculture Science (Cefas), Natural England and JNCC[87]	A literature review to define, highlight and review key areas for consideration on the use of compensatory measures offshore.
Ornithology	Collision	Reducing Seabird Collisions Using Evidence (ReSCUE).	Natural England, under OWEC[88]	A project to collect accurate flight height data from DAS and Lidar for various species and regions.
Ornithology	Collision	Prevalence of Seabird Species and Collision Events in offshore wind farms (PrediCtOr).	The Carbon Trust, under ORJIP[89]	The project aims to integrate datasets from past and future collision monitoring and conduct onshore field studies to establish best practices of seabird monitoring techniques.
Ornithology	Collision/ mitigation	Marine birds: vision-based wind turbine collision mitigation (NECR432).	Natural England[90]	A review of potential mitigation measures to reduce collision risk, including the assessment of bird vision in relation to the application of painting turbine blades.
Ornithology	Collision	Firth of Forth Seabird Interactions Study.	NnG[91]	Acquiring empirical measures of collision risk and three-dimensional flight behaviour for the key species occurring at the Neart na Gaoithe offshore wind farm.

87 Blake, S. Copley, V. Fawcett, A. Hall, K. Perry, J. and Wood, D. 2020. A review of the use of compensatory measures and applicability to UK offshore developments, Defra Project ME6032. pp. 103.
88 https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2023-the-crown-estate-invests-a-further-9m-in-new-research-to-drive-nature-positive-offshore-wind-development/
89 https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2023-the-crown-estate-invests-a-further-9m-in-new-research-to-drive-nature-positive-offshore-wind-development/
90 Martin, G. & Banks, A. (2023). Marine birds: Vision-based wind turbine collision mitigation. Global Ecology and Conservation. 42. e02386. 10.1016/j.gecco.2023.e02386.
91 https://nngoffshorewind.com/pioneering-seabird-interaction-study-underway-at-bass-rock-in-the-outer-part-of-the-firth-of-forth/

Receptor	Theme	Project	Source and/or organisation funding body	Description
Ornithology	Collision	Seabird flight behaviour and avoidance monitoring.	Vattenfall[92]	The project aims to monitor the flight patterns and responses of Gannet, Kittiwake and large gulls at Vattenfall's Aberdeen Bay European Offshore Wind Deployment Centre (EOWDC) site.
Ornithology	Collision	Spoor AI Trial Aberdeen Bay	Vattenfall[93]	The project aims to record the 3D flight behaviour of seabirds in the immediate vicinity of turbine blades.
Ornithology	Collision	Measuring mortality of kittiwake and other seabirds from collisions by monitoring turbines.		The aim of this project is to collect empirical data on mortalities for Kittiwake and other priority species at risk of collision.
Ornithology	Collision	Visualizing Avian migration across Norway supporting sustainable coastal and offshore wind energy development (VisAviS)	VisAviS[94]	This project aims to map avian migratory flyways in Norway and adjacent seas.
Ornithology	Collision	Camera-based ornithological monitoring at offshore wind farms.		This project aims to encourage developers to use camera-based ornithological monitoring.
Ornithology	Collision	Assessment of collision risk modelling against 'real life' bird collisions on an offshore wind farm using camera technology.		A study using new camera technology to assess collision risk modelling against 'real life' birds collisions on an offshore wind

92 https://group.vattenfall.com/uk/contentassets/1b23f720f2694bd1906c007effe2c85a/aoffshore wind farml_aberdeen_seabird_study_final_report_20_february_2023.pdf
93 https://group.vattenfall.com/uk/newsroom/pressreleases/2023/vattenfall-launches-an-expanded-trial-of-spoor-ai-technology-at-aberdeen-bay-offshore-wind-farm
94 https://www.nina.no/english/Sustainable-society/Renewable-energy/VisAviS

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Ornithology	Collision	Monitoring bird behaviour across multiple offshore wind farms.		Aims to expand the empirical evidence available to determine the behaviour of birds within operational wind farms.
Ornithology/FLOW	Displacement/ EMF	Predators and Prey Around Renewable Energy Developments (PrePARED).	TCE under OWEC[95]	Understanding how predators (seabirds and marine mammals) respond to changes in prey fish) distribution arising from offshore wind farm development.
Ornithology	Displacement/ baseline understanding	Auk Tagging and Monitoring.	Vattenfall[96]	A project to understand non-breeding season movements of adult Guillemots and Razorbills and their interaction with offshore wind farms in the North Sea.
Ornithology	Displacement/ baseline understanding	NnG Isle of May GPS tracking.	UK Centre for Ecology & Hydrology[97]	GPS tracking, including the analysis of displacement and barrier effects of breeding birds at the Isle of May using remote download tags.
Ornithology	Displacement	Offshore wind developments assessment - seabird collision risk, displacement and barrier effects: study.	The Scottish Government[98]	The development of a new framework to assess the collision, displacement, and barrier effects on seabirds from Offshore Renewable developments to produce a single overall assessment of combined impacts.
Ornithology	Displacement	Effects of displacement from Offshore Renewable Developments in the non-breeding season using an individual-based modelling approach & Designing studies to assess consequences of displacement (DisNBS)		Looking into the development of a new tool to be able to more accurately estimate the impact on seabirds during the non-breeding season.

