Sectoral Marine Plan – Roadmap of actions

November 2022

Scottish Government
Riaghaltas na h-Alba

Summary

The offshore wind industry is set to play a crucial part in Scotland's economy in coming decades as part of efforts to generate 50% of Scotland's energy from renewable sources by 2030 and to reach Net Zero by 2045. At present, there are five operational offshore wind farms in Scottish waters, with a further six under construction, or having received planning consent. As part of the Sectoral Marine Plan (SMP), the ScotWind Leasing rounds seeks to add further offshore wind capacity. However, several of the areas identified for development are subject to the highest levels of ornithological constraint, as defined by the SMP. The Habitats Regulations Appraisal (HRA) process concluded that further empirical evidence was required before it could be concluded that the risk to seabird populations within Plan Options (POs) E3, NE2, NE3, NE4 and NE6 could be reduced to an acceptable level.

The overarching aim of this work is to develop a roadmap of research required for addressing the evidence gaps identified in the SMP and its HRA in order to provide the evidence base to re-assess impacts to seabird populations within sites under the highest levels of ornithological constraint as part of the iterative plan review process. A Theory of Change approach was used in order to identify the outcomes, outputs and actions that were required in order to achieve the goal of unlocking offshore wind potential in Scottish waters by addressing the ornithological evidence gaps identified in the SMP. Theory of Change is a top-down approach, and over a series of workshops, stakeholders were invited to identify the sequence of events and actions that were required to deliver the overall goal. Key outcomes included:

- Reduced uncertainty over connectivity between plan options & designated features of SPAs in the breeding and non-breeding seasons
- Reduced uncertainty over collision, displacement, and barrier effects in each PO
- Understanding of population-level impacts on the populations concerned
- Understanding the contribution of marine spatial planning and mitigation to reducing impacts and unlocking plan option potential for Offshore Wind Farms

Stakeholders were then invited to identify the key outputs required to deliver these outcomes (e.g., improved spatial models of seabird distribution), and the actions required to deliver these outputs (e.g., regional aerial surveys). Finally, these actions were prioritized and used to identify a series of projects that could be used to provide the empirical evidence required to determine whether or not it could be concluded that the risk to seabird populations in the areas subject to the highest ornithological constraints could be reduced to an acceptable level.

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1. Introduction

The offshore wind industry is set to play a crucial role in Scotland's economy as part of efforts to generate 50% of Scotland's energy from renewable sources by 2030 and to reach Net Zero by 2045. This means that, as we emerge from the COVID-19 pandemic, the industry is likely to play a central role in a green economic recovery.

At present, there are five operational offshore wind farms in Scottish waters, including the world's first floating offshore wind project. A further six are either under construction or have been consented. Building on this success, the recently completed ScotWind Leasing round aimed to deliver additional energy from offshore wind. The Sectoral Marine Plan for Offshore Wind Energy (SMP) set out the spatial Plan Options for the new round of offshore wind seabed leasing, known as ScotWind and managed by Crown Estate Scotland (CES). The SMP assessed the impact of up to 10GW of new development (Figure 1). In January 2022, CES announced that Option Agreements will be offered to 17 projects with a total stated capacity ambition of up to 25GW[1] (Figure 1). Whilst offshore wind energy offers the potential to mitigate the negative impacts of climate change by reducing reliance on fossil fuels, concerns remain over the potential for negative environmental impacts, particularly in relation to birds (Bradbury et al., 2014; Furness et al., 2013; Garthe & Hüppop, 2004). The key effects associated with offshore wind are believed to be collision with turbines, displacement and barrier effects (Cook et al., 2018; Dierschke et al., 2016; Masden et al., 2012; Mendel et al., 2019;Thaxter et al., 2018). Prior to consent for a development being granted, the potential for these impacts to negatively affect populations, particularly those of designated features of protected sites, must be considered as part of the Environmental Impact Assessment (EIA) and Habitats Regulations Appraisal (HRA) processes.

The Strategic Environmental Assessment (SEA)[2] for the Scottish Governments' SMP for Offshore Wind Energy[3] highlighted the potential for negative effects in relation to the Plan Options (POs, Figure 1). Following on from this, the HRA[4] process for the SMP highlighted potential cumulative ornithological impacts as a key constraint to the future delivery of offshore wind in Scottish waters. In five of the POs (E3, NE2, NE3, NE4 and NE6), which include five option agreements with a capacity of up to 4.5 GW, it was determined that further empirical evidence was required before it can be concluded that the risk to seabird populations can be reduced or is at an acceptable level. An additional two sites (E1 and E2) were identified as needing strategic regional surveys and assessments to address

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[1] ScotWind offshore wind leasing delivers major boost to Scotland's net zero aspirations https://www.crownestatescotland.com/news/scotwind-offshore-wind-leasing-delivers-major-boost-to-scotlands-net-zero-aspirations

[2] Draft Sectoral Marine Plan for Offshore Wind Strategic Environmental Assessment https://www.gov.scot/publications/draft-sectoral-marine-plan-offshore-wind-energy-strategic-environmental-assessment/

[3] Draft Sectoral Marine Plan for Offshore Wind Strategic Environmental Assessment Habitat Regulations Appraisal https://www.gov.scot/publications/draft-sectoral-marine-plan-offshore-wind-energy-habitat-regulations-appraisal/

[4] Sectoral Marine Plan for Offshore Wind Energy https://www.gov.scot/publications/sectoral-marine-plan-offshore-wind-energy/

uncertainties about the potential cumulative impacts on seabirds, particularly in the non-breeding season.

This work aims to deliver a roadmap to identify actions that will provide an evidence base for assessing ornithological constraints on SMP POs. These projects will then facilitate the ScotWind Iterative Plan Review by identifying immediate research priorities to be undertaken by the Ornithology Working Group and the Scottish Marine Energy Research (ScotMER) programme.

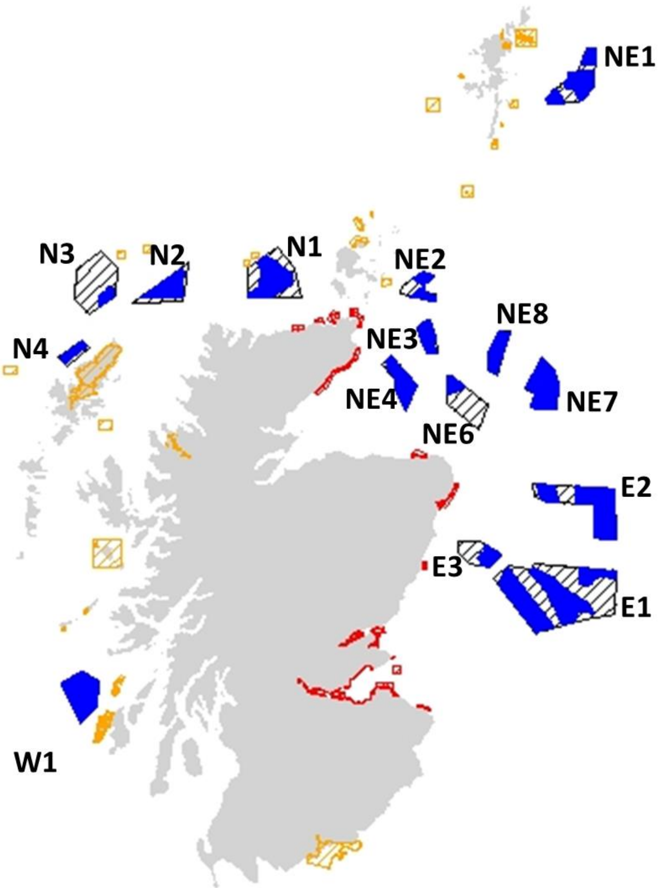

Figure 1 Plan Options identified as part of the Sectoral Marine Plan for Offshore Energy (Black) and resulting Scot Wind Agreement Offers as of February 2022. Also shown are Special Protection Areas for which the Strategic Environmental Assessment highlights the potential for negative impacts in relation to the plan options (orange), and for which the Habitats Regulations Appraisal concluded that it was not possible to conclude that there would be no adverse effects on site integrity resulting from development within POs (red) without the applications of mitigation measures discussed above.

2. Approach

2.1 Theory of Change

We used a Theory of Change (ToC) approach to support the development of an ornithology roadmap to identify the actions needed to address the uncertainties set out in the SMP. ToC is a decision support tool which uses a top-down approach to illustrate the causal links and identify the sequences of events necessary for an activity to have the desired outcome (e.g. Rice et al., 2020). The first step in this process is to identify and agree the high-level **goal** that one is trying to achieve. The next step is to identify the **outcomes** necessary to deliver this **goal** (e.g., reduced uncertainty about cumulative impacts) and consequently the **outputs** required to deliver these **outcomes**. The final step is to identify the **actions** required to deliver these **outputs** (in this instance, the research projects required to fill evidence gaps). Goals, outcomes, outputs and actions are highlighted throughout the text.

2.2 Workshop

The workshop took place over three days in March 2021. Participants were drawn from a broad range of stakeholders with interest in the offshore wind industry in Scotland including, consultants, governmental advisers and regulators, funding bodies, non-governmental organisations, academics, and other researchers (Table 1).

Table 1 Workshop Attendees.

Attendee	Organisation
Adam Butler	BIOSS
Esther Jones	BIOSS
Aonghais Cook	BTO
Daniel Johnston	BTO
Liz Humphreys	BTO
Liam Leahy	Carbon Trust/ORJIP
Lindsay Scott-Hayward	CREEM
Kate Bellew	Crown Estate Scotland
Andy Webb	HiDef Aerial Surveying Ltd.
Julie Black	JNCC
Bob Furness	MacArthur Green
Gillian Vallejo	Natural Power
Graham Cook	Natural Power
Graham Garner	Natural Power
Aly McCluskie	RSPB
Lucy Wright	RSPB
Drew Milne	Scottish Government
Gayle Holland	Scottish Government
Janelle Braithwaite	Scottish Government
Julie Miller	Scottish Government
George Lees	NatureScot
Glen Tyler	NatureScot
Francis Daunt	UKCEH
Kate Searle	UKCEH

3. Workshop Discussions

3.1 Theory of Change - Goal, Outcomes, Outputs and Actions

The application of the Theory of Change approach to identifying projects to address the key evidence gaps identified in the SMP is illustrated through an example below (Figure 1). Ahead of the workshop, the **goal** of "unlocking offshore wind potential by addressing the ornithological evidence gaps in the SMP and its HRA" was agreed with the Scottish Government. To deliver this goal, several **outcomes** are required to address these evidence gaps. For example, there is substantial uncertainty surrounding predictions of collision risk in relation to existing projects. Reducing this uncertainty is a key **outcome** required to deliver the overall **goal**. Models used to estimate collision risk are highly sensitive to input parameters, such as flight speed. Consequently, to contribute to the **outcome** of reducing uncertainty surrounding collision risk, an **output** of improved estimates of flight speed is required. Finally, to deliver this **output**, **actions**, such as the collection of high-resolution GPS data, are required.

The aim of the workshop was to identify the **outcomes**, and thus **outputs** and **actions**, required to deliver the goal of unlocking offshore wind potential by addressing ornithological evidence gaps identified in the SMP and its HRA (Figure 2).

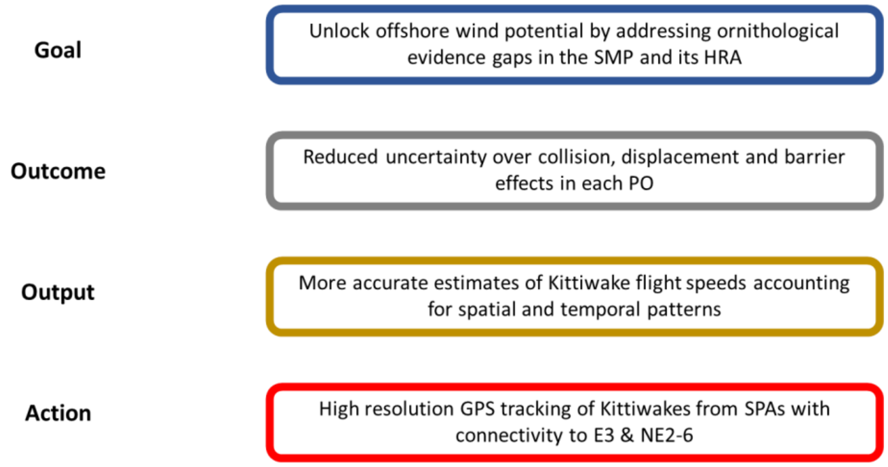

Figure 2 Example of how the Theory of Change approach was applied to the goal of unlocking offshore wind potential by addressing ornithological evidence gaps in the SMP and its HRA through the collection of high-resolution GPS data to enable more accurate estimates of flight speed and reduce uncertainty over predicted collision rates.

The primary concern of identifying measures to generate the evidence required to assess the potential to unlock areas identified by the SMP as being of high ornithological importance formed the central theme of the workshop. Consequently, the first stage of the workshop was to identify the outcomes required to deliver this goal. Discussions focussed on the primary aim towards:

- Identifying the measures needed to unlock areas identified by the SMP as being under ornithological constraint (E1-3 & NE2, NE3, NE4 & NE6).

However, additional discussion was facilitated towards uncertainties involving species and populations previously thought to be exposed to potential impacts due to lack of connectivity with offshore wind development in Scottish waters, such as shearwaters, storm-petrels and skuas, but which may have greater connectivity to POs in the North and West of Scotland. Ultimately, discussions coalesced around four topics reflecting the **outcomes** required to unlock offshore wind potential, which are summarised in Figure 3.

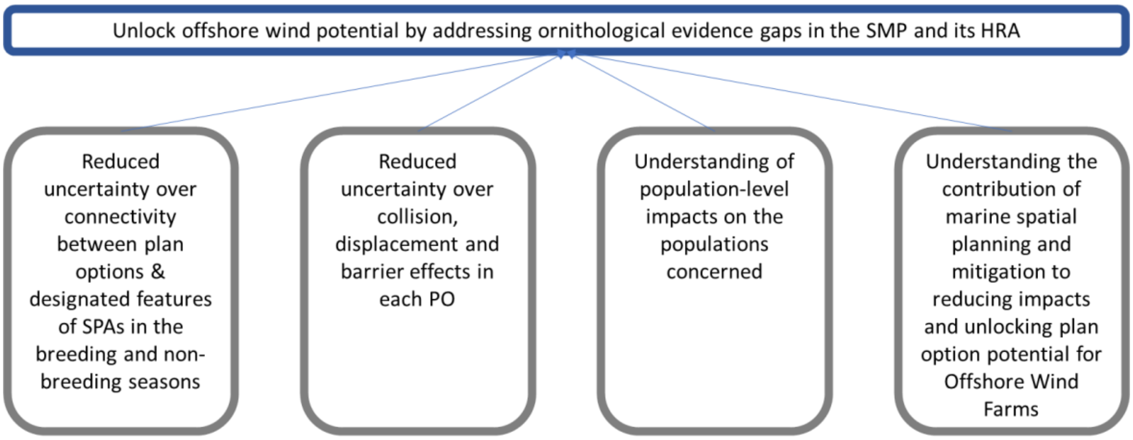

Figure 3 Goal and outcomes identified as part of the roadmap to address ornithological uncertainties identified as part of the Sectoral Marine Plan.

The relative importance of these **outcomes** varied by PO. For example, in relation to E1, E2 and N1-4, uncertainty over the potential for connectivity with Special Protection Area (SPA) populations was identified, and reducing that uncertainty was seen as key to unlocking offshore wind potential within those POs. Whilst reducing uncertainty over connectivity was also highlighted in relation to some of the other POs, it was felt that reducing uncertainty over predicted impacts from collision, barrier effects and displacement, and identifying options to reduce the predicted impacts of existing projects was of greater priority. More generally, participants also highlighted the importance of gaining a greater understanding of the potential population-level impacts on the populations concerned.

Having identified these high-level outcomes, the next step of the workshop was to identify the **outputs** required to deliver these. As part of this, workshop participants also identified the **actions** required to deliver these **outputs** (Figures 4-7).

3.1 Outcome: Reduced uncertainty over connectivity between plan options and designated features of SPAs in the breeding and non-breeding seasons (Figure 4)

A key first step in unlocking wind energy potential is to get **a better understanding of the distribution of birds within each PO and establish what connectivity exists with SPA populations [OUTPUT]** to determine whether they may be at risk from the effects associated with offshore wind farms. This applies to both the breeding season and the non-breeding seasons.

Outside the breeding season, there remains uncertainty surrounding the origins of birds within each of the PO areas. As many species are at their breeding colonies for only a small proportion of the year, uncertainty in connectivity between POs and SPA populations makes assessing population-level impacts challenging. Initially, this is likely to require an improved understanding of the distributions of birds outside the breeding season, and the processes driving those distributions. Having a clearer understanding of the distribution of birds outside the breeding season will not remove the need to have aa better understanding of the locations in which they breed. At present, this is typically done with reference to Biologically Defined Minimum Population Scales (BDMPS) (Furness, 2015). However, workshop participants highlighted the value of moving towards approaches based on tracking data with which to assess connectivity and apportion birds from outside the breeding season back to their breeding colonies, with auks a particular priority. Whilst the **miniaturisation of tracking devices [ACTION]** may make the long-term **deployment of GPS devices [ACTION]** more practical for some species, it was recognised that in most cases, this was likely to involve the **deployment of geolocators [ACTION]** due to their smaller size, long battery life and ease of long-term attachment. However, the high degree of uncertainty in distributions derived from geolocator data was acknowledged, and participants **highlighted the need to improve the spatial resolution of these data [OUTPUT]**. Whilst these uncertainties were of relevance to all the POs, they were felt to be of greatest importance in relation to E1 and E2 where uncertainties in relation to the distribution of birds outside the breeding season were identified in the SMP.

Tracking of breeding adults from selected SPA colonies will provide only partial information on origins, as many seabirds are immature or originate from colonies where tag deployment is not practical. Therefore, capture of birds at sea in POs and tracking of those birds may be necessary if a better understanding of origins is sought, though there is a need to consider both the feasibility of this and the implications in relation to the licensing of tag deployment. This may necessitate the use of approaches such as Motus tracking (Taylor et al., 2017b) given the need for lightweight devices and the challenges of recapturing birds of unknown breeding origins, and **development of the methodology for capture of birds at sea would be required [ACTION]**. Alternatively, **deploying colour marks that can be detected as part of survey efforts [ACTION]** may be valuable.