[95] https://owecprepared.org/
[96] https://group.vattenfall.com/uk/contentassets/c65a13553f864f599431d69c8c6a57b4/auk-tagging-final-report-january-2023.pdf
[97] https://www.ceh.ac.uk/news-and-media/news/dynamic-project-will-safeguard-seabirds-alongside-offshore-wind-farms
[98] https://www.gov.scot/publications/study-examine-seabird-collision-risk-displacement-barrier-effects-integrated-assessment-offshore-wind-developments/

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Ornithology	Displacement	Are red-throated divers energetically challenged in the non-breeding season?		Project tagging to assess whether Red-throated divers (RTD's) are energetically challenged in the non-breeding season.
Ornithology	Displacement	Production of a Cumulative Effects Framework for key ecological receptors.		To provide a tool that estimates the cumulative effects of marine developments at a strategic level for use in planning.
Ornithology	Displacement	Feasibility study to extend Seabird Offshore Renewable Development (SeabORD) to full breeding season.		To improve estimates of the consequences of seabird displacement.
Ornithology	Displacement	Developing non-invasive tags to measure the energy expenditure of seabirds.	Marine Scotland, St Andrews University[99]	A study that develops and pilots a new non-invasive NIRS sensor tag to measure seabird energetics.
Ornithology	Displacement	Study to Develop Best Practice Recommendations for Combining Seabird Study Data Collected from Different Platforms.	The Scottish Government[100]	This study developed best practice guidance to combine seabird survey data collected from different platforms (e.g. literature reviews).
Ornithology	Displacement	Production of Seabird and Marine Mammal Distribution Models for the East of Scotland.	The Scottish Government[101]	A report of the temporal and spatial patterns of density for seabird and marine mammal species in the eastern waters of Scotland from DAS.

[99] Development of a Novel Physiology Tag to Measure Oxygen Consumption in Free-Ranging Seabirds (pnnl.gov)
[100] Matthiopoulos, J.; Trinder, M.; Furness, B.. 2022. Study to Develop Best Practice Recommendations for Combining Seabird Study Data Collected from Different Platforms.
[101] https://www.gov.scot/publications/production-seabird-marine-mammal-distribution-models-east-scotland/

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Ornithology/ benthic/ marine mammals	Baseline understanding	Planning Offshore Wind Strategic Environmental Impact Decisions (POSEIDON).	Natural England under OWEC[102]	To help update spatial models and risk maps for key species most vulnerable to offshore wind, this project is to conduct four seasonal DAS during 2023 and 2024.
Ornithology	Baseline understanding / Cumulative and in-combination	Remote Tracking of Seabirds at Sea – MOTUS.	RSPB, JNCC, CEH, BTO, Biomathematics and Statistics Scotland (BioSS), Hull, Marine Scotland Science[103]	This project aims to test the Motus automated radio telemetry network to address three specific data gaps, highlighted in the research.
Ornithology	Baseline understanding	Procellariiform Behaviour & Demographics (ProcBe).	JNCC[104]	This project seeks to understand how seabird species, such as storm petrels and Manx shearwater interact with offshore wind farms.
Ornithology	Baseline understanding	Kittiwake survival monitoring at Flamborough & Filey Coast.		Project to colour ring and resight adult Kittiwakes at Flamborough with the long term aim of modelling survival.
Ornithology	Baseline understanding	Assessment of the current status of Black-legged Kittiwake *Rissa tridactyla* in Wales.	Natural Resource Wales[105]	Review of kittiwake population trends, demography and drivers in Welsh colonies.
Ornithology	Cumulative and in-combination	Tools for assessing the impact of marine industries on seabirds on seabirds in the North Sea	MARCIS[106]	

[102] https://naturalengland.blog.gov.uk/2023/02/01/poseidon-offshore-wind-and-nature/
[103] https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/the-crown-estate-invests-over-12million-in-new-research-to-help-protect-the-uk-marine-environment/
[104] https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2023-the-crown-estate-invests-a-further-9m-in-new-research-to-drive-nature-positive-offshore-wind-development/
[105] https://naturalresources.wales/media/696241/report-558_nrw-bto-kittiwake-report-_accessibility-updates_website-upload.pdf
[106] https://www.nina.no/english/Sustainable-society/Marcis

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Ornithology	Cumulative and in-combination	Measuring the interaction between marine features of SPAs with offshore wind farm development zones through telemetry: Lesser Black-backed Gulls on the Forth Islands SPA.	University of Aberdeen, funded by the DECC[107]	A multiyear project to improve the input data to seabird collision risk models and cumulative assessments, for lesser black-backed gulls.
Ornithology	Cumulative and in-combination	Bayesian framework for ecosystem Cumulative Effects Assessment.		North Sea scale cumulative effects assessment, ecosystems assessment and the use of bayesian methods to explore key layers and ecosystem components.
Ornithology	Cumulative and in-combination	Wendy		A holistic assessment system for realistic in-depth analysis of the cumulative social, technical and ecological cumulative impacts of wind farms.
Ornithology	Cumulative and in-combination	Strategic study of collision risk for birds on migration and further development of the stochastic Collision Risk Modelling tool.		To improve sCRM collision risk modelling tool, this project aims to establish baseline data of migratory bird routes and potential overlap with Plan Option areas.
Ornithology	Cumulative and in-combination	Investigating the feasibility and options for strategic environmental monitoring within the Offshore Wind sector.		Define what are the key strategic monitoring requirements and the key components of any strategic monitoring programme.
Ornithology	Mitigation	Mitigating the Impacts of Offshore Wind Farms on Protected Sites and Species in the UK: Part 1. Review of mitigation techniques (ME5602).	Defra[108]	A review of the current understanding, regarding the effectiveness of current mitigation measures and consideration of the feasibility of mitigation measures not currently in use.

[107] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/302624/Interaction_between_marine_features_and_SPAs_-_project_inception.pdf
[108] Greenhill, L., Howell, D., King, S. and Risch, D. 2021. Mitigating the impacts of offshore wind on protected sites and species in the UK: Part 1. Review of mitigation techniques. Report produced by Howell Marine Consulting for Defra, March 2021.

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Ornithology	Mitigation	Feasibility study on painting turbines to reduce bird collisions from offshore wind		Feasibility study considering practical aspects around how to progress the painted turbine blade concept.
Ornithology	Mitigation	Spoor AI.	Spoor AI [109]	Spoor AI is a commercial company who deploy cameras within offshore windfarms and use computer software/ AI to detect, track birds.
Marine Mammals	Baseline understanding	SCANS (Small Cetaceans in European Atlantic waters and the North Sea).	St Andrew's University[110]	A systematic widescale DAS across the northeast Atlantic to gather abundance and distribution data of cetaceans.
Marine Mammals	Baseline understanding	Marine Mammal Atlas of Wales: Modelled Distributions and Abundance of Cetaceans and Seabirds of Wales and Surrounding Waters.	Natural Resource Wales[111]	This report documents a vast (hundreds of thousands) of kilometres of cetacean survey effort from 1990 and 2020 and presents sighting rates and modelled density distribution.
Marine mammals	Baseline understanding	Celtic Sea Power (CSP) DAS.	Celtic Sea Power have commissioned APEM	Contributing to POSEIDON project to help update spatial models and risk maps for key species most vulnerable to offshore wind, this project is to conduct four DAS during 2023 and 2024.
Marine mammals	Baseline understanding	COMPASS (Collaborative Oceanography and Monitoring for Protected Areas and Species).	COMPASS [112]	A transboundary acoustic array across the Republic of Ireland, Northern Ireland and West Scotland.

[109] https://spoor.ai/
[110] https://scans3.wp.st-andrews.ac.uk/
[111] https://cdn.cyfoethnaturiol.cymru/media/696779/modelled-distributions-and-abundance-of-cetaceans-and-seabirds-of-wales-and-surrounding-waters.pdf
[112] https://compass-oceanscience.eu/

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Marine mammals	Baseline understanding	East Coast Marine Mammal Acoustic Study (ECOMASS).	Marine Scotland[113]	An array of C-PODs at 30 locations off the east coast of Scotland to record ambient noise levels, as well as other animal vocalisations.
Marine mammals	Baseline understanding	Cetacean Acoustic Trend Tracking Project (CATT)	Research Development UK[114]	A long term passive acoustic monitoring project using Chelonia F-POD acoustic loggers deployed at several coastal locations from the southwest coast to Sussex during 2021 and 2022.
Marine mammals	Baseline understanding	SMRU Habitat-based predictions of at-sea distribution for grey and harbour seals in the British Isles.	University of St Andrews, Report to BEIS[115]	To generate up-to-date at-sea distribution of harbour and grey seals, via large-scale GPS tagging across the British Isles, historic tracking data and habitat modelling.
Marine mammals	Baseline understanding	Construction Marine Mammal Monitoring Programme Fieldwork Report 2020 (University of Aberdeen).	University of Aberdeen[116]	A selection of surveys (e.g. land and boat-based photo identification) required to be carried at the Moray East offshore windfarm.
Marine mammals	Baseline understanding	National Sighting Database. Seawatch Foundation.	Seawatch Foundation[117]	A repository for sightings of marine mammals and other marine megafauna, submitted mostly by citizen scientists.

[113] https://marine.gov.scot/information/east-coast-marine-mammal-acoustic-study-ecommas
[114] https://research.uk.net/catt.html
[115] SMRU_2020_Habitat-based_predictions_of_at-sea_distribution_for_grey_and_harbour_seals_in_the_British_Isles.pdf (publishing.service.gov.uk)
[116] https://marine.gov.scot/sites/default/files/mfrag_-_fieldwork_report_2020.pdf
[117] https://www.seawatchfoundation.org.uk/sightings/

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Benthic	Baseline understanding	Natural England and JNCC advice on key sensitivities of habitats and Marine Protected Areas in English Waters to offshore wind farm cabling within Proposed Round 4 leasing areas.	Natural England and JNCC[118]	Advice is provided to help highlight locations and features of highest sensitivity to windfarm cabling activities.
Benthic	Baseline understanding	Scale of impacts of floating devices.	Cefas (Report unavailable).	Project to determine the scale of impacts of offshore floating devices on scour and winnowing through the modelling of several scenarios using the OneBenthic suite of tools.
Benthic	Baseline understanding	Benthic monitoring recommendations in the context of offshore renewable developments in Scottish waters.		To develop a consistent approach to benthic monitoring (pre and post consent).
Benthic	Baseline understanding	Defining Marine Irreplaceable Habitats.		This project will work to define intertidal and marine irreplaceable habitats through a series of literature reviews, reports and interviews with experts.
Benthic	Baseline understanding	Benthic effects of offshore renewables: identification of knowledge gaps and urgently needed research.	ICES Journal of Marine Science[119]	A review of studies to summarise how marine renewable energy devices affect benthic environments, ecosystem processes and services to decide which urgent research is required.
Benthic	Baseline understanding	Review of Cable Installation, Protection, Mitigation and Habitat Recoverability.	The Crown Estate, RPS[120]	A desk-based review of cable installation techniques and protection used for offshore wind and other cables related projects to create a better understanding of seabed impacts.

[118] https://data.jncc.gov.uk/data/3c9f030c-5fa0-4ee4-9868-1debedb4b47f/NE-JNCC-advice-key-sensitivities-habitats-MPAs-offshore-windfarm-cabling.pdf
[119] https://academic.oup.com/icesjms/article/77/3/1092/5368123?login=true
[120] https://www.rpsgroup.com/projects/ensuring-a-sustainable-future-for-offshore-wind-farm-cables/

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Benthic	Baseline understanding	Ecological Consequences of Offshore Wind (ECOWind) – Accelerate.	ECOWind – Accelerate[121]	Ecological Implications of Accelerated Seabed Mobility around Windfarms.
Benthic	Baseline understanding	Automated Identification of Fish and Other Aquatic Life in Underwater Video. Scottish Marine and Freshwater Science, Vol 11 No 18, 62pp.	Marine Scotland[122]	The objective of this study is to present the current state of technologies for automatic detection of aquatic life in underwater video footage.
Benthic	Compensation	Spatial Assessment of Benthic Compensatory Habitats for Offshore Wind Farm Impacts.	Natural England[123]	This project aims to identify benthic habitats that have a similar or identical ecological function and service provision to one another.
Fish	EFH Baseline Mapping	FishIntel.	Fish Intel[124]	Improved understanding of fish spatial distributions and use of habitats.
Fish	EFH Baseline Mapping	NE Essential Fish Habitat (EFH) projects.		Encompassing three complementary projects; including developing a suite of indicators for EFH and an evidence gap analysis of fish/habitat data for UK inshore waters.
Fish	EFH Baseline Mapping	Black seabream nest mapping project.		Collation of all black seabream nesting records within UK waters.
Fish	EFH Baseline Mapping	MMO essential fish habitat projects.		A project to develop new spatially predictive essential fish habitat models nationally.