Workshop participants also highlighted a need for **improved understanding of distribution and connectivity to SPAs during the breeding season [OUTPUT]**, both generally, and in relation to specific SPAs. In contrast to the non-breeding seasons, it was felt that it was more straightforward to identify **potential links between breeding adults from SPA populations and POs using GPS tracking studies [ACTION]**. However, such studies should not rely on a single years' worth of data, as there may be considerable interannual variation in the at-sea distribution of breeding birds from an SPA (e.g. Thaxter et al., 2015). The relative importance of a PO to foraging birds should not simply be assumed to be the proportion of years in which it is used by foraging seabirds. For example, a PO may take on disproportionate importance relative to its use if it is only used in years when foraging conditions are poor (e.g. Bogdanova et al., 2014). To account for this, it will be important to **model species distributions in relation to oceanographic variables and ecosystem processes [OUTPUT]**, some of which may vary on an annual basis (e.g. Robertson et al., 2014; Scott et al., 2010). Furthermore, it is much more difficult to assess what proportion of birds in POs are not adults from local SPAs, and that cannot easily be determined by tracking breeding birds from SPAs, highlighting the importance of **new apportioning methods [OUTPUT] that integrate tracking and survey data [ACTION]**.

In the North East region, where POs are presently under a high level of ornithological constraint, uncertainties surrounding distribution within POs and connectivity with SPAs were also highlighted. There were specific questions relating to the use of PO NE6 by kittiwakes *Rissa tridactyla* from the Troup, Pennan and Lion's Heads SPA, and the origin of great black-backed gulls *Larus marinus* within POs NE2, NE3, NE4 and NE6. **PO connectivity with SPAs at NE could be addressed by GPS tracking [ACTION]**. Great black-backed gulls are a designated feature of East Caithness Cliffs SPA, and several other SPAs on the Orkney Islands. At present, there is very limited data on great black-backed gull foraging ranges (Thaxter et al., 2012; Woodward et al., 2019), partly due to potential tag effects, meaning there is uncertainty relating to the apportioning of the predicted impacts on great black-backed gulls to SPA populations. There is a need to **consider the technical feasibility of tagging birds at new sites [ACTION]**, both in relation to the capture of individuals and the recovery of any data collected. The initial focus for this work should be the East Caithness Cliffs SPA, as the closest SPA population. However, depending on the outcome of that work, it may be necessary to expand the tracking to other SPA populations or, consider capturing birds at sea and deploying GPS-GSM tags, which download data over the mobile phone network, to link birds back to breeding populations.

There were also more general questions relating to the use of POs E1 and E2 by designated features of the Buchan Ness to Collieston Coast, Fowlsheugh, Ythan Estuary, Sands of Forvie and Meikle Loch, Firth of Tay and Eden Estuary, Firth of Forth Islands, Firth of Forth and St. Abbs Head to Fast Castle SPAs. As with the non-breeding season, workshop participants highlighted the need to develop **improved models of seabird distribution [OUTPUT]**, **combining survey and GPS tracking data [ACTION],** where available (e.g. Matthiopoulos et al., 2022). These models should incorporate environmental covariates in order to facilitate an improved understanding of the drivers of seabird distribution at sea (e.g. Cleasby et al., 2020; Waggitt et al., 2019; Wakefield et al., 2017a), and how offshore wind farms may influence this.

Building on Woodward et al. (2019), the potential for estimating SPA-specific foraging ranges was highlighted alongside an interest in **examining the extent of spatial segregation in breeding seabird foraging areas [OUTPUT]**, as suggested for gannets *Morus bassanus* and kittiwakes (Wakefield et al., 2013, 2017a). Addressing these issues will help to improve the apportioning of birds recorded within the POs back to their breeding colonies during the breeding season. To improve this further, it will be necessary to **quantify the numbers and origins of non-breeding and immature birds [ACTION]** present within each of the POs.

Regardless of season, efforts to improve methodologies for apportioning will require the accurate characterisation of baseline populations within each PO through the **collection of survey data [ACTION]**. This may be at the level of the individual PO, or, in the case of the east coast sites, a regional survey may be valuable.

Whilst not subject to a high level of ornithological constraint at present, notable uncertainty was highlighted in relation to **the potential for breeding seabirds to interact with some of the more northerly POs [OUTPUT]** (N1-4). These include species such as skuas, shearwaters and storm-petrels which have not, to date, been prominent in offshore wind farm EIAs. An added complication in the case of shearwaters and storm-petrels is the high level of nocturnal and crepuscular (twilight) activity they exhibit meaning that they may not be detected by existing survey methodologies. The **miniaturisation of tracking devices**, or, **if feasible, the use of Motus-style tracking [ACTION]**, may help with this. However, the relative importance of such studies will be determined by the extent of development planned for these POs.

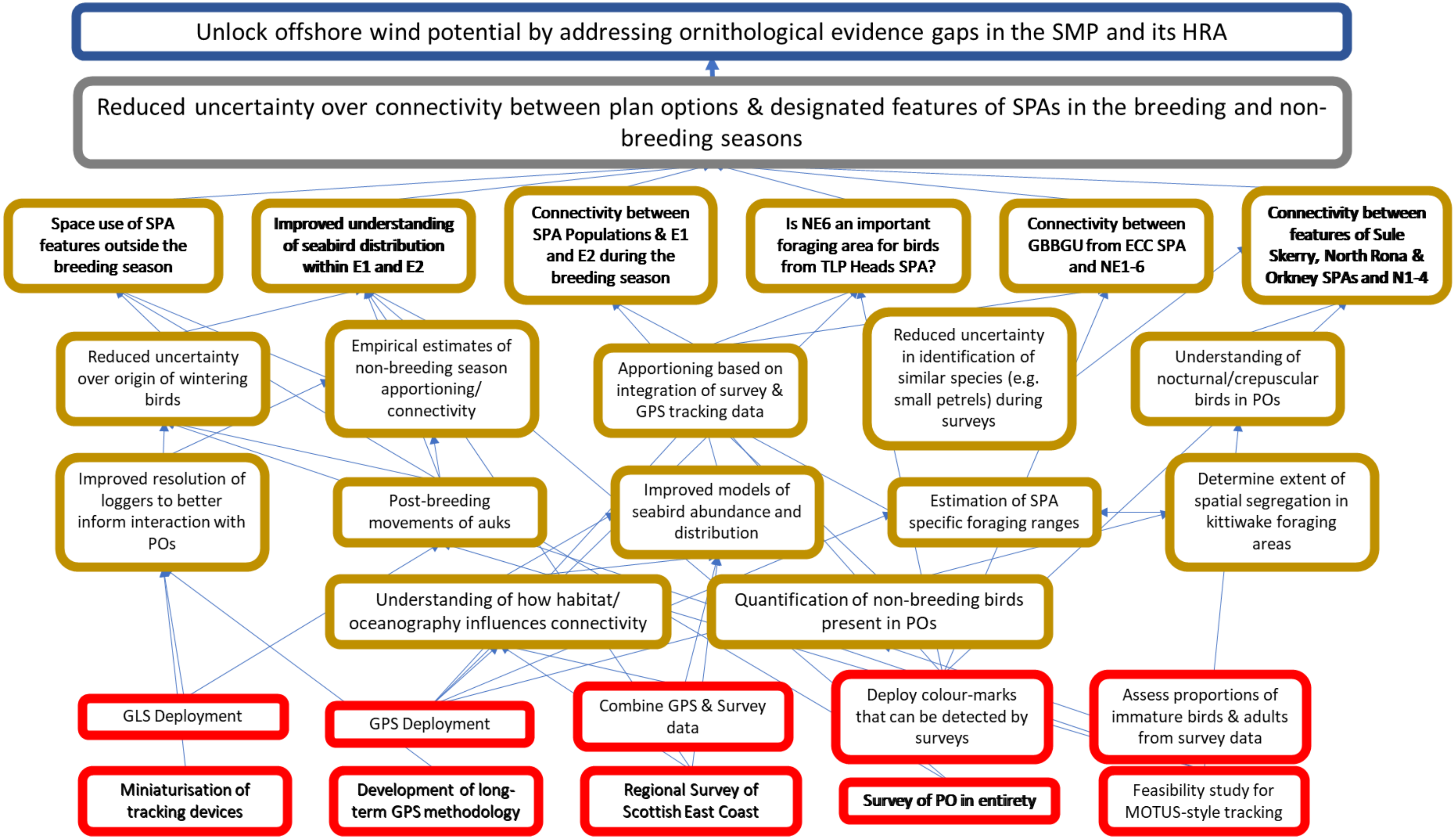

Figure 4 Outputs (orange boxes) and underpinning activities (red boxes) required to deliver reduced uncertainty over connectivity between plan option areas and designated features of SPAs.

3.2 Outcome: Reduced uncertainty over collision, displacement, and barrier effects in each PO (Figure 5)

Quantifying the impacts of collision, displacement and barrier effects are a key part of impact assessments for offshore wind farms. However, uncertainty remains in relation to predicting the population-level consequences of impacts associated with a development. At present, the predicted impacts of consented and existing projects mean that there are ornithological constraints within POs NE2, NE3, NE4, NE6 and E3. In addition to this, uncertainties surrounding the distribution of key species within POs E1 and E2 (notably gannets, but also auks), and in relation to the impacts of displacement and collision on some of the species present in N1-4, pose challenges to assessing the impacts of developments within those POs. To understand whether offshore wind potential highlighted in the SMP can be unlocked, it will be important to reduce these uncertainties.

Reducing the uncertainty surrounding the impacts of collision, displacement, and barrier effects in relation to offshore wind farms within the POs requires assessing species connectivity with wind farms and, the risk posed to the species by each of these effects. Reducing uncertainty in relation to connectivity with offshore wind farms is addressed above. However, key uncertainties remain in relation to how the population-level consequences associated with different effects are assessed.

3.2.1 Displacement and barrier effects

At present, displacement is usually assessed using a matrix approach (e.g. Busch & Garthe, 2016) which combines the proportion of birds displaced with the proportion likely to experience mortality as a consequence of being displaced. As offshore wind farms have been constructed, understanding of the proportions of birds likely to be displaced or, to experience barrier effects has improved (Dierschke et al., 2016). **Ensuring that information from post-construction monitoring studies, such as that reported in Dierschke et al., (2016), is incorporated into assessments [OUTPUT]** will help to reduce uncertainty surrounding the predicted magnitude of displacement. However, these data are biased towards populations of species present in the southern part of the North Sea. Careful consideration is required to determine whether these findings may be transferable to Scottish waters. This could include **analysis and peer-review of post-construction monitoring data from existing wind farms [ACTION]**, such as Beatrice, and others, such as Moray East and Neart na Gaoithe, which will be fully commissioned in the near future. In the past, post-consent monitoring data have been collected using inconsistent methodologies, and have been difficult to access (Marine Management Organisation, 2014). It is important to ensure that data from current and future post-consent monitoring studies are peer-reviewed, made publicly available and incorporated into tools such as Cumulative Effects Framework (CEF) being developed as part of a Scottish Government funded project[5].

[5] Cumulative Effects Framework for Key Ecological Receptors https://www.ceh.ac.uk/our-science/projects/cumulative-effects-framework-key-ecological-receptors

Whilst, for many species, we may have some understanding of the proportion of birds likely to be displaced, there is still uncertainty about the demographic consequences of that displacement at both an individual and a population level. Displacement and barrier effects are likely to affect species through an increase in the energetic cost associated with foraging and flight. The matrix approach typically assumes that this will manifest as a reduction in adult survival, while more complex and biologically realistic approaches such as SeaBORD also incorporate impacts on productivity (K Searle et al., 2018). As a result, in order to reduce the uncertainty surrounding the individual and population level consequences of displacement and barrier effects, **it is necessary to better parameterise the relationships between the energetic costs of foraging, the calorific content of food and demographic rates [ACTION]** (Gremillet et al., 2003; Langton et al., 2014). Addressing these questions is likely to require **focussed monitoring of behaviour and energy budgets as well as demographics of key vulnerable species such as auks [ACTION]**, particularly in colonies with connectivity to POs E3, NE2, NE3, NE4 and NE6, which are subject to the greatest ornithological constraint.

Workshop participants also highlighted the need to better understand the potential responses to offshore wind farms by species such as skuas, shearwaters and storm-petrels, which have not been a key feature of assessments to date, but which may be present in POs N1-4 and NE1 during the breeding season. The availability of GPS tracking data for Manx Shearwaters *Puffinus puffinus* from the Irish Sea region, where there are existing offshore wind farms (e.g. Dean et al., 2015) offers a valuable dataset with which to understand the potential response of this species to developments. **Analyses of these data [ACTION] could reduce uncertainty surrounding the extent of displacement of this species by offshore wind farms, and in relation to parameters of relevance to collision risk, such as flight heights and speeds [OUTPUT]**. However, the relative importance of such work will be determined by the extent of development planned for these POs.

There is also a need to understand the consequences of displacement outside the breeding season, when birds are no longer tied to their breeding colonies. This is likely to be challenging given the difficulties associated with long-term deployments of GPS devices on many of the species concerned. However, geolocation loggers typically record wet-dry and temperature data, and **devices such as time-depth-recorders (TDRs) should be deployed alongside geolocation loggers [ACTION]** (e.g. Duckworth et al., 2018; Dunn et al., 2020); the resulting data can be used to infer daily activity budgets, and together with colony monitoring could inform for **the potential demographic consequences of displacement during the non-breeding season [OUTPUT]** should core foraging areas be lost. This may have direct impacts on over-winter survival or, carry-over effects on productivity or survival in the subsequent breeding season (McKnight et al., 2020) The value of deploying geolocators to establish connectivity between SPAs and POs is highlighted above. However, if analytical methods could be developed to enable a more refined estimate of a birds' location, this could be used to give a clearer indication of the winter range of birds from a given colony, and hence their vulnerability to being displaced from a foraging area. If combined with an assessment of a birds' daily activity budget from wet/dry/temperature or TDR data, this could give a clearer indication of the demographic and energetic consequences of displacement during the non-breeding season. Any impact of displacement on survival during the nonbreeding season is likely to interact with impacts of food abundance and weather on overwinter survival (Fort et al., 2013; Reynolds et al., 2011). There may be no impact of displacement on birds with abundant food, whereas birds that are working to their limit in an environment where food is scarce may die if displaced, meaning a better understanding of relationships between food abundance and overwinter survival would be desirable, especially for auks. Whilst a key question in relation to POs E1 and E2 relates to the extent of connectivity with SPAs outside the breeding season, it is also important to understand the potential consequences of displacement from these areas. This will help to **reduce uncertainty surrounding the demographic consequences of loss of foraging habitat, including potential carry-over effects, outside the breeding season [OUTPUT]** and is also of importance to the POs subject to the greatest ornithological constraint (NE2, NE3, NE4, NE6 & E3).

3.2.2 Collision

Whilst post-construction data are available to reduce uncertainty in relation to displacement and barrier effects, estimates of collision risk are still largely reliant on modelled outputs. A lack of validation of these collision risk models (CRMs), and their individual components, means that there is still uncertainty surrounding the impact of collision on designated features of SPAs (Masden & Cook, 2016; Masden et al., 2021). Workshop participants identified three key areas where uncertainty surrounding collision risk could be reduced, potentially helping to unlock offshore wind potential within POs under greatest ornithological constraint: 1) **Validation of the model and its components [OUTPUT]**; 2) **Improved quantification of key model parameters [OUTPUT]**; 3) **Revising collision estimates [OUTPUT]** based on the best available data, and consistent models.

The most widely used model is the Band (2012) CRM, and there is a need to **validate both the model itself, and its key components, the Probability of Collision (PColl) and the flux rate [OUTPUT]**. Validation of the model and PColl is likely to require direct observation of seabird interactions, and **quantifying collisions at existing turbines [ACTION]**, with turbine rotor-swept areas through projects such as the Offshore Renewables Joint Industry Programme Bird Collision Avoidance (ORJIP BCA) Project (Skov et al., 2018), and the ongoing project at the European Offshore Wind Deployment Centre (Tjomlov et al., 2021). As such, these may be longer-term aspirations. In addition to collecting data on collisions, a key aspect of these studies has been attempts to quantify avoidance behaviour. Further studies involving the use of **GPS tags [ACTION]** (e.g. Thaxter et al., 2018) and/or **avian radar [ACTION]** would be valuable in quantifying avoidance behaviour at a macro- and meso scale. However, as highlighted in Bowgen & Cook (2018), there is still uncertainty in relation to how these values relate to the avoidance rates used by CRMs, as they do not incorporate aspects of model error. **Reducing uncertainty surrounding how to apply these avoidance rates [OUTPUT]** will be a key part of reducing uncertainty surrounding predicted collision rates.

Estimated flux rates are likely to be a key component of model error (Masden et al., 2021). Using GPS tracking data, it may be possible to test the assumptions relating to bird movements that underpin estimates of the flux rate (e.g., birds move through the wind farm in a straight line at a constant height and speed), **with a view to validating or generating more robust estimates of flux [OUTPUT]** and reducing uncertainty surrounding collision rates within the POs under greatest ornithological constraint. However, in doing this, it will be important to consider the implications for the avoidance rates currently recommended for the Band (2012) Model. At present, in addition to avoidance behaviour, the avoidance rate captures aspects of model error, including in relation to the estimation of flux. Consequently, if we modify how flux is estimated this will have implications for how error is incorporated into the model (Cook, 2021), and avoidance rates would need to be revised to account for changes to the estimation of flux.

Estimated collision rates are also sensitive to estimates of species density, flight height and speed, though the range of values over which these parameters operate is not always clear (Masden et al., 2021). Methods to collect density data have developed in recent years, particularly in relation to the use of digital aerial surveys (Buckland et al., 2012). However, there has been less focus on ensuring robust data are available in relation to species flight heights and speeds. At present, recommended flight speeds are typically based on studies with limited sample sizes (Alerstam et al., 2007), resulting in uncertainty surrounding their wider applicability. Recent GPS tracking data differ from those recommended in current guidance, and show variation according to local conditions (Fijn & Gyimesi, 2018; Masden et al., 2021). **Further analysis of flight speed data [OUTPUT]** to reduce uncertainty surrounding predicted collision rates.