[121] https://ecowind.uk/projects/ecowind-accelerate/
[122] Mackiewicz, et al. 2020. Automated Identification of Fish and Other Aquatic Life in Underwater Video. Scottish Marine and Freshwater Science, Vol 11 No 18, 62pp
[123] Spatial assessment of benthic compensatory habitats for offshore wind farm impacts - NECR443 (naturalengland.org.uk)
[124] https://www.france-energies-marines.org/en/projects/fish-intel/

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Fish	EFH Baseline Mapping	Identifying juvenile fish habitats for sustainable fisheries.		This project aims to evaluate the importance of coastal areas as nursery habitats for juvenile fishes by undertaking surveys of the fish fauna in habitats throughout the southwest.
Fish	EFH Baseline Mapping	NEST.		Natural England Sensitivity Tool (NEST) for marine habitats.
Fish	EFH Baseline Mapping	A verified distribution model for the lesser sandeel *Ammodytes marinus*.	The Scottish Government[125]	Using distribution models to predict the occurrence and density of sandeels in parts of the North Sea and Celtic Sea.
Fish	EFH Baseline Mapping	Unknown.		No more detail currently available - funding yet to be approved at time of writing.
Fish	EFH Baseline Mapping	Developing essential fish habitat maps: report by Marine Scotland.	The Scottish Government[126]	The project helped define areas of the sea essential to fish for spawning, breeding, feeding, or growth to maturity.
Fish	EFH Baseline Mapping	Essential spawning grounds of Scottish herring: current knowledge and future challenges.	William Grant Foundation[127]	Current knowledge on Scottish herring spawning grounds, retrieved through literature searches and fisher interviews.
Fish	EFH Baseline Mapping	Follow on to the development of spatial models of essential fish habitat for the South Inshore and Offshore Marine Plan Areas.	Marine Management Organisation[128]	Includes stakeholder consultation and validation activities to fulfil objectives relating to fish habitat maps, data predictions and marine plans.

[125] Langton R., Boulcott P. and Wright P. (2021) A verified distribution model for the lesser sandeel *Ammodytes marinus*. Marine Ecology Progress Series 667, 145–159.
[126] https://www.gov.scot/publications/developing-essential-fish-habitat-maps-fish-shellfish-species-scotland-report/
[127] Frost, M. and Diele, K., 2022. Essential spawning grounds of Scottish herring: current knowledge and future challenges. Reviews in Fish Biology and Fisheries, pp.1-24.
[128] Franco, A. and Shona, T., 2016. Follow on to the development of spatial models of essential fish habitat for the South Inshore and Offshore Marine Plan Areas.

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Floating offshore wind	Entanglement			CFA work on potential anchoring, mooring and cabling system options for CS by ORE Catapult can help to support potential impact inference.
Floating offshore wind	Entanglement	Accelerating offshore wind: the role of innovative technology in decision making and faster consenting.	Cornwall FLOW Accelerator Project[129]	Investigates if and where the potential exists for smart technology to streamline the data gathering, analysis and decision-making process.
Floating offshore wind	Entanglement/ EMF	Literature review on barrier effects, ghost fishing, and electromagnetic fields for floating windfarms. Equinor, 2022.	Equinor and Ocean Science Consulting Limited[130]	Reviews information relating to barrier effects, entanglement risks from ghost fishing gear, and includes research relating to EMF at FLOW sites.
Floating offshore wind	Entanglement	A High Current Underwater Platform for the Long-Term Monitoring of Fine-Scale Marine Mammal Behavior Around Tidal Turbines.	St Andrews[131]	A report on the design, and performance, of a seabed mounted sensor platform for monitoring the fine scale movements of cetaceans and pinnipeds around operational tidal turbines.
Floating offshore wind	Entanglement	Encounters of Marine Animals with Mooring Systems and Subsea Cables.	Welsh Government[132]	Information notes on to support the consenting of wave and tidal stream energy projects.
Floating offshore wind	Entanglement		Tethys[133]	A source to search affiliated marine and wind energy documents relating to entanglement.

[129] https://ore.catapult.org.uk/wp-content/uploads/2023/07/Project-Pipeline-Report_FINAL.pdf
[130] https://cdn.equinor.com/files/h61q9gi9/global/434c3452ed651ae8ac9d256794981145ce942334.pdf?osc-study-floating-windfarms-2022-equinor.pdf.
[131] Gillespie, D., Offshore windald, M., Hastie, G. and Sparling, C., 2022. Marine Mammal HiCUP: A High Current Underwater Platform for the Long-Term Monitoring of Fine-Scale Marine Mammal Behavior Around Tidal Turbines. Frontiers in Marine Science, p.283.
[132] https://www.gov.wales/sites/default/files/publications/2022-06/information-note-encounters-of-marine-animals-with-mooring-systems-and-subsea-cables.pdf
[133] Entanglement | Tethys (pnnl.gov)