There has been an expansion in efforts to collect species flight height data in recent years (Largey et al., 2021). This has included the use of GPS tags (Ross-Smith et al., 2016), altimeters (Cleasby et al., 2015), radar (Fijn et al., 2015), LiDAR (Cook et al., 2018), laser rangefinders (Harwood et al., 2018), boat (A. Johnston et al., 2014), and digital aerial survey (A. Johnston & Cook, 2016). However, there have been challenges in using these data to assess collision risk (Péron et al., 2020), particularly in relation to understanding how bias and error may drive differences in flight heights recorded using different technologies. Consequently, whilst the collection of site-specific flight height data from POs subject to the highest levels of ornithological constraint would be of value in relation to reducing uncertainty associated with collision risk, this value could be further enhanced **through the collection of flight height data as part of a multi-sensor study [ACTION]**. This would enable better quantification of the error and uncertainty associated with different methods for assessing seabird flight heights. In addition to this, there is the potential for birds to alter their flight heights within a wind farm, or close to turbines, as part of avoidance behaviour (Cook et al., 2014; Thaxter et al., 2018). Consequently, **a comparison of seabird flight heights inside and outside wind farms [ACTION]** would be valuable to explore the extent of this behaviour. Whilst ongoing work funded by the Scottish Government is investigating this using LiDAR, there would be value in extending this more widely using a greater variety of techniques, including GPS tracking data and data obtained using standard digital aerial surveys.

A **better understanding of the influence of behaviour on collision risk [OUTPUT]** is likely to help reduce uncertainty further. Both flight height and speed vary spatially (Cleasby et al., 2015; Fijn & Gyimesi, 2018; Masden et al., 2021), by sex (Lane et al., 2020), and are likely to be linked to behaviours such as foraging and commuting. Approaches such as Hidden Markov Models (HMMs) can be used to classify behaviours, and identify areas used for foraging and/or commuting flight (Thaxter et al., 2019). **Identifying areas used for specific behaviours [ACTION]** may enable us to reduce uncertainty in collision estimates further using **behaviour specific estimates of flight height and speed [ACTION]**. This would also help with spatial planning in each of the POs by identifying areas where collision risk is lowest. Generating the data necessary for these analyses, and to inform analyses of flight height and speed, will require the **deployment of high-resolution GPS tags [ACTION]** on vulnerable species within east coast SPAs, including gannets, kittiwakes, and great black-backed gulls. To ensure that the data reflect the breeding season as a whole, and potentially, parts of the non-breeding season, it will be important to **develop approaches that allow for the long-term deployment of tags [ACTION]** for the species concerned.

In addition to a greater range of data being available to feed into collision risk models, aspects of those models have also changed. The original Band et al. (2007) CRM has been updated to better reflect data collection in the offshore environment (Band, 2012), and take advantage of the continuous flight height distributions produced by Johnston et al., (2014). This has subsequently been refined further through the development of the stochastic collision risk model (sCRM) (Masden, 2015; McGregor et al., 2018) which incorporates variability in the model input parameters in order to characterise the uncertainty surrounding the estimated collision risk. Workshop participants highlighted the potential to reduce uncertainty within the POs subject to greatest ornithological constraint through **refining existing collision risk estimates based on the latest available data [OUTPUT]**, and most up to date iteration of the collision risk model, which could potentially be facilitated using the CEF tool.

Finally, recent data has highlighted individual variation in the responses of both common guillemot *Uria aalge* and gannets to offshore wind farms (Peschko et al., 2021; Peschko, Mercker, et al., 2020). Workshop participants highlighted the need to **better understand individual variation in relation to offshore wind farms [OUTPUT]**, and the implications for the assessment of displacement, barrier effects and collision risk at a population level.

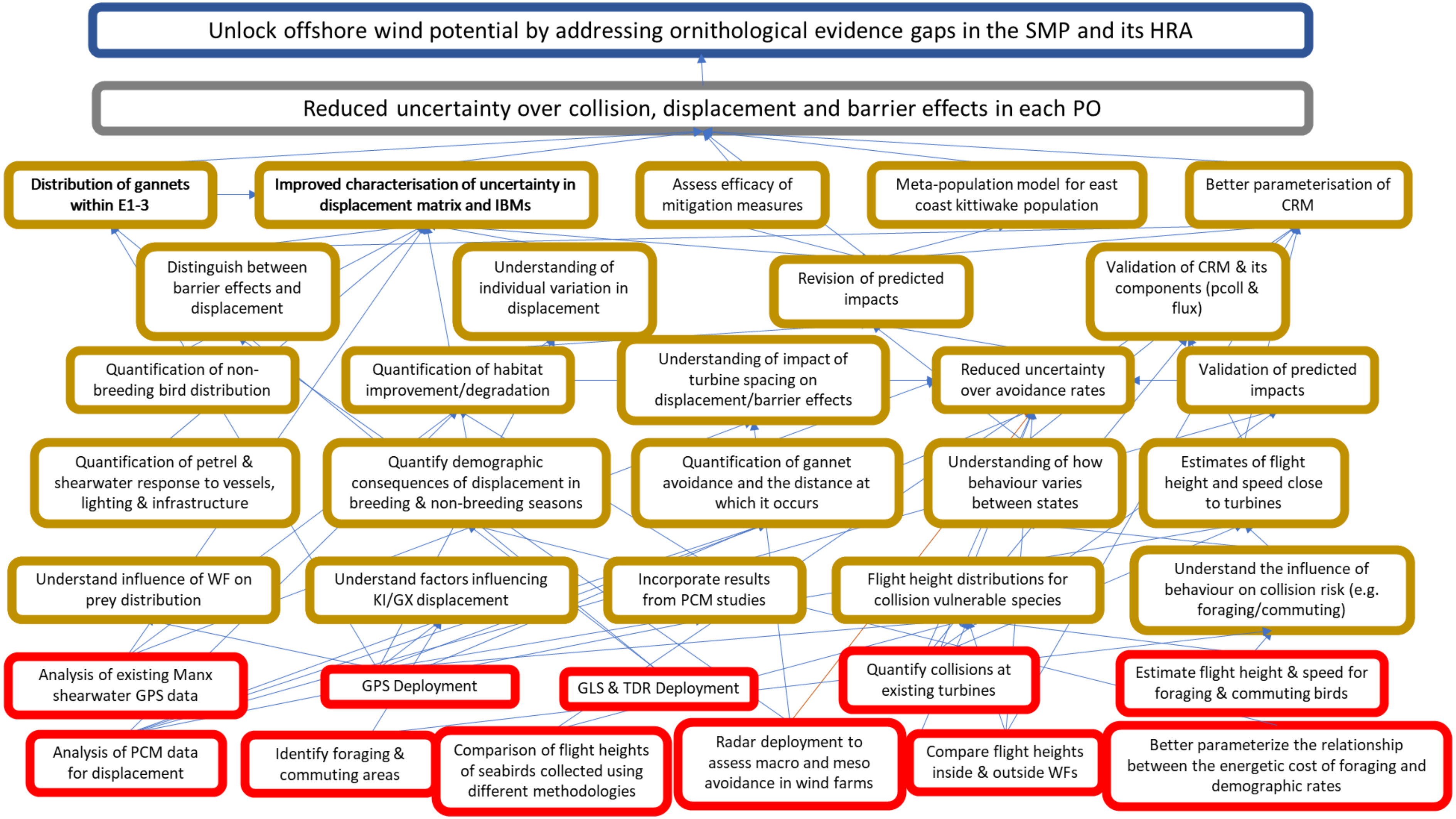

Figure 5 Outputs (red boxes) and underpinning activities (orange boxes) required to deliver reduced uncertainty over collision, barrier effects and displacement within each plan option

3.3 Outcome: Understanding of population level impacts on the populations concerned (Figure 6)

A crucial part of the assessment process is estimating the population level consequences of predicted impacts on designated features of protected sites. This relates to both the impact of an individual wind farm and the cumulative impact of multiple wind farms. The assessments are typically based on population models (Cook & Robinson, 2017) which can be highly sensitive to assumptions relating to demographic parameters and processes (Miller et al., 2019). However, data to parameterise these models are often limited (O'Hanlon et al., 2021; Horswill & Robinson, 2015) meaning that estimates must be inferred from elsewhere, potentially introducing considerable uncertainty into the process. Workshop participants highlighted the need to improve both models and the data underpinning them.

At present, monitoring at colonies where adverse effects on site integrity could not be ruled out is insufficient to detect impacts of the magnitude associated with offshore wind farms (Cook et al., 2019; Horswill et al., 2018). Consequently, there is uncertainty surrounding the data used to parameterise the population models, and the resulting predictions relating to population level consequences. Reducing the uncertainty surrounding the predicted population level consequences associated with offshore wind farms is likely to be a key part of unlocking offshore wind potential in POs. Improving data availability will be key to this. As a first step, there may be historic monitoring data which have yet to be digitised and made available through the Seabird Monitoring Programme. Workshop participants highlighted the value in **ensuring that historic colony population size data are obtained and digitised [ACTION]**, as this would help to **reduce uncertainty surrounding existing colony data, and baseline estimates of population size [OUTPUT]**.

The importance of supporting the expansion of demographic monitoring more widely was highlighted. Existing schemes, including the Seabird Monitoring Programme[6] and Retrapping Adults for Survival[7], are key to this. The impacts associated with offshore wind farms are likely to be detected in demographic rates before they become apparent in population counts. At present, much of this monitoring is carried out by volunteers, and the importance of **ensuring a strategy is put in place to fund and support monitoring work [ACTION]** was highlighted. Reflecting the importance of generating robust estimates of survival, workshop participants identified establishing and **co-ordinating large scale colour ringing studies of vulnerable species such as kittiwakes as a priority [ACTION]** (O'Hanlon et al., 2021). **Establishing the feasibility of novel technologies to improve estimates of demographic parameters (e.g., MOTUS tracking for survival and remote camera monitoring for productivity) [ACTION]** was also discussed.

[6] JNCC Seabird Monitoring Programme Webpages https://jncc.gov.uk/our-work/seabird-monitoring-programme/

[7] BTO Retrapping Adults for Survival https://www.bto.org/our-science/projects/ringing/surveys/ras

Given evidence of individual-level differences in response to offshore wind farms (Peschko et al., 2021; Peschko, Mercker, et al., 2020), there is a need to **better understand the demographic consequences of individual variation in response to offshore wind farms [OUTPUT]**. This is likely to require **GPS tracking studies [ACTION]** to quantify the extent of individual variation in usage of offshore wind farms. Where possible, these should be combined with the demographic monitoring described above, and empirical studies that **quantify effects on fitness-related traits (e.g., behaviour, energetics) and demographic rates at the individual level [OUTPUT]**. This would offer a powerful approach for quantifying population-level consequences, and such opportunities should be fully considered and implemented where possible.

A key concern relating to the POs under the highest levels of ornithological constraint is the potential for significant, negative cumulative impacts. Given the levels of ornithological constraint associated with POs on the East coast, this highlights the need for **validation and/or revision of the levels of mortality likely to result in an adverse effect on site integrity [OUTPUT]**. This will require a better understanding of the processes influencing cumulative impacts. For example, it is unclear whether the impact of multiple wind farms are likely to be additive or multiplicative (Humphreys et al., 2016). Similarly, it is unclear how the impacts associated with multiple anthropogenic pressures should be incorporated into cumulative impact assessments, though the impact of one pressure may exacerbate the impact of another. For example, Frederiksen et al. (2004) highlighted how the impact of industrial fisheries could exacerbate the impact of climate change on kittiwake populations, and Searle et al. (in press.) highlighted the importance of accounting for climate change when quantifying the effects of offshore renewables.

Individual-based models provide one possible way of moving beyond simple additive assumptions in relation to cumulative impacts by simulating the energetic, behavioural and demographic consequences of interacting with multiple wind farms (K Searle et al., 2018), or of interacting with one wind farm in multiple ways (e.g. being susceptible to both displacement and collision effects) (Searle et al., *in press*). However, as a first step, workshop participants highlighted the need to **ensure cumulative impact assessments within those POs were based on currently accepted methodologies, and the latest available data, using tools such as CEF [ACTION]**. Given current constraints and uncertainties associated with offshore wind farms on the Scottish east coast, workshop participants highlighted the value of a **robust cumulative impact assessment for gannet populations within Scottish SPAs [OUTPUT]**.

Kittiwakes pose a particular consenting risk to future Scottish Offshore Wind Farm development. Workshop participants suggested that the **development of a meta-population model for the Orkney and east coast kittiwake population [OUTPUT]** would be of value in relation to reducing uncertainty surrounding projected population level consequences associated with developments in POs NE2, NE3, NE4, NE6 and E3. To develop such a model, there is a need for a **better understanding of the pressures acting on the kittiwake populations concerned, and how these drive processes such as density dependence, immigration, and emigration [OUTPUT]**. Besides the expansion of offshore wind farms, seabirds are subject to multiple pressures (Burthe et al., 2014) including; climate change (Sydeman et al., 2021), fisheries (Sydeman et al., 2017), oil and gas extraction (Begg et al., 2013) and shipping (Schwemmer et al., 2011). A better understanding of how these processes are driving population trends and demographic rates will help to reduce uncertainty in models of population response to offshore wind farm impacts.

Whilst incorporating demographic processes into population models can increase biological realism, in many cases, they act as a buffer to the predicted negative effects associated with wind farms. At present, the evidence with which to properly parameterise these processes is very limited (Horswill & Robinson, 2015). As a result, given the need for assessments to be precautionary, models are typically fitted assuming closed populations and no density dependence (Cook & Robinson, 2017), resulting in increased uncertainty surrounding the predicted population level consequences associated with offshore wind farms. Consequently, to properly parameterise models with greater biological realism, there will be the need to ensure that the impacts of existing pressures arere properly accounted for in demographic rates and processes. This would necessitate **the collection and collation of colony-specific kittiwake data from Orkney and east coast colonies [ACTION]** to properly **quantify baseline population estimates** and **demographic rates [OUTPUT]**, and an examination of these data to **quantify any density dependent processes experienced by these kittiwake populations [ACTION]**.

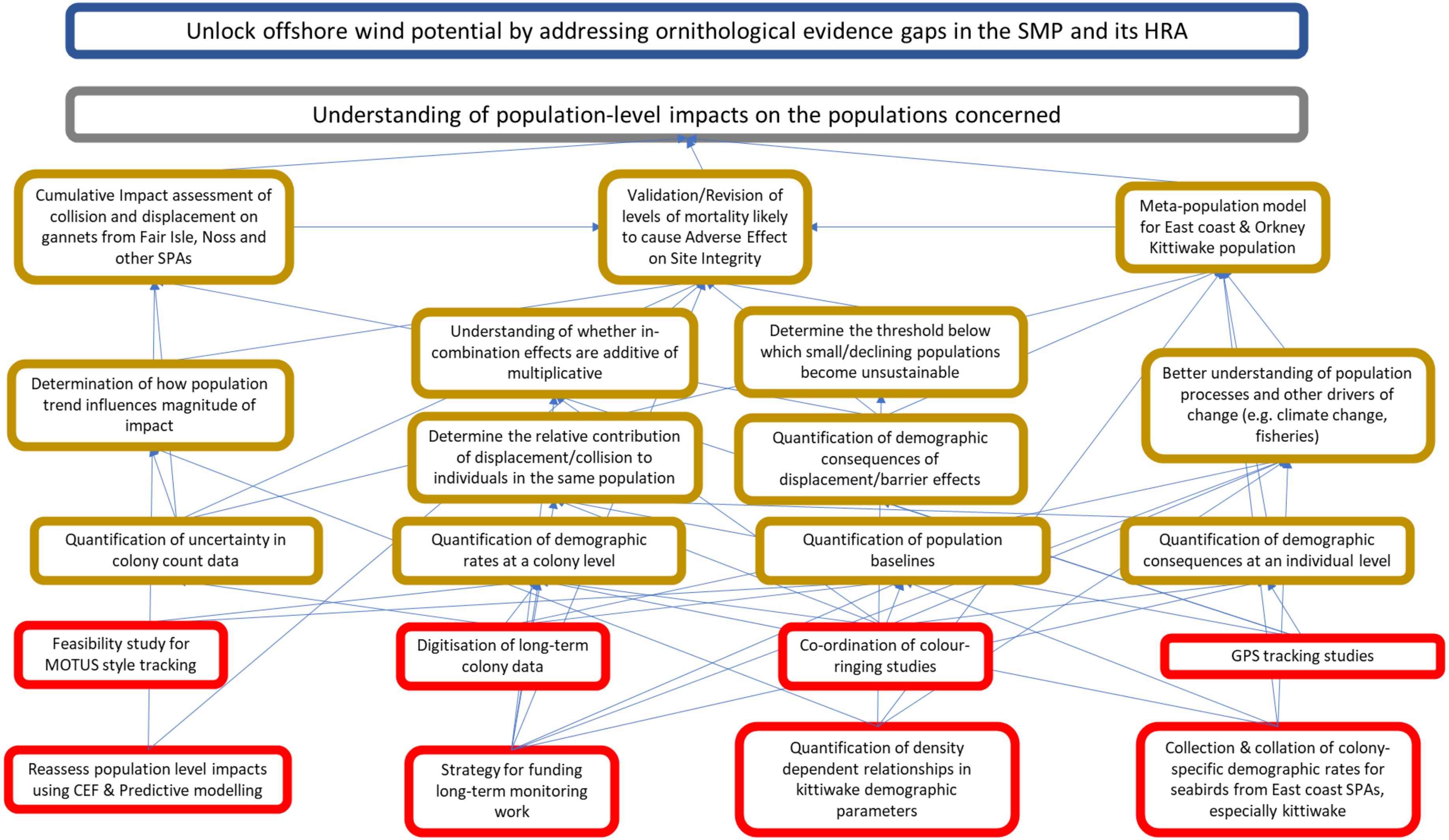

Figure 6 Outputs (orange boxes) and underpinning activities (red boxes) required to deliver an improved understanding of population level impacts on the populations concerned.

3.4 Understanding spatial marine planning and mitigation towards reducing impacts and unlocking plan option potential for OWF (Figure 7)

In relation to POs under a high level of ornithological constraint (E3, NE2, NE3, NE4, NE6), workshop participants considered the potential to reduce this constraint through the revision to predicted impacts based on updated evidence and analytical methodologies and determining the potential for mitigation options to reduce predicted impacts either pre- or post-construction.

Approaches to impact assessment have developed in recent years. In relation to displacement and barrier effects, in addition to the widely used matrix approach (e.g. Busch & Garthe, 2016), Individual Based Models (IBMs) such as SeaBORD are available (Searle et al., 2018). Similarly, the original Band CRM (Band et al., 2007), developed for use onshore, has been replaced by one which better reflects data collection in the offshore environment (Band, 2012), and has recently been updated to incorporate stochasticity (sCRM) (Masden, 2015; McGregor et al., 2018). In parallel, as set out above, data collection to parameterise these models has advanced, though there remains some uncertainty about how such data should be used. Where robust pre- and post-construction survey data are available, it is possible to get a clearer understanding of the proportions of birds displaced (Dierschke et al., 2016) and changes in distribution (e.g. Mendel et al., 2019; Peschko, Mendel, et al., 2020) in response to the wind farm. This may include e whether there is the potential for any positive impacts, for example an artificial reef effect (Inger et al., 2009). The **deployment of collision monitoring systems, radar, and GPS [ACTION]** to better capture the movements of birds in and around wind farms may improve this further. Incorporating the most recent data alongside consistent and updated approaches to impact assessment offers the potential to reduce ornithological constraints in E3, NE2, NE3, NE4, NE6 through **revising predicted cumulative impacts [OUTPUT]** within these POs using both a consistent methodology, and the most recently available evidence, enabling us to reduce the level of precaution assumed in the models. The CEF tool, currently under-development, will offer a practical feasible means to achieving this.

In addition to reducing uncertainty through revision to predicted impacts, it may be possible to reduce impacts through mitigation and careful marine spatial planning. Workshop participants highlighted that **exploring the potential for post-construction mitigation may be particularly valuable [OUTPUT]**. A range of potential mechanisms were highlighted with varying degrees of complexity. This may include established measures such as painting blades to make them more visible to birds, and hence less of a risk in terms of collision (May et al., 2020), or instigating temporary shutdowns at times when turbines pose the greatest risk (Hayes et al., 2019). Further measures may include increasing the height of existing turbines to reduce collision risk, or in extreme cases, removing individual turbines, especially where they pose a disproportionate risk. Workshop participants highlighted the value of **a review to determine the feasibility of applying these and other mitigation measures post-construction [OUTPUT]**.

Should it be possible to reduce or revise impacts within the POs under a high level of ornithological constraint, it will be important to **determine how to make optimal use of the available space [OUTPUT]**. This should consider both installed capacity, and ornithological and other environmental impacts. To facilitate this, **ornithological survey data should be combined with data collected using GPS [ACTION]** to better understand space use by seabirds within each PO, and **identify areas used for foraging and commuting and other behaviours [ACTION]**. Models of these datasets should incorporate spatio-temporal variables to help reduce uncertainty surrounding seabird distribution by enabling a better understanding of the drivers of that distribution.

In addition to ensuring optimal deployment of turbines within each PO, it will be important to ensure that appropriate mitigation measures are put in place. This will necessitate an **analysis of post-construction monitoring data from existing wind farms [ACTION]**. Such an analysis should seek to determine **the influence of turbine spacing on displacement rates [OUTPUT]** and **differences in species flight heights inside and outside wind farms [ACTION]**. For POs where nocturnal or crepuscular species may be present, **a review of the response of these species to lighting, infrastructure and vessel traffic [ACTION]** would also be valuable in understanding design mitigation.

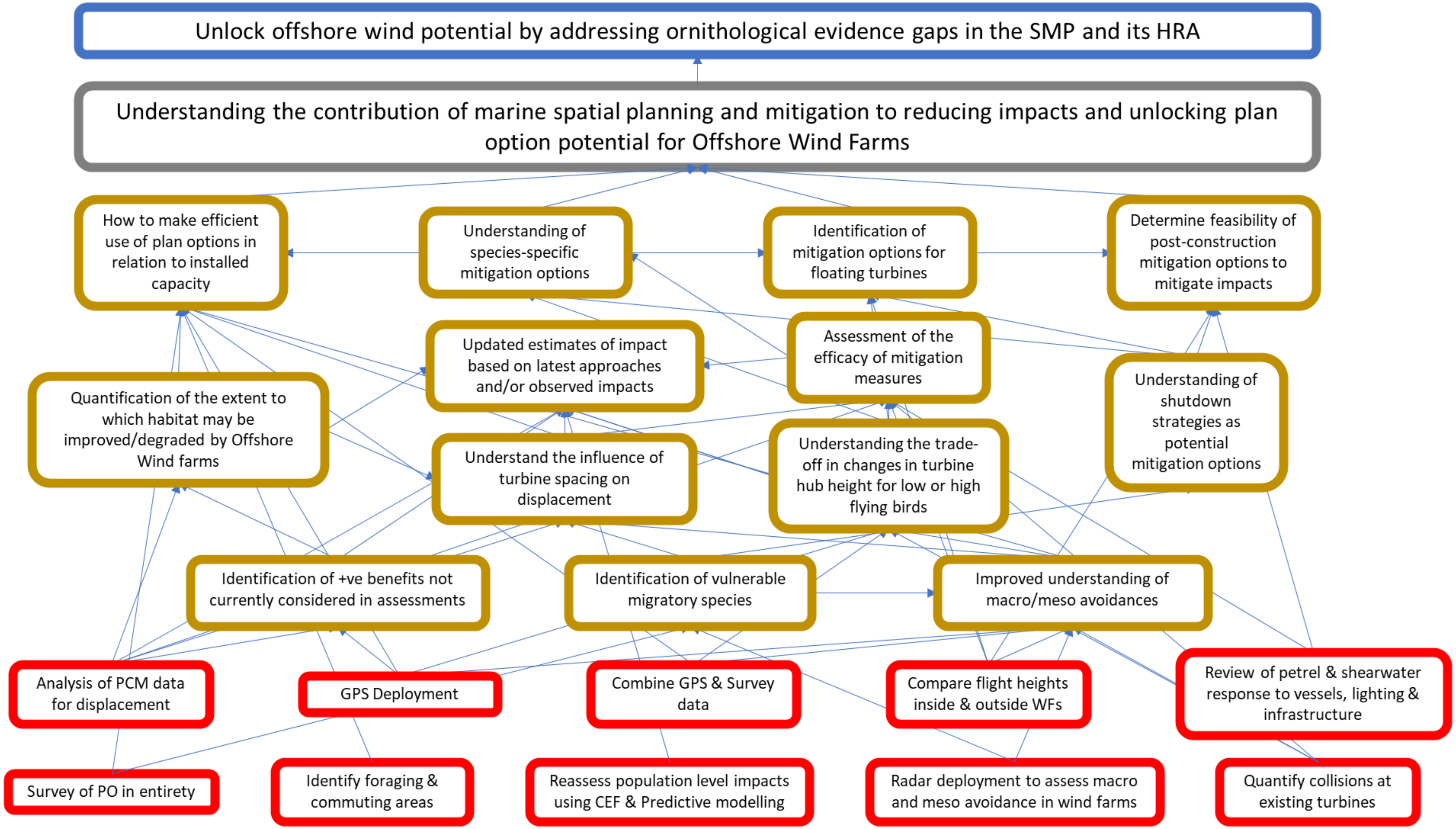

Figure 7 Outputs (orange boxes) and underpinning activities (red boxes) required to deliver an understanding of the potential for marine spatial planning and mitigation to unlock plan options.

4. Ongoing research of relevance to ScotWind Plan Options

At present, there is extensive ongoing research on seabirds and their interactions with offshore wind farms in Scottish waters. Much of this has been summarised in the Offshore Environmental Evidence Register (OWEER)[8] led by JNCC and funded by the Crown Estate. This work can broadly be broken down into three categories 1) new data collection; 2) the review and analysis of existing data and information; and 3) developing new tools and framework. The work has been funded by a range of organisations including developers as part of post-construction monitoring programmes, strategic funding bodies (e.g., ORJIP, OWSMRF), government (e.g., ScotMER) and research councils (e.g., NERC). The key research of relevance to Scottish waters is summarised below.

4.1 New data collection

4.1.1 Tracking

At present, there are several seabird tracking projects taking place at Scottish colonies, informing on seabird activity in Scottish waters. In addition to funding from governmental bodies, such as Marine Scotland, many have been funded by industry directly through monitoring projects tied to specific offshore wind farms. There are several long-established breeding season tracking projects in the Forth Islands SPA covering kittiwakes, gannets, guillemots, and razorbills (e.g., Cleasby et al. 2015, Wakefield et al. 2017). In summer 2021, further studies were carried out on kittiwakes within the Fowlsheugh, St. Abbs Head to Fast Castle, and Buchan Ness to Collieston Coast SPAs, with additional studies on small petrels within the Treshnish Isles and St. Kilda SPAs.

Outside the breeding season, work is underway using geolocators and time-depth recorders to investigate the wintering locations and foraging behaviour of red-throated divers breeding in the Northern Isles, and of Guillemots and Razorbills breeding within several colonies in Scotland and England. In addition to this, a trial is underway to test harnesses for kittiwakes with a view to enabling longer term GPS deployment and a finer scale assessment of habitat use outside the breeding season.

A final project, recently funded by the Offshore Wind Evidence and Change (OWEC) Programme, is a feasibility study for developing and deploying MOTUS tags on gannets and kittiwakes to assess connectivity with offshore wind farms and gain a better understanding of demographic parameters such as dispersal and survival.

[8] Offshore Wind Environmental Evidence Register https://beta.marinedataexchange.co.uk/details/3480/2021-jncc-offshore-wind-evidence-and-change-programme-offshore-wind-environmental-evidence-register-/summary

Table 2 Current and recently completed seabird tracking projects of relevance to ScotWind Plan Option Areas

Species	Tag	Season	Location(s)	Funder(s)/ Commissioners
Leach's Petrel	GPS + Geolocator	Breeding + Non-breeding	St Kilda SPA	EMFF/ Marine Scotland
European Storm-petrel	GPS + Geolocator	Breeding + Non-breeding	Treshnish Isles SPA	EMFF/ Marine Scotland
Gannet	GPS	Breeding	Forth Islands SPA	BEIS SEA
Gannet	GPS	Breeding	Forth Islands SPA	Neart na Gaoithe, Seagreen and Berwick Bank
Kittiwake	GPS	Breeding	Forth Islands SPA, Fowlsheugh SPA, St Abbs Head to Fast Castle SPA	Neart na Gaoithe, Seagreen
Kittiwake	GPS	Breeding	Buchan Ness to Collieston Coast SPA	Vattenfall
Lesser Black-backed Gull	GPS	Breeding	Forth Islands SPA	BEIS SEA
Herring Gull	GPS	Breeding	Forth Islands SPA	NatureScot, Marine Scotland
Great Black-backed Gull	GPS	Breeding	Forth Islands SPA*	Marine Scotland
Great Black-backed Gull	GPS	Breeding	East Caithness Cliffs*	Moray Firth Regional Advisory Group
Guillemot	GPS	Breeding	Forth Islands SPA	Neart na Gaoithe, Seagreen
Razorbill	GPS	Breeding	Forth Islands SPA	Neart na Gaoithe, Seagreen
Red-throated Diver	Geolocator + time depth recorder	Non-breeding	Orkney (including Hoy SPA) and Shetland	JNCC, BEIS SEA, Industry, The Crown Estate
Guillemot	Geolocator	Non-breeding	Colonsay, Treshnish Isles, Canna, Shiant Islands, Foula, Fair Isle, Orkney, East Caithness	Vattenfall, Equinor, SEATRACK, Marine Scotland

Species	Tag	Season	Location(s)	Funder(s)/ Commissioners
			Cliffs, Whinnyfold, Isle of May, Farne Islands	
Razorbill	Geolocator	Non-breeding season	Colonsay, Treshnish Isles, Canna, Shiant Islands, Foula, Fair Isle, Orkney, East Caithness Cliffs, Whinnyfold, Isle of May, Farne Islands	Vattenfall, Equinor, SEATRACK, Marine Scotland
Kittiwake**	PTT	Non-breeding season	Buchan Ness – Collieston Coast SPA	Vattenfall, BEIS SEA
Kittiwake, Gannet***	*Motus*	Year-round		OWEC

*Pending further development of capture and tagging methodology ** Trial of long-term tag attachment for kittiwake ***Trial of MOTUS Tracking to collect demographic & connectivity data in Kittiwake

4.1.2 Collision Monitoring

Building on the ORJIP Bird Collision Avoidance study (ORJIP BCA Skov et al., 2018), a further three collision monitoring projects are either underway, or planned for Scottish Offshore Wind Farms. These include a project at the European Offshore Wind Development Centre (EOWDC) making use of the same MUSE system that was used as part of the ORJIP BCA (Tjomlov et al., 2021) and a project at Kincardine Offshore Wind Farm using the DT Bird system. Results from the EOWDC study are expected in spring 2022. A third study is planned for Neart na Gaoith Offshore Wind Farm in 2023.

Table 3 Ongoing collision monitoring projects in Scottish waters

Location	System	Status
European Offshore Wind Development Centre (Aberdeen Bay)	MUSE – combined camera-radar system	Reporting Autumn 2022
Kincardine	DT Bird HD & Thermal Cameras	Ongoing
Neart na Gaoithe	STRIX radar and camera system	Planned deployment 2023

4.1.3 Other monitoring

Other monitoring taking place includes colony monitoring (survival and productivity) of kittiwakes, guillemots, razorbills, and gannets within the Forth Islands, Fowlsheugh and St. Abbs Head to Fast Castle SPAs. There is also a planned trial of cameras to monitor puffin nest attendance at East Caithness Cliffs SPA as part of the post-construction monitoring of Beatrice Offshore Wind Farm. A final, recently completed study, assessed the feasibility of widescale deployment of colour rings on kittiwakes (O'Hanlon et al., 2021)

4.1.4 Surveys

There have been digital aerial surveys as part of post-construction monitoring at Beatrice and Kincardine Offshore Wind Farms, with post-consent digital aerial surveys carried out at Seagreen and Neart na Gaoithe and further surveys planned for the post-construction periods. In addition to this, regional scale digital aerial surveys have been carried out encompassing the broad Firth of Forth and Tay region on behalf of Neart na Gaoithe, Inch Cape, Seagreen and Berwick Bank Wind Farms. It is also apparent that digital aerial surveys have been carried out in relation to some, or all, of the ScotWind Plan Option Areas. However, for reasons of commercial confidentiality, it is not clear exactly which sites have been surveyed, or what protocols have been followed at this stage. Finally, a survey combining LiDAR and digital still photography has been carried out in and around Beatrice Offshore Wind Farm with a view to collecting data on species flight heights and investigating how these may vary in relation to distance from turbines.

Table 4 Surveys underway in Scottish waters

Site	Methodology	Project Status
Beatrice Offshore Wind Farm	Digital Aerial Survey	Post-construction
Kincardine Offshore Wind Farm	Digital Aerial Survey	Post-construction
Seagreen	Digital Aerial Survey	Post-consent
Neart na Gaoithe	Digital Aerial Survey	Post-consent
Firth of Forth and Tay Region (encompassing Neart na Gaoithe, Inch Cape, Seagreen and Berwick Bank)	Digital Aerial Survey	Post-consent
ScotWind Sites*	Digital Aerial Survey	Baseline data collection
INTOG developers*	Digital Aerial Survey	Baseline data collection
Beatrice Offshore Wind Farm & elsewhere in Moray Firth	Combined LiDAR and Digital Aerial Survey	Post-construction

*Whilst it is apparent that some surveys have been undertaken by developers, at this stage, for reasons of commercial confidentiality, it is unclear which sites have been covered. However, it is assumed that the majority of Scot Wind Sites have pre-application baseline surveys underway.

4.2 Reviews and analyses of existing data and information

4.2.1 Data analyses

Analyses of the tracking data being collected as part of the studies highlighted above aim to generate a better understanding of the behaviour of the species concerned, particularly in relation to parameters such as flight speed and height, which are relevant to the assessment of collision risk. In addition, both the GPS and geolocation data aim to give a better understanding of the distribution of species in relation to offshore wind farms in the breeding and non-breeding seasons. Further analysis of GPS data, as part of a project funded by Marine Scotland and Crown Estate Scotland, will generate refined estimates of nocturnal activity and behaviour-specific (foraging and commuting) estimates of flight speed and flight heights for gannet, kittiwake, and lesser black-backed gulls. Finally, work is underway to develop refined estimates of mortality for displaced birds.

4.2.2 Reviews

Understanding the impacts of offshore wind farms on petrels and shearwaters is a knowledge gap in relation to some of the northern Plan Option Areas. To address this, two complementary reviews are underway. The first of these, funded by the Offshore Wind Strategic Monitoring and Research Fund (OWSMRF) considers monitoring both at colonies and at sea to get a better understanding on population trends, demography, at sea distribution and behaviour. The second, funded by Marine Scotland[9], aims to explore impact pathways and potential mitigation options, to understand how factors such as turbine lighting may influence the species collision risk, and what options may exist to mitigate this.

Recently completed work has reviewed avoidance rates for collision risk models (Cook, 2021), with further work currently underway to critically appraise the recommendations arising from that review.

4.3 Developing Tools and Frameworks

As the offshore wind industry has developed, more data have become available with which to understand the potential impacts on the environment. Consequently, there is growing interest in developing tools with which to make best use of these data and enable a more robust assessment of environmental impacts.

Sensitivity mapping is a valuable tool for identifying areas where there may be a risk of negative impacts from offshore wind farms on seabirds. Work is currently underway to extend the existing Marine Scotland Sensitivity Mapping Tool (Searle et al., 2019) to cover additional species and a broader geographic area. In addition to this, two projects recently funded by OWEC[10] aim to deliver an improved understanding of the drivers of seabird distribution at sea. The POSEIDON project aims to deliver an improved understanding of the baseline distribution of key species to help guide future development. The PrePARED project aims to deliver a better understanding of how seabirds and other marine top predators will

[9] Study for the risk of collision and displacement risk in petrels and shearwaters https://www.publiccontractsscotland.gov.uk/search/show/search_view.aspx?ID=MAY448666

[10] Offshore Wind Evidence and Change Programme | Offshore Wind Evidence and Change Programme (thecrownestate.co.uk)

respond to changes in the distribution of key prey species as a result of offshore wind farm construction and operation.

Collision risk is seen as a key concern in relation to future offshore wind development. An online RShiny App has been developed to make a stochastic assessment of collision risk to seabirds (McGregor et al., 2018). Work is currently underway to improve the functionality and flexibility of this app, and to develop a complementary RShiny App for the assessment of collision risk in migrating birds[11]. This work is due to complete in autumn 2022.