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Floating offshore wind	Entanglement	Potential impacts of floating wind turbine technology for marine species and habitats.		A report focusing on the risks, including primary and secondary entanglement in mooring lines, that floating turbines may pose to marine life.
Floating offshore wind	EMF	ElasmoPower.	Wageningen University and Research[134]	This project reflects on the effects of EMF from Offshore Floating Wind developments on elasmobranchs in the North Sea.
Floating offshore wind	EMF	Marine Fish Ecology Database (MFED).	CEFAS	A compilation of a citations database and literature reviews to be made widely available to support decision making in the environment.
Floating offshore wind	EMF	Innovative monitoring of fish distribution and behaviour around floating and fixed wind turbines: a review.	CEFAS	A review of methodological approaches to set out a plan for combined methods to assist with determining use of offshore wind farms by fish species.
Floating offshore wind	EMF	Electromagnetic Fields (EMFs) from subsea power cables in the natural marine environment.	The Crown Estate OWEC[135]	The findings from a workshop delivered through OWEC (2023), resulting in suggestions of a standardised approach for EMF measurement and recommended further research.
Floating offshore wind	EMF	The effect of artificial electromagnetic fields on the early-life stage development of electro- and magneto-sensitive North Sea species.	Scottish Fishermen's Federation and the Nesbitt-Cleland Trust[136]	An investigation into the effect of artificial EMF exposure on the early development of North Sea elasmobranch, cephalopods and crustacean species.

[134] ElasmoPower: How thrilled are elasmobranchs about electromagnetic fields in offshore wind farms? Effects of electromagnetic fields from subsea power cables on benthic Elasmobranchs in the Dutch North sea — Research@WUR
[135] Electromagnetic Fields (EMFs) from subsea power cables in the natural marine environment (pnnl.gov)
[136] JMSE | Free Full-Text | The Effects of Anthropogenic Electromagnetic Fields (EMF) on the Early Development of Two Commercially Important Crustaceans, European Lobster, Homarus gammarus (L.) and Edible Crab, Cancer pagurus (L.) (mdpi.com)

Receptor	Theme	Project	Source and/or organisation funding body	Description
FLOW Floating offshore wind	EMF	Current state of knowledge Electromagnetic fields: Electromagnetic fields and the Marine Strategy Framework Directive Descriptor 11 – Energy.	Rijkswaterstaat[137]	Technical report including a literature survey and modelling exercise of electromagnetic field levels of the Dutch Continental Shelf.
Floating offshore wind	EMF	Characterisation of the potential impacts of subsea power cables associated with offshore renewable energy projects.	France Energies Marines[138]	Review of the potential interactions between the electric power cables of ORE projects and benthic organisms.
Floating offshore wind	EMF	Magnetic fields generated by the DC cables of offshore wind farms have no effect on spatial distribution or swimming behavior of lesser sandeel larvae (*Ammodytes marinus*).	Institute of Marine Research[139]	This project conducted a behavioural experiment on lesser sandeel larvae to assess the possible impact of static magnetic fields from the DC cables that connect offshore wind farms.
Floating offshore wind	EMF	A modelling evaluation of electromagnetic fields emitted by buried subsea power cables and encountered by marine animals: Considerations for marine renewable energy development.	St Andrews[140]	This report modelled the emissions from a HVDC 132 transmission cable under different scenarios to explore the EMF environment that receptive species will experience.

[137] A Hermans., B Schilt., J Bekkers., and J Tams. (2022).
[138] Taormina, B., Quillien, N., Lejart, M., Carlier, A., Desroy, N., Laurans, M., D'Eu, J.F., Reynaud, M., Perignon, Y., Erussard, H. and Derrien-Courtel, S., 2020. Characterisation of the potential impacts of subsea power cables associated with offshore renewable energy projects. SPECIES project (2017-2020): Review and perspectives.
[139] Hutchison, Z.L., Gill, A.B., Sigray, P., He, H. and King, J.W., 2021. A modelling evaluation of electromagnetic fields emitted by buried subsea power cables and encountered by marine animals: Considerations for marine renewable energy development. Renewable Energy, 177, pp.72-81.
[140] Hutchison, Z.L., Gill, A.B., Sigray, P., He, H. and King, J.W., 2021. A modelling evaluation of electromagnetic fields emitted by buried subsea power cables and encountered by marine animals: Considerations for marine renewable energy development. Renewable Energy, 177, pp.72-81.

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Floating offshore wind	EMF	Anthropogenic electromagnetic fields (EMF) influence the behaviour of bottom-dwelling marine species.	Bureau of Ocean Energy Management[141]	Assessing the behavioural responses of the presumed, magneto-receptive American lobster and the electro-sensitive Little skate to (EMF) emissions.
Floating offshore wind	EMF	Review of the effects of underwater sound, vibration and electromagnetic fields on crustaceans.	Seafish[142]	This report was written to support the UK seafood industry when engaging with offshore development proposals that may result in anthropogenic sound, seabed substrate-borne vibration, and EMFs.
Floating offshore wind	EMF	Orientation behavior and swimming speed of Atlantic herring larva (*Clupea harengus*) in situ and in laboratory exposures to rotated artificial magnetic fields.	Institute of Marine Research[143]	A study recording the behaviour and orientation of herring larvae post hatch, while drifting in a behavioural and magnetic chamber laboratory.
Floating offshore wind	EMF	Magnetic fields produced by subsea high voltage DC cables reduce swimming activity of haddock larvae (*Melanogrammus aeglefinus*).	Institute of Marine Research[144]	This report tested the behaviour of haddock larvae by exposing the larvae to a B-field intensity in a raceway tank.

[141] Hutchison, Z.L., Gill, A.B., Sigray, P., He, H. and King, J.W., 2020. Anthropogenic electromagnetic fields (EMF) influence the behaviour of bottom-dwelling marine species. Scientific reports, 10(1), pp.1-15

[142] Scott, K., Piper, A.J., Chapman, E.C. and Rochas, C.M., 2020. Review of the effects of underwater sound, vibration and electromagnetic fields on crustaceans.

[143] Cresci, A. Allan, B. J. M., Shema, S. D., Skiftesvik, A. B., Browman, H. I. 2020. Orientation behavior and swimming speed of Atlantic herring larva (Clupea harengus) in situ and in laboratory exposures to rotated artificial magnetic fields. Journal of Experimental Marine Biology and Ecology.