To understand the population level consequences of the impacts associated with offshore wind farms, these must be apportioned back to the populations concerned. A variety of tools exist to do this drawing from sources such as tracking data (Wakefield et al., 2017a) and reviews of species foraging ranges (Woodward et al., 2019). The Marine Scotland Apportioning Tool (Butler et al., 2020) offers a means to apportion impacts back to breeding colonies for four species – kittiwake, shag, guillemot and razorbill – during the breeding season based on analyses of GPS tracking data. Further work is underway to extend this approach to lesser black-backed gulls, and to develop a similar approach to apportioning for guillemot and razorbill outside the breeding season.

In addition to the tools above for sensitivity mapping (Searle et al., 2019), collision risk modelling (McGregor et al., 2018) and apportioning (Butler et al., 2020), others exist for population viability analysis (Searle et al., 2019) and the assessment of displacement (Searle et al., 2018). To facilitate robust cumulative impact assessment, it was recognised that there was a need to bring all of these tools together within a single framework, alongside the data that underpin them. The project to deliver this Cumulative Effects Framework[12] is due to report in summer 2022.

As the number of offshore wind farms increases, the potential for significant, negative cumulative impacts also increases, and after consideration derogation could be triggered under the Habitat Directives. To complement this Roadmap, an additional project is developing a framework with which to assess the efficacy and appropriateness of compensatory measures proposed to compensate for any negative impacts associated with offshore wind development.

In addition to the projects described above, there are two ongoing PhD projects that are of strategic relevance to the ScotWind project. The first of these is the development of an individual based model with which to assess the impact of offshore wind farms on gannets based at the University of Leeds and is due to complete in spring 2022. The second is an investigation of kittiwake metapopulation modelling, which has started in 2021 at the University of Aberdeen.

[11] Strategic study for the collision risk of birds on migration. https://www.publiccontractsscotland.gov.uk/search/show/search_view.aspx?ID=SEP395028

[12] Cumulative Effects Framework for Key Ecological Receptors | UK Centre for Ecology & Hydrology (ceh.ac.uk)

5. Prioritisations of projects for Sectoral Marine Plan Roadmap of Actions

In total, 54 projects were identified which could reduce uncertainty and help determine whether POs subject to high levels of ornithological constraint could be unlocked (Appendix 2). The key focus of this project was to identify projects which could contribute to reducing the uncertainty associated with the projects progressing from the ScotWind leasing round and determine whether POs subject to a high level of ornithological constraint can be unlocked. Consequently, whilst projects which can reduce wider uncertainties are valuable, the focus for this prioritisation is on projects which can be carried out over the next 2-3 years, reflecting the likely timescales of the consenting process for ScotWind. Given the likely costs and timescales involved in this work, it is important to ensure that the existing work, highlighted above, is not duplicated. Discussions in the workshops highlighted a particular need to focus on reducing the uncertainty surrounding predicted impacts, particularly in relation to black-legged kittiwake, northern gannet, great black-backed gull, guillemot, and razorbill.

5.1 Reduce uncertainty around collision

Discussions about reducing uncertainty surrounding the estimated collision rates focussed on two key areas, collecting data on collision rates at operational wind farms, and refining the models, and their input parameters, used to estimate collision risk.

It was noted that there are collision monitoring systems installed at EOWDC, with an additional project planned for the Firth of Forth. There was interest in seeing a similar project in the Moray Firth. However, it was suggested that to add value beyond the studies already in progress, any additional projects would need to include a trial of mitigation measures, such as raising turbine hub height (e.g. Johnston et al., 2014) or painting a turbine blade black (e.g. May et al., 2020). The practicalities of such a study were discussed. **It was felt that challenges involved in such a project, including reaching an agreement with a developer to host such a study, retrofitting equipment to turbines and, the overall cost, meant that it was unlikely that such a study would be of value in relation to reducing uncertainty for the projects progressing under ScotWind. Instead, it was suggested that this was an option that could be recommended as part of Post-Construction Monitoring within projects consented as part of ScotWind.**

Given the importance placed in reducing the uncertainty associated with collision risk, and the fact that the study highlighted above was seen as a long-term aspiration, rather than something that would produce results that could feed into the ScotWind consenting or further planning processes, it was felt alternative projects were required. Two key areas were identified.

1) Reducing uncertainty surrounding species flight heights
2) Improving the realism of Collision Risk Models

It was noted that there are currently several projects underway with the aim of collecting additional flight height data. These include a Marine Scotland funded project using LiDAR[13], and work being undertaken using GPS tagging and altimeters in the Firth of Forth as part of post consent monitoring. At present, LiDAR is seen as being the most precise method for measuring species flight heights, although it is acknowledged that LiDAR does not detect heights for birds flying close to the sea surface (~2.5m, Cook et al., 2018). **As such, the collection of additional flight height data using LiDAR was highlighted as a priority to reduce uncertainty surrounding collision risk estimates as part of ScotWind. Such a project should be at a sufficient scale to enable the generic flight height distributions from** Johnston et al. (2014) **to be updated.** However, it was also recognised that LiDAR may be prohibitively expensive, meaning that, at a project level, alternative methodologies may be required. Flight height estimates may be affected by environmental variation as well as sources of error and bias associated with the data collection methodology. This makes comparing flight heights collected using different approaches challenging. **Consequently, a study comparing flight heights from different methodologies, with data collected in similar locations, over a similar period, was highlighted as a priority in relation to reducing the uncertainty surrounding estimated flight heights to feed into collision risk models in relation to ScotWind applications.**

At present, collision risk assessments are based on either the Band Collision Risk Model or, the stochastic Collision Risk Model (sCRM). However, a lack of validation means that there is uncertainty surrounding predicted collision rates. The models are based on a simple set of assumptions relating to how birds move through a wind farm and have two key components – an estimate of the total number of birds passing through a turbine rotor swept area, and an estimate of the probability of a bird passing through a rotor swept area colliding with a blade. Interest was expressed in moving towards an individual based model type approach for assessing collision risk. However, given data availability, this was felt to be a longer-term aspiration, as opposed to something that was feasible in relation to ScotWind applications. **Instead, it was felt that moving towards a more modularised approach to assessing collision risk would be valuable, this will be facilitated through changes being made to the sCRM at present. Such a project would include considering how different types of data could be incorporated at each stage to ensure collision risk assessments were based on the best available data. These data include GPS estimates of flight speed and height** (Cleasby et al., 2015; Masden et al., 2021; Ross-Smith et al., 2016) **and estimates of avoidance behaviour obtained from collision monitoring systems** (Skov et al., 2018)**, or GPS** (Johnston et al., 2021)**. As part of this, it would be important to carefully consider how avoidance rates were incorporated and used following any revisions to the model. This project was felt to be a priority in relation to reducing uncertainty surrounding collision risk estimates as part of ScotWind.**

[13] Collection of seabird flight height data at an operational wind farm using LiDar https://www.publiccontractsscotland.gov.uk/search/show/search_view.aspx?ID=NOV399475

5.2 Reduce uncertainty around displacement

The proportion of birds displaced is a key source of uncertainty associated with the assessment of displacement. As projects have developed, we have gained a greater understanding of the proportions of birds from different species likely to be displaced. As these data were collected in the Southern North Sea, there is some uncertainty surrounding their applicability to offshore wind farms in Scottish waters. However, as projects develop, this uncertainty is likely to be reduced through the collection of post-construction monitoring data at operational wind farms in Scottish waters. It is important that there is strategic oversight of this monitoring to ensure that it is carried out in a consistent fashion. **Whilst there was some discussion over the potential to investigate the role of turbine spacing on displacement, it was felt that this was a longer-term aspiration, rather than a project that could contribute to reducing uncertainty in relation to ScotWind applications.**

At present, SeaBORD is a key tool for estimating the demographic consequences of displacement and assessing the resultant population level consequences. At present, its use is restricted to the chick-rearing period, though it would be relatively straightforward to extend it to also cover incubation and post-fledging. However, the greatest reduction in uncertainty would be achieved if the approach could be extended to cover the non-breeding season(s). Obtaining the energetic data necessary for Individual Based Model (IBM) approaches such as SeabORD can be challenging outside the breeding season and away from well-studied colonies. However, the deployment of Time-Depth-Recorders (TDR) and wet-dry sensors offers the potential to collect the necessary data, alongside the location information from geolocators. **It was felt that updating SeabORD to cover the incubation and fledging periods initially and developing a similar approach for the non-breeding period(s) was a high priority which could make an important contribution to reducing uncertainty surrounding the potential impacts of displacement as part of ScotWind.**

5.3 Surveys

Surveys are required to reduce uncertainty surrounding the abundance and distribution of birds within each of the POs. POs E1 and E2 are further offshore than the other sites, with greater uncertainty surrounding the distribution and abundance of birds within them (Waggitt et al. 2019). Consequently, **a regional survey covering the Scottish East Coast, encompassing POs E1 and E2 with a 12km buffer around each, as a minimum, was highlighted as a key priority in relation to reducing uncertainty for the ScotWind applications**. Following the guidance presented in Donovan & Caneco (2020), these surveys should deliver at least 5% coverage of the area, with transects no more than 5km apart. Surveys should be carried out on a monthly basis for a minimum of two years (24 months) and start either at the beginning of the breeding season (March) or the beginning of the non-breeding season (September). **It is important that all survey data collected should be modelled with an appropriate set of environmental and oceanographic covariates** (e.g. Waggitt et al., 2019)**, with a view to improving understanding of the drivers of seabird distribution at sea. If possible, consideration should be given to combining these data with data obtained from GPS tracking to establish links to breeding colonies and give a clearer indication of how birds are using the areas concerned.**

There was some discussion surrounding work that could be carried out in relation to existing survey data. Whilst topics such as understanding the ability of digital aerial surveys to distinguish between small petrel species were not thought to be a priority, a better understanding of the proportions of juvenile/immature birds detected was thought to be of importance. This would enable two key advances. Firstly, it would enable a better understanding of the distribution of juvenile/immature birds at sea, making it more straightforward to apportion impacts on adults back to the relevant breeding colony. Secondly, it would make it possible to incorporate impacts to juvenile/immature birds into PVAs, reducing uncertainty surrounding predicted population level impacts. There was discussion as to whether such analyses should be restricted to recent digital aerial survey data or include information from other sources such as ESAS. It was felt that for QA purposes, and to ensure analyses reflected the situation at present, this work should be restricted to data collected using recent digital aerial survey data, including the data collected as part of the regional survey of the Scottish East Coast and the surveys of the POs described above. **Analysis of the distribution of juvenile/immature birds from digital aerial survey data was highlighted as a priority in relation to reducing uncertainty for ScotWind applications.**

5.4 Tracking – breeding season

Initial discussions focussed on the species and colonies that should be prioritised for GPS tracking during the breeding season. It was acknowledged that there are several tracking projects underway at present (Table 2). However, the majority of these are in the Firth of Forth and Tay region, and do not include birds from populations most likely to be impacted by developments in the POs. Where studies have been carried out, these began in the 2021 breeding season. As there can be substantial variation in habitat use between breeding seasons (Robertson et al., 2014; Thaxter et al., 2015), it is important that these studies are continued over multiple years to properly establish connectivity with POs. It was agreed that further tracking of black-legged kittiwake was a high priority, and that tracking of northern gannet, great black-backed gulls, and auk species (including Atlantic puffin) were similarly important. However, issues relating to the potential for tag effects and colony accessibility were highlighted for some species. Of the remaining species, it was felt that the proximity of Plan Option E3 to key colonies meant that there may be value in relation to tracking of Herring Gulls. Whilst uncertainties over predicted impacts were acknowledged, it was felt that GPS tracking of other species (including Sandwich tern, European storm-petrel, Manx shearwater, great skua and Arctic skua) were not a priority in relation to reducing uncertainty as part of the ScotWind leasing round.

Consequently, the prioritisations of species for GPS tracking was as follows:

1) Black-legged kittiwake
2) Northern gannet, great black-backed gull, auks (guillemot, razorbill, puffin)
3) Herring gull
4) Sandwich tern, European storm-petrel, Manx shearwater, great skua, Arctic skua

In addition to establishing connectivity between SPA populations and POs, the GPS data can be used to investigate patterns in seabird flight height, speed and avoidance of existing offshore wind farms (Cleasby et al., 2015; Johnston et al., 2021; Masden et al., 2021; Ross-Smith et al., 2016). By collecting more GPS data from these species within SPAs where there is likely to be connectivity with ScotWind POs, we will have greater power to investigate spatial and temporal patterns in these parameters, and better understand how they may be influenced by weather conditions. This will allow us to better quantify these parameters and consequently, reduce uncertainty surrounding estimates of collision risk.

5.4.1 Black-legged kittiwake

It was noted that tracking programmes are currently underway at Fowlsheugh, The Isle of May and St Abbs Head as part of post-consent monitoring programmes for offshore wind farms in the Firth of Forth. Given the between year variation in habitat use (Robertson et al., 2014) and the proximity of these colonies to ScotWind POs, it is important to ensure that this work continues, and is expanded to other colonies close to POs so that any connectivity can be properly assessed. This will also necessitate close co-ordination between the organisations concerned, to ensure any data collected are complementary. **It was felt that tracking work would be valuable to reduce uncertainty in relation to connectivity between SPA populations and the ScotWind POs. Reflecting the locations of the POs, the key SPA populations highlighted as needing further tracking work were Buchan Ness to Collieston Coast, Troup, Pennan and Lions Heads, East Caithness Cliffs and Copinsay. However, it was recognised that there may be challenges in accessing birds within some colonies. Consequently, a two-stage process was suggested with a feasibility study to identify suitable sites for tracking in the first year, followed by tracking in the second. It was also felt that there may be value in tagging birds in and around the Moray Firth and Aberdeenshire Coast, but outside SPAs, with a view to improving apportioning.**

5.4.2 Northern Gannet

The need for additional GPS tagging of northern gannets was discussed to reduce uncertainty surrounding connectivity between SPA populations and ScotWind POs, and to improve apportioning. It was noted that tagging work would continue at the Bass Rock as part of post-consent monitoring for offshore wind farms located in the Forth and Tay region. It was felt that additional GPS tagging of SPA populations on Fair Isle, Sule Skerry and Noss may be valuable. In addition, whilst not a designated feature of Troup, Pennan and Lion's Heads SPA, it was also felt that deploying GPS tags at this site would be valuable in relation to improving apportioning. However, it was noted that there may be accessibility issues at these sites. **Consequently, it was recommended that a feasibility study was carried out in summer 2022 to identify suitable locations to deploy GPS tags within these colonies, with a view to deploying tags in summer 2023.**

5.4.3 Great Black-backed Gull

Whilst great black-backed gulls have been observed in and around offshore wind farms and ScotWind POs within the Moray Firth, there is considerable uncertainty surrounding the origins of these birds. A variety of options were discussed including tagging birds within the East Caithness Cliffs and Copinsay SPAs and attempting to capture birds at sea. **Of these, deploying GPS tags on birds within the Copinsay SPA was felt to be the most immediately feasible option, with GPS tagging of birds within East Caithness Cliffs SPA also of value.**

Such deployment would be dependent upon potential tag effect issues being resolved. In addition to facilitating an assessment for potential interactions with POs in the Moray Firth, such a study would provide valuable behavioural data for a species which is currently data limited, reducing uncertainty surrounding the assessment of collision. Ass an initial planning task, a feasibility study should be undertaken to identify accessible nests at which to capture birds. Consideration over whether to capture birds at sea should await the outcome of a review of potential methods and will require careful discussion with the Special Methods Technical Panel of the BTO ringing committee.

5.4.4 Common Guillemot and Razorbill

There was some discussion in relation to whether the purpose of tracking would be to assess connectivity or, to quantify potential displacement and/or barrier effects. It was felt that inferences about the potential for displacement and/or barrier effects could be drawn from data collected as part of post-construction monitoring on the Isle of May, and, as such, the focus should be on establishing connectivity. At present, common guillemot and razorbill are not believed to make substantial usage of the North-Eastern cluster of sites, though there is some uncertainty surrounding their potential usage of NE7 and NE8, which are further offshore than the other NE POs. GPS tracking of birds from the East Caithness Cliffs SPA could address this uncertainty, though there are questions over the accessibility of birds within this SPA. **Consequently, a feasibility study of capturing birds within this site was suggested**, alongside consideration of the feasibility of capturing birds at sea. Given their locations, the potential for connectivity between birds within the Fowlsheugh and Buchan Ness to Collieston Coast SPAs and POs E1-E3 was highlighted as being of importance. **GPS tagging of common guillemot and razorbill within Fowlsheugh and Buchan Ness to Collieston Cliffs SPAs was highlighted as a priority to reduce uncertainty surrounding the potential impacts of POs E1-E3 on these species.** These POs include six lease agreement offers, consequently these projects would benefit from a strategic approach to data collection.

5.4.5 Atlantic Puffin

A lack of published data on Atlantic puffin foraging ranges means that there is still considerable uncertainty surrounding the potential for species to interact with offshore wind farms. Whilst UKCEH have been carrying out trials of GPS tracking Atlantic puffins, potential tag effects mean that these data may not be suitable for use in assessments for offshore wind farms. Robust GPS data would enable a more accurate assessment of the species foraging range and reduce uncertainty surrounding apportioning. A trial using loggers of different sizes would help disentangle potential tag effects, enabling future deployment of GPS tags within SPAs where birds may interact with the ScotWind POs including Noss, Fair Isle, North Caithness Cliffs and Sule Skerry and Sule Stack. **Consequently, a trial of different logger types to understand potential device effects on Atlantic puffins was highlighted as a priority for reducing uncertainty in relation to the ScotWind applications.**

5.4.6 Herring Gull

Whilst it was noted that herring gulls are unlikely to be an issue for most of the POs, they have been observed offshore, and roosting on the turbines at Kincardine Offshore Wind Farm, close to PO E3. Given the large number of birds present in urban colonies on the East coast, there is considerable uncertainty surrounding the origin of birds in the offshore environment. **Consequently, it was felt that GPS tracking of birds from the Fowlsheugh and Buchan Ness to Collieston Coast SPAs would be valuable to reduce uncertainty surrounding the potential for interactions with POs E1-E3.**

5.4.7 Other Species

It was highlighted that there is considerable uncertainty over the potential for some other designated features of SPAs to interact with ScotWind POs. These include Manx shearwater, European Storm-petrel, Leach's petrel, great skua, Arctic skua and Sandwich tern. In some cases (e.g., Arctic skua) the size of the population concerned is small, meaning any impact could have a significant effect at a population level. However, given the location of the POs relative to SPAs for which these species are designated features, and what we know about their ecology, it was felt that these were unlikely to pose a constraint to the ScotWind leasing round, and are therefore not a priority for GPS tracking at this stage.