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Receptor	Theme	Project	Source and/or organisation funding body	Description
Floating offshore wind	EMF	Literature review on the potential effects of electromagnetic fields and subsea noise from marine renewable energy developments on Atlantic salmon, sea trout and European eel.	Scottish Natural Heritage[145]	This report reviews the current state of knowledge with regard to the effect of Marine Renewable Energy Developments (MREDs) on Atlantic salmon, sea trout and European eel.

[145] Gill, A.B. and Bartlett, M.D., 2010. Literature review on the potential effects of electromagnetic fields and subsea noise from marine renewable energy developments on Atlantic salmon, sea trout and European eel. Scottish Natural Heritage Commissioned Report.

D Recommended Research Areas

Critical Evidence Gap	Research Recommended	Rationale	Next steps
Ornithology – compensation	▪ Investigate the pressures impacting on each species at each colony to establish where focus can best be targeted to ensure the overall coherence of the UK national sites network. ▪ Identify key prey species within seabird diets. ▪ Identify which spawning populations/and or habitats fish are associated with local seabird colonies (identify EFH – could use stable isotope analysis, though would require feasibility study to investigate). ▪ Fisheries assessment to establish whether forage fish that are key prey species are currently harvested and what controls can and cannot be put in place. ▪ GIS based exercise to identify areas where EFH overlaps with potentially damaging activities (e.g. trawling, scallop dredging etc). ▪ Compensation for displacement could involve consideration of habitat fragmentation at the marine spatial planning stage. Features such as flight corridors could run through several sites in order to allow birds safe flight routes through increasingly built-up areas of sea. ▪ Further work to establish realistic potential benefits of proposed compensation measures at a strategic scale. ▪ Research on quiet zones for Red-throated Diver.	Compensation will only be effective if it tackles a factor that is limiting either survival or productivity. Limiting factors will differ in importance between sites. Apart from avian influenza[146], lack of prey remains the greatest pressure on seabirds, so focus on prey-related items is most likely to provide the scale of compensation required. However, investigation of a range of factors de-risks compensation, as there are numerous political issues with restricting fishing.	SPA reviews (to be developed with site managers) would inform development of potential compensatory measures. Studies on seabird diet, to be linked to studies on EFH. Then look at pressures affecting local prey populations as a means of identifying compensatory measures[147].

[146] It has been assumed that (at least at the time of writing) vaccination of wild birds against avian influenza is not feasible due to disturbance, licencing restrictions etc.
[147] Consultation should be undertaken with COWSC (Collaboration on Offshore Wind Strategic Compensation), ECOWind and OWEC funded projects (including the OWIC led OWEC strategic compensation project) to address some of the gaps and ensure that research is not duplicated.

Ornithology - Collision	▪ Post-construction monitoring needs to be designed to monitor bird collisions in the field. This could include various studies to look at flight altitude distributions, flight patterns and reactive responses using Global Positioning System (GPS) tracking, LiDAR, radar and/or (thermal) camera systems[148]. ▪ As well as often expensive remote technology, bird observers could be deployed on service and maintenance vessels/floating hotels etc to make observations on bird activity and flight heights in operational wind farms. This could be used to add to data gathered using remote monitoring methods, and to provide fine-scale detail that may not be achievable using remote monitoring. ▪ Densities of birds at onshore coastal sites and offshore sites could be compared by surveying across both types of wind farm using a systematic point-based sampling technique, to see if the difference in bird collision rates onshore and offshore can be explained by differing densities of birds within differing habitats. ▪ Key data gaps remain in relation to avian vision and in particular how seabirds perceive rotational motion, which differs significantly from human perception (G. Taylor, Oxford University *pers.comm*). Systematic study of seabird vision, flight characteristics (speed, height), environmental conditions (wind, weather, light), obstacle avoidance strategies and investigation of potentially influential factors such as turbine size, spacing, motion smear, blade tip speed, and rpm would be helpful in improving understanding around the level of risk posed by different turbine models (offshore turbines being much larger and with lower rpm and higher blade tip speed), and improve understanding of risk and improve confidence in decision making. This could involve a combination of laboratory-based and field-based investigations. ▪ An analysis of video footage from the various vendors of curtailment systems could be systematically analysed in order to strengthen the evidence base around collisions, and also to analyse the flight behaviour of different species around wind turbines. ▪ Similar radar work to that undertaken in Holland[149] could be undertaken to establish whether collision risk to birds could be materially reduced by turning off sites during peak migratory periods.	There is still a lack of dedicated collision monitoring studies relative to the number of offshore turbines installed, leading to uncertainty. This data gap can and should be filled. There is a concern that collisions offshore are under recorded it is known that seabird species are vulnerable to collision from data from onshore coastal studies. Although the PrediCtOr project will infill gaps around the monitoring technology, it is unclear whether underlying densities of bird differ significantly between offshore and onshore coastal habitats, and whether this, coupled with differing turbine characteristics, may provide a reason why collision rates observed offshore are lower than expected. Other likely influential factors can also be investigated, especially blade tip speed in relation to the flight speed of particular species. Understanding why collision rates are lower than expected is important to progress development of an improved and agreed assessment system for bird collision.	Data from collision monitoring studies would be used to inform assessment of collision. Improved understanding of why collision rates are lower offshore than onshore (if additional monitoring shows this to be the case) would ensure that there is proper support any updates to the current system and increased confidence in its outputs.