5.4.8 Further analysis of tracking data

Having collected tracking data, it is important to consider how these data can be used to reduce uncertainty in relation to ScotWind beyond simply quantifying connectivity between designated features of protected sites and the POs. Three key areas were identified:

1) Improve apportioning
2) Link offshore behaviour to demography
3) Better describe the flight characteristics of foraging and commuting behaviour

Key to this is understanding why birds are where they are, and what the consequences of this may be in relation to impacts from offshore wind farms. At present, apportioning is based on rough criteria such as foraging ranges and colony size. By using GPS tracking data to establish connectivity between sites, this can be improved. Further refinements can be made through behavioural classification to understand whether birds detected during surveys are likely to be using an area for foraging or commuting behaviour, and therefore better understand what the consequence of any loss of habitat might be.

To reduce the uncertainty surrounding the potential consequences of displacement and barrier effects, it is important to better understand the link between behaviour and demography. Whilst obtaining sufficient data to quantify the impact on adult survival is likely to be challenging, detecting impacts on breeding success and body mass (a potential surrogate for survival) may be more achievable. Examining this in more detail would enable us to better understand the relative importance of different marine areas to a colony, and the energetic and demographic consequences of losing an area.

Collision risk is likely to be driven by behaviour. At the highest level, this may be linked to differences in flight height and speed between foraging and commuting flight. However, it is also likely to be affected by environmental variation driven by factors such as wind speed and direction, or changes to behaviour inside an operational wind farm. GPS tracking data enable us to better investigate this variation and consider the likely consequences for collision risk.

In developing the tracking studies set out above, in addition to assessing connectivity between designated features of SPAs and ScotWind POs, researchers should consider the extent to which the resulting data could also be used to address one, or more, of the topics set out below.

Tracking – non-breeding season

Building on the discussions above, there was consensus that the greatest reduction in uncertainty relating to the non-breeding season would be a reduction in the uncertainty surrounding the consequences of displacement. Whilst there was agreement that a better understanding of the exposure of migrating northern gannets and skuas to offshore wind farms was important, it was felt that black-legged kittiwakes and auks (including puffins) were the priority for this work.

Efforts are underway to enable the collection of data that can be used to investigate finer scale distributions of birds outside the breeding season through the development of long-term attachment methods, the miniaturisation of GPS tags and assessing the feasibility of MOTUS type tracking. However, these efforts are unlikely to result in the development of an approach that can be deployed at the scale necessary within the timeframes allowed by the ScotWind process. Consequently, collection of these data is likely to rely on the widespread deployment of geolocators. Despite the low precision of spatial locations derived from these data, they are likely to be of value in relation to apportioning impacts outside the breeding season back to SPA populations. However, the precision of these data could be improved through the collection of temperature or stable isotope data alongside the geolocator data and through the adaptation of the analysis to incorporate these additional data sources.

Deploying geolocators would enable us to investigate whether birds are using marine areas where offshore wind development is taking place outside the breeding season. However, the use of activity loggers such as TDRs or wet/dry sensors would enable us to investigate activity budgets outside the breeding season. In combination, these data would enable us to investigate the potential consequences of loss of wintering habitat, particularly if tied to individual level data such as breeding success or changes in adult body mass over winter. This would make it possible to move towards an IBM-type approach to assessing the consequences of displacement outside the breeding season, as alluded to above.

It was acknowledged that, to be of most value, a project such as this would need to involve international collaboration (e.g., with SEATRACK) to capture data from birds outside Scottish waters. Such a project has the potential to substantially reduce uncertainty in relation to the consequences of displacement outside the breeding season within the timeframes allowed by ScotWind. **To facilitate this work, it was recommended that geolocators should be deployed on kittiwakes, guillemots, razorbills, and puffins from a minimum of 10 Scottish colonies, and involve collaboration with researchers working in colonies outside Scottish**

waters, to enable more robust apportioning. Where size allows, activity loggers (e.g., TDRs or wet/dry sensors) should be deployed alongside the geolocators to enable activity budgets outside the breeding season to be inferred.

5.5 Demography

It was recognised that robust demographic data and models will be key to assessing future impacts and providing a baseline against which any compensatory measures can be assessed.

A key project discussed related to the development of a meta-population model for East Coast Kittiwake colonies. This has the potential to reduce uncertainty surrounding the predicted impacts of existing offshore wind farms and determine whether any of POs NE2, NE3, NE4, NE6 and E3 can be released from high levels of ornithological constraint. It is important that such a model should take account of biological processes, such as immigration/emigration and density dependence, and other pressures acting on the population such as fisheries and climate change. However, it was also acknowledged that, in the absence of more robust demographic data, the utility of such a model is likely to be limited, for example to identifying key gaps in our knowledge of the species demography. **As such, whilst developing a model such as this is seen as important, it is also seen as a longer-term aspiration rather than an immediate priority for ScotWind projects. Aspects of this work may be addressed by a PhD project at the University of Aberdeen that started in autumn 2021.**

A more pressing priority is the collection and collation of demographic monitoring data. Whilst kittiwakes are a priority for this, other species including great black-backed gull, gannet and auks are also important. Reflecting the locations of the POs subject to high levels of ornithological constraint, the focus for this work should be on North East and East Coast as well as the Orkney colonies. The resulting data could be used to feed into meta-population models, such as the one described above, but also to establish baselines against which population level impacts, and the effectiveness of any compensatory measures, if these are determined to be required, could be judged. Data collection on this scale will require substantial effort, and it is important that this effort is adequately resourced. Opportunities for novel approaches to data collection (e.g., the use of Motus-style tracking to investigate return rates and dispersal, cameras for remote monitoring of productivity) should be considered. However, this work is likely to be a long-term project. It can take a minimum of 5 years, and ideally 10, to generate the data necessary to estimate robust survival rates depending on the type of data being collected and levels of inter-annual variability. **Consequently, despite the importance of this work, it is unlikely to result in data that can contribute to reducing uncertainty in relation to the ScotWind projects. However, both to assess any population level consequences of ScotWind, and to inform future planning and leasing rounds, it is of vital importance that a long-term funding strategy for collecting seabird demographic data is put in place.**

5.6 Timelines and key considerations

The projects identified above include the collection of new data, analysis of existing data and continued development of existing tools. Strategic oversight of these projects is vital to ensure that they complement one another and maximise opportunities for reducing uncertainties surrounding impacts on key species. Details of these projects, including key deliverable, constraints and indicative budgets are given in Table 5.

Table 5 Projects prioritised in order to reduce uncertainty surrounding predicted impacts of ScotWind projects

Project	**How project will address ornithological constraints**	**Data & expertise requirements**	**Key constraints in delivery**	**Deliverables**	**Timescales**	**Mechanisms for delivery**	**Budget**
Regional Digital Aerial Survey covering E1 and E2	Reduced uncertainty surrounding species abundance and distribution within POs E1 and E2 in the breeding and non-breeding seasons	Familiarity with principles of survey design to ensure unbiased data collection Familiarity with digital aerial survey protocols Appropriate QA procedures for species ID from digital imagery *(Potential added value – ability to estimate species flight heights)*	Availability of survey plane & equipment Weather conditions	Monthly estimates of abundance and distributions of seabirds on the Scottish East Coast	Monthly surveys over 1 year starting September 2022/March 2023 (to coincide with start of breeding or non-breeding season) and to cover 2023 breeding season to allow comparison with GPS tagging data	Collaborative funding involving developers in Option Agreements 1,2,3,4 & 5	£500,000+
Regional LiDAR survey to collect flight height data	Reduced uncertainty surrounding species flight heights to estimate the proportion of birds at collision risk height for the purposes of collision risk modelling	Familiarity with principles of survey design to ensure unbiased data collection Familiarity with digital aerial survey protocols	Availability of survey plane and LiDAR equipment Weather conditions	Monthly measurements of flight heights for species vulnerable to collision risk (e.g., Kittiwake, Gannet & large gulls)	Monthly surveys over 1 year starting September 2022/March 2023 (to coincide with start of breeding or non-breeding season) and to	Strategic monitoring programme	£500,000+

		Familiarity with LiDAR data processing Appropriate QA procedures for species ID from digital imagery			cover 2023 breeding season to allow comparison with GPS tagging data		
Analyse proportions of adult and immature birds from Digital Aerial Survey imagery	Reduced uncertainty about population age-structure, understanding of the exposure of different age-classes to the effects associated with offshore wind farms	Familiarity with data from digital aerial surveys. Familiarity with the processes and limitations involved in identifying and assigning age classes to birds from digital imagery. Consideration of potential biases in digital imagery. Understanding of the estimation of population age structures from	Commercial confidentiality associated with digital aerial imagery. Availability of suitable data.	Modelled distributions of adult and juvenile/immature age classes. Comparison of observed and expected population age structures.	Six months to coincide with the second year of data collection of regional digital aerial survey.	Scottish government, SNCB, or strategic funding.	c. £50,000

		demographic models & how to compare observed and expected age structures.					
Feasibility study for widespread tagging studies	Determine the feasibility of GPS & GLS data collection at multiple sites in summer 2023, highlight most appropriate approaches (e.g., tags, sample sizes) to ensure tagging studies deliver data to reduce uncertainty about impacts of offshore wind farms on seabirds	Experience of delivering seabird tagging projects on a wide range of species Understanding of licensing conditions relating to device deployment on seabirds Understanding of how to work safely, while causing minimum disturbance in seabird colonies.	Accommodation during breeding season Weather conditions Transport to remote locations Access to field sites	Understanding of the key practicalities involved in a widespread tagging programme in summer 2023, including key limitations and constraints (e.g., availability of suitably trained personnel). Understanding the feasibility of deploying tags in new sites (Copinsay, Fair Isle, North and East Caithness Cliffs, Troup, Pennan and Lions Heads).	Summer 2023 breeding season (June/July) for site visits with final recommendations and plans submitted winter 2023/22	Developers with projects in areas of high ornithological constraint (NE2, NE3, NE4, NE6, E3)	c. £50,000

Investigation into potential device effects on Puffins	Determine the feasibility of deploying GPS tags on Puffins as a means to reducing uncertainty surrounding potential interactions with offshore wind farms.	Experience of delivering seabird tagging projects, particularly in relation to burrow-nesting species. Understanding of licensing conditions relating to device deployment on seabirds. Understanding of how to work safely, while causing minimum disturbance in seabird colonies. Understanding of importance of monitoring & assessing potential tag effects	Accommodation during breeding season Weather conditions Transport to remote locations Access to field sites Availability of easily accessible and observable puffin nests.	Assessment of the potential for tag effects on puffins, recommendations about how these can be minimised and whether further GPS deployment can be justified on ethical grounds and in relation to the quality of the data collected.	To begin November 2022 to enable tag orders to be placed by January 2023 at the latest and ensure all licensing and site permissions can be completed in time to ensure tag deployment in 2023 breeding season. Data analysis to follow with initial outputs winter 2023.	Scottish government, SNCB, or strategic funding.	c. £50,000

Multi-colony & species GPS deployment	Reduced uncertainty surrounding connectivity of designated features of SPAs and ScotWind POs and Agreement Options. Reduced uncertainty surrounding species distribution in relation to SPAs and ScotWind POs and Agreement Options. Understanding of species behaviour (e.g., Foraging/commuting) in SPAs and ScotWind POs and Agreement Options. Reduced uncertainty surrounding species flight heights and speeds.	Experience of delivering seabird tagging projects on a wide range of species Understanding of licensing conditions relating to device deployment on seabirds. Understanding of how to work safely, while causing minimum disturbance in seabird colonies. Experience with the analysis of distribution and behavioural data from GPS tags. GPS tags with high sampling rates and remote	Lead in time for tag delivery, licensing & site permissions (typically 6 months) Accommodation during breeding season Weather conditions Transport to remote locations Access to field sites	Modelled distributions of species foraging and commuting behaviour. Estimate of the % time spent within each Agreement Option Understanding of differences in distribution between conditions when traditional surveys can and cannot be carried out Estimates of flight heights and speeds when birds are foraging and commuting.	To begin November 2022 to enable tag orders to be placed by January 2023 at the latest and ensure all licensing and site permissions can be completed in time to ensure tag deployment in 2023 breeding season. Data analysis to follow with initial outputs autumn 2024.	Funding from developers with projects in areas of high ornithological constraint (NE2, NE3, NE4, NE6, E3) with close collaboration between all organisations involved in tagging and strategic oversight from key stakeholders including Scottish Government, SNCBs and industry representatives.	c. £150-250,000 per species and site depending on the number tags deployed and potential efficiencies through the collection and analysis of data from multiple species at the same colony

		download capabilities. Potential to set geofences and provide instantaneous estimates of speed. Altimeters to estimate flight altitudes.					
GLS & TDR Deployment	Reduced uncertainty surrounding the distribution of seabirds outside the breeding season and potential connectivity with POs and Agreement Options. Understanding of activity budgets and energy expenditure outside the breeding season to allow better quantification of potential energetic costs associated with any loss of habitat.	Experience of delivering seabird tagging projects on a wide range of species Understanding of licensing conditions relating to device deployment on seabirds. Understanding of how to work safely, while causing minimum	Accommodation during breeding season Weather conditions Transport to remote locations Access to field sites		To begin November 2022 to enable tag orders to be placed by January 2023 at the latest and ensure all licensing and site permissions can be completed in time to ensure tag deployment in 2023 breeding season. Tag retrieval in 2024 breeding season with analysis over the following year.	Strategic funding (e.g., ORJIP, OWEC)	c. £100-200,000 per species and site depending on the number tags deployed and potential efficiencies through the collection and analysis of data from multiple species at

		disturbance in seabird colonies. Experience with the analysis of GLS and TDR data					the same colony
Extension of SeabORD to cover full breeding season	Reduced uncertainty surrounding the population level consequences of displacement during the breeding season	Familiarity with SeabORD tool. Understanding of individual/agent-based models. Understanding of energetic models. Experience in the analysis of GPS tracking data.	Availability of suitable data	Updated SeabORD model	c. 6 months	Scottish government, SNCB, or strategic funding.	c. £50,000
Revision of cumulative impact assessment using CEF	Reduced uncertainty in relation to the magnitude of cumulative impacts associated with offshore wind farms in the Moray Firth and Firth of Forth.	Familiarity with data underpinning assessments of the environmental impact of offshore wind farm.	Availability of CEF tool. Agreement about a standard set of parameters to incorporate into model.	Revised assessment of population level consequences of collision and displacement in the Moray Firth and Firth of Forth based on a common set of	June – December 2022, or 6 months following final delivery of CEF tool	Scottish government, SNCB, or strategic funding.	c. £50,000

		Familiarity with EIA process and precautionary principle. Familiarity with the tools underpinning EIAs (e.g., Band CRM, SeabORD, NE PVA tool).		parameters and best available data.			
Developing an IBM approach to assessing displacement outside breeding season	Reduced uncertainty about the individual and population level consequences of displacement outside the breeding season.	Familiarity with the analysis of GLS and TDR data. Familiarity with individual/agent-based modelling. Familiarity with energetic modelling. Understanding of the potential population-level consequences of displacement.	Availability of GLS and TDR data from multiple species (Kittiwake, Guillemot, Razorbill)	An individual based model with which to assess the consequences of displacement outside the breeding season.	c. 1 year following retrieval of GLS and TDRs	Strategic funding (e.g., ORJIP, OWEC)	c. £100-250,000
Modularisation of CRM & determine how GPS data	Reduced uncertainty in relation to collision estimates following	Understanding of different collision risk models	Availability of suitable data to incorporate in model(s)	Recommendations about what constitutes best available data for	c. 6 months	Scottish Government or Strategic Funding	c. £50,000

& data from collision monitoring studies should be incorporated into CRM	consideration of alternative approaches to estimating different elements of the CRM (e.g., Flux rate, Probability of Collision), and improved understanding of how different elements of collision risk models contribute to final estimates and how different data sources may contribute to these elements.	Understanding of different data sources that may contribute to CRMs (e.g., GPS, Digital Aerial Survey, LiDAR		each element of CRM. Recommendations about how different types of data should be incorporated into CRM. Assessment of the validity of alternative approaches to estimating flux and probability of collision.			
Comparison of flight height data collected using different methodologies	Reduced uncertainty in relation to different estimates of species flight heights through a better understanding how comparable data from different sources may be.	Familiarity with methodologies for flight height data collection. Understanding of potential sources of uncertainty in flight height data.	Availability of flight height data from multiple sources (e.g., GPS, altimeter, LiDAR, Digital Aerial Survey).	Standardised approach to estimating species flight height distributions. Quantification of uncertainty associated with flight height estimates from different methodologies. Revised flight height distributions for key species.	6 months following completion of regional LiDAR survey	Scottish Government or strategic funding.	c. £50,000

In the short term, there are several desk-based projects that could be undertaken over the next 6-12 months (Figure 8). These include extending SeaBORD to cover the breeding season as a whole, the modularisation of the sCRM along with the development of guidance setting out how data collected using GPS and collision monitoring studies should be incorporated into collision risk models and revising estimates of cumulative impacts using a standardised set of tools and data using the CEF. These projects are of relevance to all the sites under ornithological constraint. Also of value, though a lower priority, would be an analysis of the proportions of adult and immature birds recorded using digital aerial survey, and how this varies spatially and temporally.