[148] GPS tagging could have additional advantages of providing data on birds in the non-breeding season to aid apportionment, if projects is designed accordingly.
[149] See Leemans et al 2022 and also this link: Offshore wind farms shut down for the first time to protect migratory birds | News | Rijksoverheid.nl

Ornithology - Displacement	▪ Meta analysis using data from multiple sites could be undertaken to better describe the factors that may affect displacement rates and therefore improve assessment of likely displacement. ▪ The best method available to look at the consequences of displacement is GPS tracking and NIRS loggers to track individuals from different breeding colonies before, during and after offshore wind construction, with a view to look for differences in body condition, breeding success and survival pre- versus post-construction (although acknowledging the difficulties with detecting minor change against the other major pressures affecting birds). ▪ Collect empirical data and apply statistical models to estimate and quantify uncertainty in the relationship between end of season condition and subsequent overwinter survival. ▪ Further research building on the outputs of PELAgIO and PrePARED will be required in order to confirm (or reject) the hypothesis that displacement for some species at least may be caused by a redistribution of prey. ▪ Research on use of operational wind farm sites, 10 and 20 years after construction could helpfully be undertaken to look at habituation. This may be particularly relevant in relation to highly sensitive species such as Red-throated Diver where avoidance distances are known to vary between sites, and where habituation may be a relevant explanatory factor.	Need to improve characterisation of displacement, understand the driving causes (e.g. redistribution of prey) and then the consequences of it. There is also a need to understand whether habituation occurs (or not), as temporary impacts generally are considered more tolerable in assessment.	Understanding how displacement differs between sites and the mechanisms driving displacement could make assessment less precautionary, though equally could demonstrate ecosystem level impacts on prey. Understanding the consequences of displacement could again reduce precaution in assessment if impacts are tolerable (although for some species in some locations they may not be). If displacement is temporary this could be acknowledged in assessment.
Ornithology – Baseline Understanding	▪ Fill data gaps relating to seabird diet, by developing techniques to analyse prey using eDNA. ▪ Further tagging to understand which areas are used by different populations in the breeding and non-breeding seasons. Stable isotope analysis could help in cases where males and females occupy different areas. ▪ Visual observations remain a cost-effective way of providing fine-scale detail on how birds forage at sea. ▪ There is also a need for more regular monitoring in the light of avian influenza, both to monitor losses, but also health (e.g. discolouration of Gannet irises) and population response.	Understanding prey (potentially using eDNA) helps development of effective compensation[150]. Understanding areas used by birds when not in UK waters provides understanding that is helpful to both compensation and in-combination and cumulative effects. Visual observers are a cheap and effective way of gathering fine-scale detail on birds e.g. age, sex, foraging activity, multispecies foraging aggregations etc. (if added to vessels already needed on site.)	Understanding does not feed directly into the assessment system, and some aspects recommended here may suggest impacts from offshore wind farms both during breeding and overwintering periods. Conversely understanding the range of pressures birds face during the winter may help develop compensatory measures (as most mortality occurs during the winter period).

[150] Although the ECOWINGS project is looking at this, there is likely to be much more work needed in this area.

Ornithology – Cumulative Effects	▪ Further work on collision and displacement needed to ensure cumulative impacts are accurately assessed. Should include consideration of ecosystem change. ▪ Further work on barrier effects – need to understand whether these occur in regions with multiple wind farm sites as this is currently unstudied. ▪ An alternative approach to the problem of cumulative impacts, could be to negotiate agreed areas for development, potentially building on the outputs of POSEIDON and using approaches such as Raghukumar *et al.* 2023 to consider ecosystem change to establish which areas could be developed with fewest impacts. ▪ A cumulative impacts assessment framework for migrant species at flyway scale needs to be developed, including assessment of potential collision, displacement, and barrier effects[151].	It is acknowledged that offshore wind farms have negative impacts. Some of the research that is being recommended will gather more data that confirms this. However, wind farms are a critical element of the energy mix to meet climate and energy security goals and a marine spatial planning approach that considers how to develop with least damage to ecosystems would be a robust approach by ensuring that cumulative and ecosystem impacts are minimized.	A marine spatial planning approach has been adopted in Germany, although there appears to be no easy way of avoiding damage. However, the approach adopted by Raghukumar *et al.* 2023 may be useful in selecting a best-case development scenario.
Ornithology – mitigation	▪ Test the mitigation currently being adopted, namely that bigger turbines with higher air blade gap reduce collisions. This needs verification (see Huso *et al.* 2021). ▪ Other potentially useful mitigation options need trialling and testing: flight corridors, bird friendly design, shape of wind farm (exclude corner turbines), benefits of curtailment systems need to be quantified, investigation of radar to inform switch off during migration, painted turbine blades to reduce bird collisions, auditory alerts and deterrents, and use of less impactful lighting for petrels and shearwaters.	Offshore wind farm design can be optimized to potentially reduce impacts on birds but there is lack of evidence around potential mitigation techniques, and the lack of a funding mechanism constrains progress. Mitigation options should be explored as a priority as some measures may be effective in reducing compensation requirements.	Since all potential mitigation option lack data and evidence to support them, investigation of these potentially useful options could be progressed at a site where compensation is difficult or uncertain.
Benthic – Baseline Understanding	▪ Provide high resolution mapping of benthic features deemed to have a relatively high consenting risk in relation to offshore wind. ▪ Develop an agreed approach on how to value, mitigate and, if required, compensate sandbank features	Maps indicating areas of relatively higher consenting risk will be used to inform Marine Spatial Planning (MSP) and direct offshore wind development towards areas of relatively lower consenting risk via future leasing processes. Sandbank features may be geographically specific in their ecological value and function, determining how these should be valued, mitigated and if required, compensated would benefit offshore wind moving forward, as it would reduce consenting delays.	Engage with programmes such as POSEIDON, ECO-WIND Accelerate, Collaboration on Offshore Wind Strategic Compensation (COWSC), PELAgiO as well as SNCBs. Acknowledge outputs of benthic programmes along with specialist advice to develop mapping and an agreed approach to identifying suitable sandbank compensation.

[151] For example, if we understand the migratory routes of a particular population, we can look at which offshore wind farms these birds may pass through and the likely cumulative collision and displacement impacts from multiple birds, flying through and flying around multiple developments.