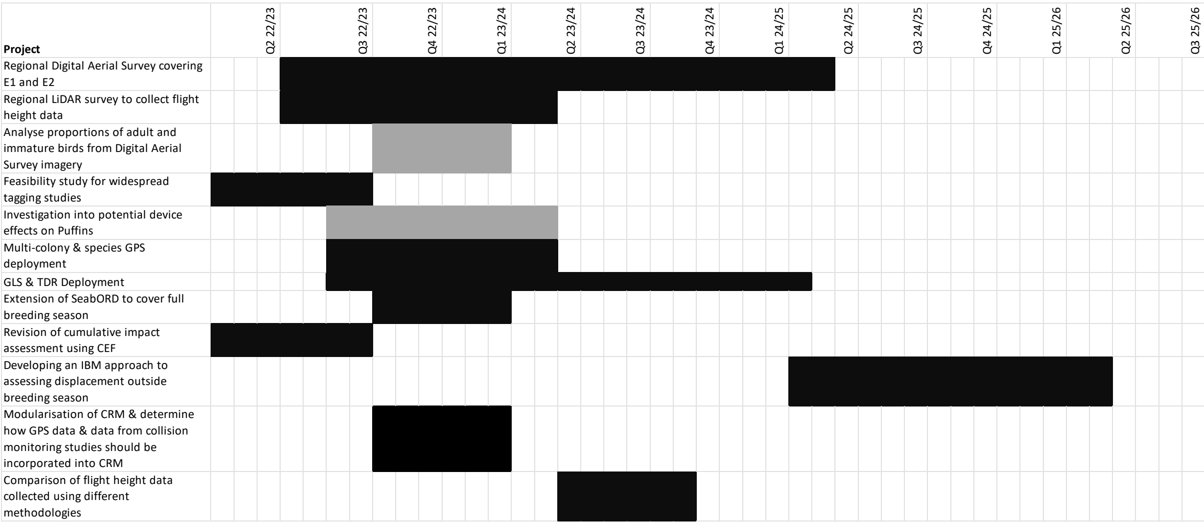

Figure 8 Gantt chart setting out potential timelines for projects identified as part of the roadmap of actions. Projects considered lower priority are highlighted in gray.

Workshop participants highlighted the value of further collection of GPS data. In addition to quantifying connectivity between SPA populations and POs, these data could be used to reduce uncertainty surrounding apportioning and the parameters used in the assessment of collision risk and displacement. It was recognised that issues relating to capacity and logistics meant that such data collection was unlikely to be feasible in the 2022 breeding season. However, as tagging is likely to take place at new sites, there would be value in recce-ing those sites during the 2022 breeding season with a view to identifying sites for tagging work in the 2023 breeding season. The species and colonies for which further tracking work would be of value are highlighted in Table 6, along with the POs which are likely to be of relevance to the populations concerned. It may be possible to secure funding to support some of these projects from developers who have been secured agreement offers in the POs concerned. It is important that there is strategic oversight of all data collection, and that collaboration and data sharing agreements are in place to maximise the value of any data collected. Workshop participants also highlighted the potential value of a wider investigation of tag effects in puffins, but this was a lower priority.

Table 6 Species and colonies which were highlighted as being of importance for collecting GPS tracking data during the breeding season to assess connectivity with ScotWind POs.

Species	**Colony**	**Relevant PO(s)**	**Recce in 2022 required?**
Gannet	Fair Isle	NE2, NE3, NE4, NE6, NE7, NE8	Y
Great Black-backed Gulls	East Caithness Cliffs	NE2, NE3, NE4, NE6, NE7, NE8	Y
Guillemot	Buchan Ness to Collieston Coast	NE2, NE3, NE4, NE6, NE7, NE8, E1, E2, E3	
Guillemot	Fowlsheugh	E1, E2, E3	
Herring Gull	Buchan Ness to Collieston Coast	NE2, NE3, NE4, NE6, NE7, NE8, E1, E2, E3	
Herring Gull	Fowlsheugh	E1, E2, E3	
Kittiwake	Copinsay	NE2, NE3, NE7, NE8	Y
Kittiwake	East Caithness Cliffs	NE2, NE3, NE4, NE6, NE7, NE8	Y
Kittiwake	Troup, Pennan and Lion's Heads	NE2, NE3, NE4, NE6, NE7, NE8	Y
Kittiwake	North Caithness Cliffs	NE2, NE3, NE4, NE6, NE7, NE8	Y
Kittiwake	Buchan Ness to Collieston Coast	NE2, NE3, NE4, NE6, NE7, NE8, E1, E2, E3	
Kittiwake	Fowlsheugh	E1, E2, E3	
Razorbill	Buchan Ness to Collieston Coast	E1, E2, E3	
Razorbill	Fowlsheugh	E1, E2, E3	

The consequences of displacement outside the breeding season were highlighted as a key uncertainty. The potential to combine geolocation data with data from time-depth recorders, or wet-dry sensors, was identified as a valuable methodology for collecting information on both the distribution and the activity levels of birds outside the breeding season. Such data would be of value in developing an Individual Based Model (IBM) approach to assessing the consequences of displacement outside the breeding season. The key species for this are those that are known to be present in the North Sea outside the breeding season and which post-construction monitoring suggest may be vulnerable to displacement – kittiwake, guillemot, razorbill, and puffin. As with the GPS data, it is unlikely to be feasible to deploy tags during the 2022 breeding season, but effort should be made to deploy tags in the 2023 breeding season. Tags should be deployed at multiple colonies, similar to the approach in Buckingham et al. (2021), and could coincide with the deployment of GPS tags. The resulting data should be used to develop an IBM-type approach to assessing displacement outside the breeding season, similar to SeaBORD. The scale of a project of this nature, means that strategic funding bodies such as ORJIP or OWEC may be potential sources of funding.

The need for additional survey data was also highlighted during the workshops. Substantial uncertainty remains over the distribution of birds further offshore around POs E1 and E2, particularly outside the breeding season (Waggitt et al., 2019). There is a need for a wider, regional survey or the Scottish East Coast, covering these two POs with a 12 km buffer around each as a minimum, to address this uncertainty. All data should be analysed using a consistent spatial modelling approach, incorporating an appropriate set of environmental covariates.

In addition to further survey data, there was considerable interest in developing an updated set of generic flight height distributions for use in collision risk modelling to replace those of Johnston et al. (2014). It was felt that these data would be best collected using a wide-scale LiDAR survey carried out over a year on a monthly basis. Again, it was felt that there was a need to ensure strategic oversight of this project. There is considerable uncertainty in collision mortality estimates as a result of differences in flight heights measured using different approaches (e.g., GPS, LiDAR, Digital Aerial Survey). To maximise the value of these surveys, it is important to ensure they coincide with other data collection. Data should be collected in areas that are likely to be used by birds in the GPS tracking studies given above (Table 5), and should begin no earlier than August 2022, to ensure that they cover the 2023 breeding season, when flight height data will be collected using GPS. Ideally, spatial coverage should also include areas covered by standard Digital Aerial Surveys. This would enable a comparison of flight height distributions obtained using LiDAR, GPS, and Digital Aerial Survey during the 2023 breeding season, meaning that it would be possible to identify differences between them, and consider reasons for these differences. This would help to substantially reduce uncertainty surrounding estimates of species flight heights, a key parameter for the assessment of collision risk, by enabling an assessment of the sources of error, bias and uncertainty associated with each methodology. The cost for a project of this nature is likely to be substantial, meaning it may require multiple developers working collaboratively or, a strategic funding mechanism such as ORJIP.

5.7 Longer-term research priorities

Whilst not of immediate relevance to the ScotWind projects , workshop participants highlighted several other projects they felt were of importance in relation to reducing the uncertainty associated with the predicted impacts of offshore wind farms on seabird populations. Key amongst these was developing a long-term strategy to support demographic monitoring of East Coast seabird populations, particularly kittiwake. At present, monitoring is insufficient to detect the population level changes that might be associated with offshore wind development (Cook et al., 2019). Understanding consequences at a population level will be key to reducing uncertainty in relation to future leasing rounds. In order to do so, it will be necessary to collect additional colony-based data on demographic rates which should be made freely available and utilised fully. For example, any breeding abundance and productivity data collected should follow standard protocols for data collection and be entered into the Seabird Monitoring Programme database (https://app.bto.org/seabirds/public/index.jsp). There may also be scope with the proposed update to the Seabird Monitoring Programme handbook to include emerging methods such time lapse cameras (e.g. Seabirdwatch, see Youngflesh et al. (2021), or drone technology (Rush et al., 2018). With respect to survival, in addition to standard metal ringing studies, a range of approaches to data collection should be considered. Options should include the use of Retrapping for Adult Survival (RAS) studies (Horswill et al., 2018), large scale approaches to colour-ringing (O'Hanlon et al., 2021) and more novel approaches such as the use of MOTUS tracking (Taylor et al., 2017a), the two latter of which will also have scope to look at dispersal rates. Over the longer term, these data could be used to support the development of a meta-population model for key populations, such as the East Coast kittiwake population.

Workshop participants also highlighted projects to reduce uncertainty surrounding collision and displacement which should be considered as part of future post-construction monitoring plans. The first of these was to carry out additional collision monitoring studies. For added value, these should be used to assess the efficacy of mitigation measures, such as painting blades black and increased hub heights. The second relates to a more detailed analysis of the impact of wind farm layout, including turbine spacing, on displacement rates.

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Appendix 1 Research priorities for each Plan Option Area

A1.1. W1

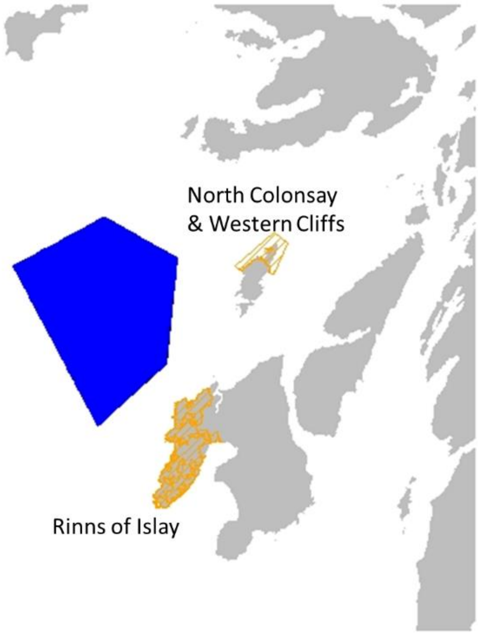

Figure 9 Plan Option W1 (black), including ScotWind Option Agreement 17 (blue), and SPAs at which the potential for significant effects was identified as part of the Strategic Environmental Assessment (orange).

The SMP SEA concluded that the residual effect on key receptors following the construction of wind farms within W1 was likely to be minor negative – moderate negative (Figure 9). Accordingly, whilst no ornithological constraints were identified in relation to this site, uncertainties remained in relation to the potential for displacement of seabirds from key foraging areas, and the potential collision risk associated with migrating waterbirds, particularly Whooper Swans and the geese which are designated features of SPAs on Islay and Colonsay.

The ongoing strategic review of migration and development of a migratory sCRM funded by the Scottish Government will help to reduce uncertainty surrounding the risk to migrants in this PO.

Further work is needed to assess the potential consequences of displacement and barrier effects in PO W1 for common guillemot, razorbill *Alca torda* and kittiwake. Analysis of GPS tracking data collected from Colonsay by the RSPB as part of the FAME/STAR Programme highlights potential overlap between foraging areas of birds from the North Colonsay and Western Cliffs SPA and PO W1 (Thaxter et al., 2019). Whilst not specific to PO W1, workshop participants highlighted the **value of carrying out studies to reduce uncertainty surrounding the energetic costs of displacement and barrier effects on breeding seabirds [OUTPUT]**, such as **the analysis of GPS data to identify foraging and commuting areas [ACTION]**.

A1.2 N1

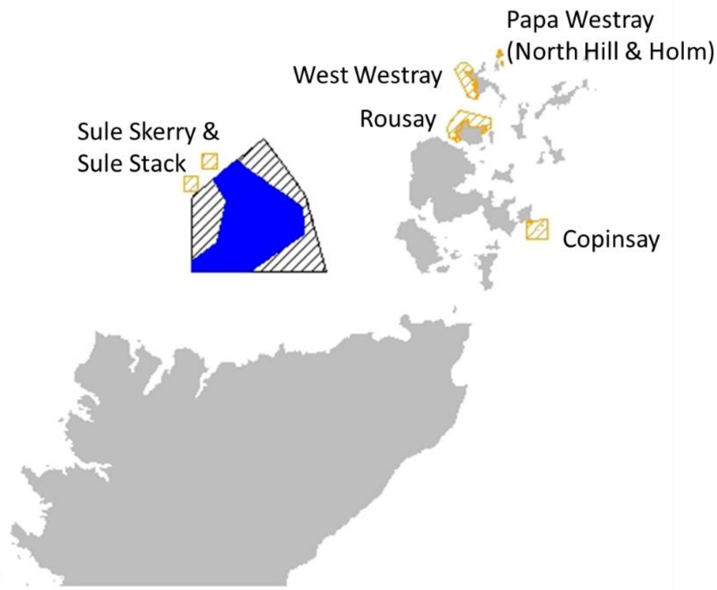

Figure 10 Plan Option N1 (black), including ScotWind Option Agreement 13 (blue) and SPAs at which the potential for significant effects was identified as part of the Strategic Environmental Assessment (orange).

The SMP SEA concluded that the residual impact on key receptors following the construction of wind farms within N1 was likely to be minor negative – moderate negative. Whilst the proximity of the PO to Sule Skerry and Sule Stack SPA (Figure 10), and SPAs on Orkney, means there is high connectivity with parts of the PO by species including kittiwake, gannet and auks (see also Waggitt et al., 2019), careful marine spatial planning could help avoid high usage areas. However, workshop participants also highlighted the presence of nocturnally active species, such as Manx shearwater and European storm-petrel *Hydrobates pelagicus* (Waggitt et al., 2019) which may not be reliably detected by survey methodologies such as digital aerial survey, as a key source of uncertainty within this PO.

Workshop participants highlighted that the key to reducing uncertainty in relation to this PO was getting **a better understanding of species distributions, and connectivity with SPA populations [ACTION]**. GPS tracking data are available to assess connectivity for designated features of some of these SPAs (Wakefield et al., 2013, 2017), more data are required for others. The availability of lightweight GPS devices means that it is now possible to collect data on some of the smaller species that may be present within the PO, such as European storm-petrels (Bolton, 2021) from Sule Skerry and Sule Stack SPA. This is particularly important given that these species may be nocturnally active, and so less well covered by traditional surveys (Deakin et al., 2022). Workshop participants highlighted the need to assess the potential risk to these species within these POs and, if determined to be at risk, the potential for them to be detected by digital aerial survey and, for digital aerial survey to distinguish between smaller species with similar appearances, such as European storm-petrel and Leach's petrel *Oceanodroma leucorhoa*.

Workshop participants highlighted that development within this PO was likely to result in interactions with offshore wind farms involving species such as Manx shearwater and European storm-petrel, which have not been an important feature of offshore wind farm EIAs to date. As nocturnally active species, particular concerns were noted in relation to the potential for birds to be attracted to turbine lighting with a review of this topic highlighted as a research need to reduce the uncertainty associated with this. Secondly, ongoing GPS tracking studies of Manx shearwater in the Irish Sea region, where there are several existing offshore wind farms, were highlighted. **Further analysis of these data may offer insights into how the species is likely to respond to developments within this PO [ACTION]**, and may help also help **reduce uncertainty in relation to parameters such as flight height and speed [OUTPUT]**, which are important for collision risk modelling (Masden et al., 2021).

A1.3 N2

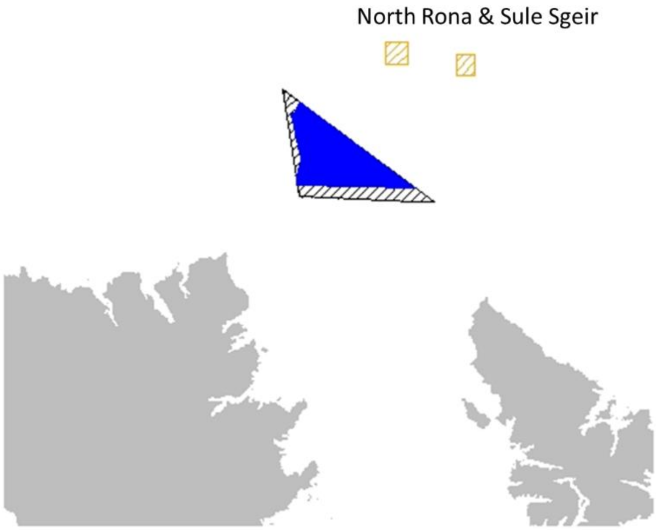

Figure 11 Plan Option N2 (black), including ScotWind Option Agreement 14 (blue) and SPAs at which the potential for significant effects was identified as part of the Strategic Environmental Assessment (orange).

The SMP SEA concluded that the residual effect on key receptors following the construction of wind farms within N2 was likely to be negligible – minor negative. Whilst the PO is close to North Rona and Sula Sgeir SPA (Figure 11), overall bird usage of this area is believed to be low (see also Waggitt et al., 2019), and water depth means that it is unlikely to be a core foraging area. However, key uncertainties remain in relation to the potential impact on migrating birds. These are likely to be reduced by the ongoing strategic review of collision and development of a migrant collision risk modelling tool. Workshop participants highlighted uncertainties relating to nocturnally active species present in the area such as Manx shearwater and European storm-petrel. The work required to reduce these uncertainties includes **a review of the potential impact of turbine lighting on these species (which may be inferred from responses to vessels or other sources of light) [ACTION]**, and **an analysis of existing GPS tracking data from Manx shearwater in the Irish Sea region [ACTION]** to better understand how the species may respond to offshore wind farm development within this PO.

A1.4 N3

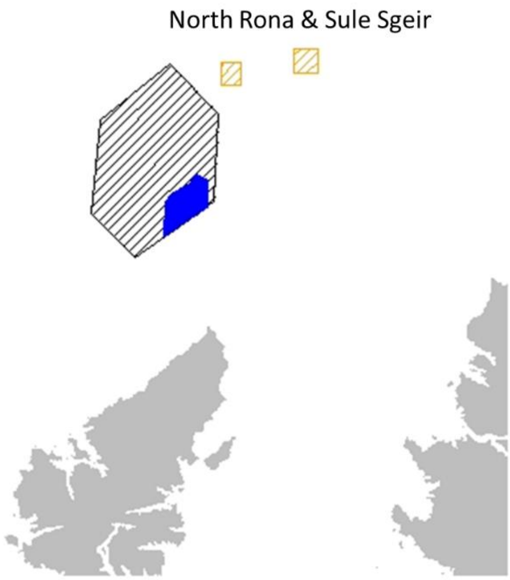

Figure 12 Plan Option N3 (black), including ScotWind Option Agreement 15 and SPAs at which the potential for significant effects was identified as part of the Strategic Environmental Assessment (orange).