Benthic – Compensation	▪ No specific areas have been recommended for research at this time.	It is acknowledged that there are inherent difficulties around the compensation of subtidal features such as sandbanks. Once Marine Net Gain is mandated, consideration of how to compensate sandbank and other subtidal features will be required. Work to understand these features and the potential for compensation is needed.	Engage with groups such as COWSC.
Marine Mammal – Baseline Understanding	▪ Review current monitoring guidelines (baseline, construction and post-construction), set out an agreed methodology for generating abundance estimates from PAM, or combining DAS/PAM datasets	Current monitoring is based on DAS alone, and densities are considered too low in comparison with other datasets. Correction factors are being developed for Harbour Porpoise but will be harder to generate for other species (except seals) potentially leading to uncertainty within assessments. Routine use of PAM, supplemented by DAS, would hugely improve quality and quantity of baseline data gathered.	Marine mammals are likely to become a greater consideration at future sites which are further offshore. Establishing better methods to assess impacts would potentially reduce uncertainty and delay.
	▪ Investigate techniques which can be used to look at foraging activity to improve understanding around how an area is being used - e.g. foraging buzzes from PAM, or tagging for seals.	Understanding activity and usage is important in establishing the value of a potential development area: if a site is located in a migration corridor, the nature of the impacts could be low, whereas if it is located in a calving area impact would be greater.	PAM data would provide some of this information for some species, so guidelines would need to specify that this is a required component of analysis.
	▪ Individual-based studies (within strategically selected locations/populations) could be used to support understanding, for example using either pelage patterns in seals or fin or fluke marks in cetaceans. Mark-recapture analysis accounting for imperfect detection can be used to analyse data. This can over time provide information on survival rates and reproductive rates.	This demographic data, if gathered consistently over time, could be used in multiple ways: i) to look for potential signs of negative impacts on local populations, ii) to look at where there may be detectable benefits due to offshore wind farm development as fish aggregating devices, or iii) to look for benefits to populations from fisheries-related compensation (also likely to benefit marine mammals as well as seabirds).	Look for locations where this type of study could be easily undertaken by tourist vessels, volunteers, local groups.

	▪ A baseline understanding of the development area, extending around physical oceanographic features such as gyres, eddies, and currents, which influence the distribution of predators.	Could inform selection of development areas within a wider region to avoid areas of high ecological value.	Agree on procedure whereby demonstrable avoidance of high-risk areas could accelerate consenting timescales. Look at methods whereby this type of monitoring could be achieved and whether it could be integrated within other surveys typically required for offshore wind fam development (e.g. geophysical surveys).
	▪ Monitoring temperature and salinity before and after construction will indicate whether the installation of the wind farm has changed natural patterns of water mixing or stratification, which in turn may impact on prey and top predator distributions.	Baseline understanding required to ensure impacts can be monitored in the post-construction period.	Work with developers and regulators to set up long term monitoring programmes
	▪ Similar studies to ECO-Wind Accelerate and PrePARED will be required at floating offshore wind farm sites in order to understand whether floating sites could have a reef effects and/or effects on the seabed. (While floating offshore wind farms may have less of an impact on the seabed, their structures still reach several meters into the water column).	Baseline monitoring is needed to look at potential impacts within the post-construction phase. Monitoring FLOW sites now is an important step in de-risking future FLOW development.	If impacts of FLOW are assessed carefully this could de-risk future development, especially if construction and operational effects are reduced relative to fixed-base sites.
Marine Mammals – entanglement with FLOW infrastructure	▪ Underwater monitoring programmes at operational FLOW sites will provide information on entanglement risk.	As with bird collisions, entanglement is likely to be a rare event, and therefore applying significant monitoring effort now will reduce future uncertainty, and provide the data required to make consenting decisions in time for the scale up of FLOW technology.	Engagement with existing monitoring programmes, look at expanding these to monitor a greater area – data would be used in future FLOW assessments.

Fish – EFH Baseline Mapping	▪ Update mapping of herring spawning habitat and sandeel habitat. ▪ Apply other ecological datasets (bird utilisation areas; key marine mammal foraging grounds) to updated mapping outputs. ▪ Determine the condition of key sandeel and herring spawning habitat and existing pressures.	As herring and sandeel show high site fidelity there is greater confidence in mapping their habitats than many other fish species. They are also a key part of the trophic web forming essential prey for a number of seabirds and marine mammals. Outputs from the research will confirm the location of the most important fish habitats within UK waters and thus mitigate the potential for offshore wind proposals to overlap through their acknowledgment in the MSP process.	A number of EFH studies are underway (e.g. work by NE). Initially engagement with UK wide SNCBs (and regulators) should be sought to understand how the outputs of these and/or recent work (e.g. Marine Scotland EFH maps) might be aligned/updated to provide high confidence outputs for herring spawning and sandeel habitat across the UK. The intention to amalgamate these updated mapping outputs with spatial mapping work on other ecological features (e.g. seabirds, mammals) will require engagement with groups such as Royal Society for the Protection of Birds (RSPB), British Trust for Ornithology (BTO), Seawatch Foundation and Sea Mammal Research Unit (SMRU) as the work progresses.

Fish – EMF with FLOW	▪ Determine potential for cumulative effects from EMF emittance at commercial FLOW farms. ▪ Development of suitable intra-array cable materials which provide optimal EMF insulation. ▪ Multiple research programmes to further understand the sensitivity of UK pelagic (commercial) and diadromous fish species to EMF.	There exists significant uncertainty around potential EMF effects on pelagic fish and whether the potential for an effect could be increased cumulatively (multiple cables in one farm and/or multiple FLOW developments). Reducing this uncertainty will help mitigate future consenting risks for FLOW.	Agreement on suitable proxies with stakeholders for progressing work on potential EMF effects. With the adoption by developers of cable materials which effectively reduced EMF emittance, the requirement for long term monitoring programmes (to inform understanding of cumulative effects) and multiple research studies would be mitigated. This possible approach should be explored.

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