The SMP SEA concluded that the residual effect on key receptors following the construction of wind farms within N3 was likely to be negligible – moderate negative. Whilst bird usage of the area is generally considered to be low (see also Waggitt et al., 2019), there are important populations present within the North Rona and Sula Sgeir SPA (Figure 12). These include both Leach's Petrel and European storm-petrel, which have not yet been widely considered as part of impact assessments for offshore wind farms. Consequently, there is considerable uncertainty surrounding the potential impacts on these species, exacerbated by the fact they are nocturnally active, are not well covered by traditional survey methods, and their population sizes and population trends are highly uncertain. There are also uncertainties relating to the potential impacts on migratory waterbirds.

The presence of both Leach's petrel and European storm petrel within the vicinity of this PO raises uncertainty in relation to potential offshore wind impacts on populations of these species. The availability of lightweight GPS devices means that it is now possible to collect **GPS data on these species from the North Rona and Sule Sgeir SPA [ACTION]**. This may be important given that these species may be nocturnally active, and so less well covered by traditional surveys. Consequently, analyses of these data should include a comparison of distributions during conditions in which surveys can and cannot be completed (e.g. Thaxter et al., 2019). Furthermore, workshop participants highlighted the need to **gain a clearer understanding of how well approaches such as digital aerial survey could distinguish**

between smaller species with similar appearances, as European storm petrel and Leach's storm petrel [ACTION].

Reflecting the likely presence of nocturnally active species within the PO, developments would benefit from a **review of the impact of lighting on these species, and other procellariforms [ACTION]**. In may also be possible to reduce uncertainty relating to potential impacts on Manx Shearwater **through analysis of existing GPS tracking data from the Irish Sea region [ACTION]**.

A1.5 N4

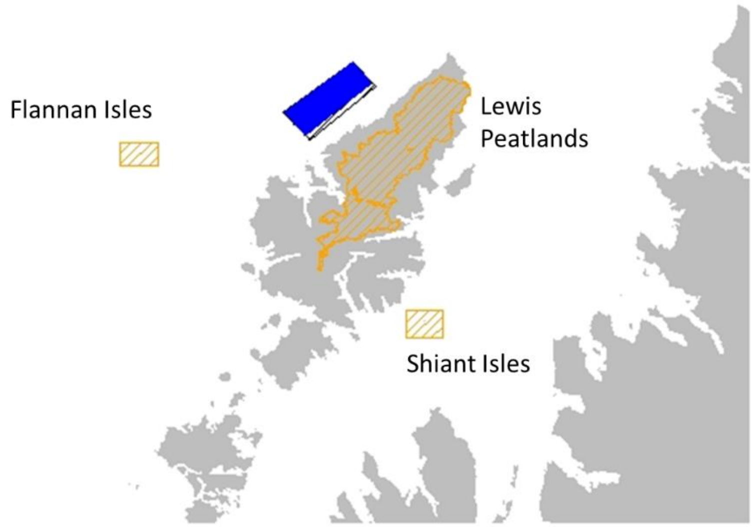

Figure 13 Plan Option N4 (black), including ScotWind Option Agreement 16 and SPAs at which the potential for significant effects was identified as part of the Strategic Environmental Assessment (orange).

The SMP SEA concluded that the residual effect on key receptors following the construction of wind farms within N4 was likely to be negligible – minor negative. Bird usage of the area is likely to be low (see also Waggitt et al., 2019), though there is the potential for interactions with breeding seabirds from the Flannan Isles and Shiant Isles SPAs (Figure 13). There is also uncertainty surrounding potential interactions with migratory species, particularly whooper swan.

Uncertainties surrounding potential impacts on migratory species will be reduced by the ongoing strategic review of migration and development of a migrant collision risk tool. As Leach's petrel is a feature of the Flannan Isles SPA, **a review of the potential for lighting to attract nocturnally active species [ACTION]** would be of benefit in relation to this PO.

A1.6 NE1

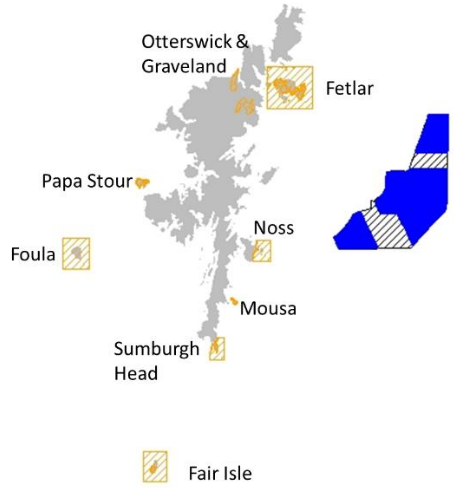

Figure 14 Plan Option NE1 (black) and SPAs at which the potential for significant effects was identified as part of the Strategic Environmental Assessment (orange).

The SMP SEA concluded that the residual effect on key receptors following the construction of wind farms within NE1 was likely to be negligible – moderate negative. Whilst bird usage of the area is generally low (see also Waggitt et al., 2019), there are a number of important seabird populations within Shetland SPAs, such as the Sumburgh Head SPA and Fair Isle SPA (Figure 14). These include populations of species such as great and Arctic skua which have not been an important feature of impact assessments for offshore wind farms to date. Furthermore, there is uncertainty about the potential for migratory birds interact with this PO. Workshop participants also highlighted the potential for nocturnally active species, such as European storm petrel to be present within this PO.

The water depth within this PO is in excess of 100 m throughout. Consequently, it is unlikely to be a key seabird foraging area. Under a realistic maximum development scenario, up to 53% of this PO would be developed. There is a need to **carry out surveys of this PO in its entirety [ACTION]** to confirm that bird density within the PO is low, and to **determine the optimal distribution of turbines [OUTPUT]** whilst minimising environmental impacts. **For species such as gannet and kittiwake, which are suspected to be sensitive to the impacts associated with offshore wind farms, and for which predicted cumulative impacts are approaching levels of concern (Busch & Garthe, 2017), GPS tracking studies may prove valuable as a means to determining the behaviour of birds within the PO and identify key commuting routes between breeding colonies and foraging areas [ACTION]. Whilst not a key ornithological constraint, GPS tracking of gannets from the Fair Isle SPA would be valuable for establishing potential connectivity with this PO [ACTION]**.

Given water depths within this PO, any development is likely to involve floating turbines. Through careful marine spatial planning, these can be positioned to avoid areas of highest bird densities. This should carefully consider factors such as the **potential impact of turbine**

spacing on displacement rates [OUTPUT]. However, the use of floating turbines may also enable a more adaptive management approach to be used. It may be possible for turbines in an array to be moved in response to post-construction monitoring data to reduce the impact associated with the development. **A review of the practicalities of post-construction mitigation measures such as this would be beneficial for reducing some of the uncertainties associated with development in this PO [OUTPUT]**.

At present, collision risk models have been developed for use with fixed turbines with hub heights measured relative to highest astronomic tide. It will be important to consider how to adapt guidance for use with floating turbines which will remain a constant height above sea-level. Where flight height estimates are based on survey data, these will reflect height above the sea surface, and may be directly transferable to the assessment of collision risk at floating turbines. However, where flight heights have been measured using GPS data, these are likely to be aggregated and reflect height above mean sea-level rather than the height above the sea surface experienced by the birds. Adapting these data for collision risk modelling will require careful consideration. This may also have implications for **assessing the efficacy of raising turbine hub height as a mitigation measure for reducing collision risk [OUTPUT]**.

Whilst not presently a key ornithological constraint, there is uncertainty surrounding the potential for cumulative impacts on gannets from the Noss and Fair Isle SPAs given the potential for birds to interact with multiple POs. **A cumulative impact assessment of the potential impacts of the POs on these populations [OUTPUT]**, for example **incorporating methods and approaches available as a result of the CEF [ACTION]**, will be valuable to reduce this uncertainty.

Given the potential presence of nocturnally active species, such as European storm petrels, within the PO, **a review of the potential for turbine lighting to attract these species [ACTION]** may be valuable.

A1.7 NE2 and NE3

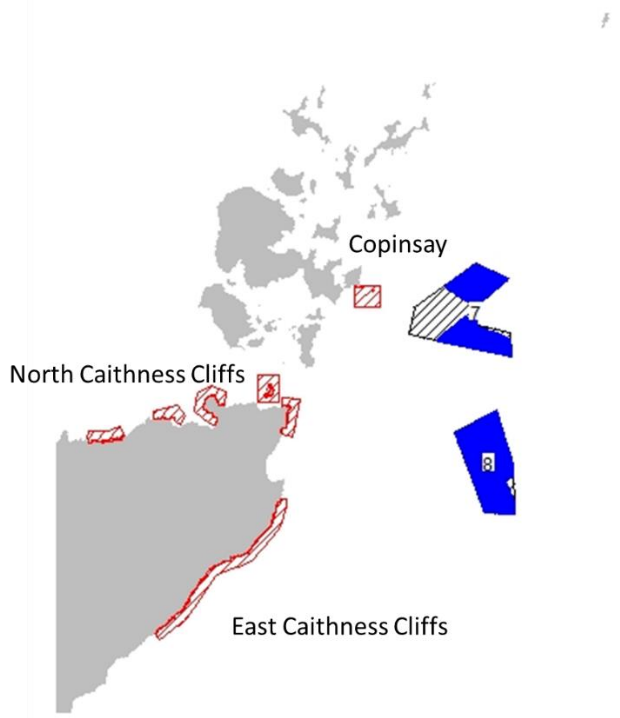

Figure 15 Plan Options NE2 and NE3 (black), including ScotWind Option Agreements 7 and 8 (blue) currently subject to a high level of ornithological constraint as a consequence of potential impacts on designated features of SPAs, including those shown in red.

The SEA for the SMP considered bird usage of NE2 and NE3 was likely to be low (see also Waggitt et al., 2019). However, the proximity of the PO to the Copinsay SPA, East Caithness Cliffs SPA and North Caithness Cliffs SPA (Figure 15), for which kittiwake is a designated feature, and the predicted cumulative impacts of offshore wind developments on the east coast and Orkney kittiwake population more generally, means that the residual effect of NE2 and NE3 was assessed as minor negative – major negative. **Reflecting this, the SMP HRA concluded that an Adverse Effect on Site Integrity was likely to arise as a consequence of developments within NE2 and NE3 in combination with existing and consented offshore wind farms in the Moray Firth.** As a result, NE2 and NE3 was identified as being subject to higher levels of ornithological constraint, meaning that development within these POs cannot take place until such time that enough evidence on the environmental capacity for seabirds exists to reduce the risk to an acceptable level. This assessment is based on currently predicted levels of impact but, if evidence is presented that would enable these impacts to be revised downwards, it may be possible for development to proceed.

The key to unlocking offshore wind potential within these POs will be reducing uncertainty in existing assessments with a view to obtaining evidence that would enable more accurate estimation of impacts. Workshop participants highlighted three key routes to achieving this:

1) **Reduce uncertainty surrounding the magnitude of the predicted cumulative impacts of collision and displacement within offshore wind farms in the Moray Firth [OUTCOME]**
2) **Reduce uncertainty surrounding the predicted population level effects of offshore wind farms in the Moray Firth [OUTCOME]**
3) **Reduce uncertainty surrounding the distribution of birds in NE2 and NE3 [OUTCOME]**

A1.7.1 Reduce uncertainty surrounding the magnitude of the predicted cumulative impacts of collision and displacement within offshore wind farms in the Moray Firth

The first step to unlocking offshore wind potential within POs NE2 and NE3 will be to reduce the uncertainty surrounding the magnitude of predicted cumulative impacts of collision and displacement within offshore wind farms in the Moray Firth. This can be achieved in two ways. Firstly, by intensive and robust monitoring of constructed sites and **revising the impacts predicted within EIAs based on observed impacts [OUTPUT]**. Given the challenges of collecting data on collisions in the offshore environment, this is likely to be of most relevance to displacement. Secondly, by **revision to model input parameters from those originally used in the AA to any that have been subsequently revised using the CEF [OUTPUT]**. This relates to both collision, where models are sensitive to parameters such as avoidance, flight height and speed (Chamberlain et al., 2006; Masden et al., 2021), but also to displacement, where predicted impacts are sensitive to assumptions surrounding energetics and mortality rates (Busch & Garthe, 2016; K Searle et al., 2018).

The key focus within NE2 and NE3 relates to kittiwake. Evidence relating to kittiwake displacement from existing offshore wind farms is equivocal, ranging from weak attraction to weak displacement (Dierschke et al., 2016). Intensive and robust monitoring of the Beatrice and Moray East offshore wind farms, and **analysis of the resulting data [ACTION]**, will enable a comparison of the observed proportion of birds displaced with that predicted in the EIA. This will help to reduce the uncertainty surrounding the proportion of birds displaced by the existing wind farms in the Moray Firth. This must be combined with work to **reduce uncertainty in the demographic consequences of displacement [OUTPUT]**, for example by **better quantifying the link between the energetic costs of foraging, survival, and productivity [OUTPUT]** (e.g., using IBMs such as SeabORD and critically **the collection of GPS and demographic data [ACTION]** to assist in improving the parameterization and validation of these processes within IBMs). Such analyses may unlock potential within NE2 and NE3 by reducing uncertainty surrounding the predicted cumulative impact of displacement associated within offshore wind farms within the Moray Firth.

Given the proximity of NE2 and NE3 to the Copinsay SPA, the cumulative impact of collision risk of kittiwake is of concern. At present, models of collision risk rely on generic sources of data for key parameters including avoidance rates (Cook, 2021, 2014), flight speed (Alerstam et al., 2007) and flight heights (A. Johnston et al., 2014). However, such data are often derived from limited sample sizes and/or in a specific set of conditions. Furthermore, these values may differ according to whether birds are engaged in commuting or foraging flight (Thaxter et al., 2019). **Analyses of new and existing GPS data can serve to reduce**

uncertainty surrounding some of these parameters, and in turn reduce uncertainty surrounding predicted collision rates [OUTPUT] (Masden et al., 2021). **Ideally, these data should be collected on a site-specific basis, e.g., high resolution GPS tracking data from kittiwake within the Copinsay SPA [ACTION]**.

The availability of flight height estimates from a variety of platforms results in considerable uncertainty in relation to the available datasets. These datasets are likely to be subject to multiple sources of bias, error, and uncertainty. In the absence of **a multi-sensor study with flight height estimates made concurrently from different technologies [ACTION]**, it is unclear how comparable estimates from these datasets are. Such a study would be of considerable value in relation to **reducing uncertainty surrounding species flight height estimates [OUTPUT]**.

Having revised the input parameters for the collision risk model, there may be the potential to reduce uncertainty in estimated collision rates through revisions to the model itself. At present, uncertainty in collision estimates due to "model simplification" is believed to be in the range of 20% (Band, 2012). Whilst the sCRM accounts for uncertainty in the model input parameters, it does not account for uncertainty resulting from model simplification (McGregor et al., 2018). Recent analysis by Masden et al. (2021) highlights how the estimation of the probability of collision (PColl) and flux rate can influence estimated collision rate. **However, neither PColl nor flux have been validated, contributing to uncertainty. There is a need to consider how these can be validated, potentially in conjunction with consideration of alternative models such as the Flux Collision Model [OUTPUT]** (Kleyheeg-Hartman et al., 2018).

Having updated both the models and input parameters used to assess collision and displacement, **revising the estimated cumulative impacts, using the CEF [ACTION]**, associated with offshore wind farms in the Moray Firth will help reduce uncertainty surrounding predicted impacts and may help unlock offshore wind potential within NE2 and NE3.

A1.7.2 Reduce uncertainty surrounding the predicted population level effects of offshore wind farms in the Moray Firth

At present, the population level consequences associated with offshore wind farm development are typically assessed using a Leslie Matrix Model with a simplistic set of assumptions, including a closed population and no density dependence. Reflecting the consenting risks highlighted in the SMP SEA, the focus for such studies in relation to POs NE2 and NE3, workshop participants highlighted the value of **developing a meta-population model for the Orkney and east coast kittiwake population [OUTPUT]**. Such a model should factor in links between effects and demography at the individual level, incorporate key processes at the population level such, as density dependence and net movements between colonies, and incorporate the impact of other pressures on demography where possible. This requires **collating and collecting demographic data on a colony-specific basis [ACTION]**. Where colony-specific data are not available, this model should be based on the best available data (e.g. Horswill et al., 2021), and refined as new data become available.

The use of data which are not colony-specific should be seen as a temporary solution, and development of the model should not be at the expense of key data collection.

Horswill et al., (2018) and O'Hanlon et al. (2021) highlight that whilst a minimum of 10 years data are required to estimate reliable survival rates, the uncertainty surrounding these rates can be narrowed with five years of data. Reflecting the priorities associated with NE2 and NE3, **demographic data collection for a meta-population model in relation to these POs should focus on the kittiwake population within the North Caithness Cliffs SPA, East Caithness Cliffs SPA and Copinsay SPA [ACTION]**. It may also be possible to use novel approaches such as Motus type tracking to monitor return rates and increase the recapture probability of these birds, potentially, reducing the time required to obtain robust survival estimates. **A feasibility study for this approach (potentially captured in an OWEC funded MOTUS study), and other remote methods for demographic data collection, would be valuable [ACTION]**.

Using this model to assess the cumulative impact of existing and consented wind farms on the east coast of Scotland would help to reduce uncertainty surrounding the predicted population-level consequences of these wind farms and may help unlock offshore wind potential within NE2 and NE3.

A1.7.3 Reduce uncertainty surrounding the distribution of birds in NE2 and NE3

Modelled distributions for key species, including kittiwake, should be produced from survey data for each Option Agreement. **Ideally these models should incorporate GPS tracking data from kittiwakes within the North Caithness Cliffs SPA, East Caithness Cliffs SPA and Copinsay SPA [ACTION]** to **better apportion impacts arising from offshore wind developments within NE2 and NE3 back to the SPAs [OUTPUT]** during the breeding season. These data would also help to **identify key foraging and commuting areas for kittiwake [ACTION]** (e.g. Thaxter et al., 2019), which would be of value in relation to identifying areas where birds may be particularly vulnerable to displacement. Given the potential for annual variation in foraging areas between years, it is important that such data are collected over multiple years, and to **better understand distributions in relation to oceanographic and ecosystem conditions [OUTPUT]**.

Survey data suggest usage of these POs by vulnerable species including gannets, common guillemot, razorbill and kittiwake during the winter may be relatively high, though there is some uncertainty surrounding this (Waggitt et al., 2019). Geolocation studies suggest that some of the auks may originate from Scottish east coast SPAs (e.g. Dunn et al., 2020; St. John Glew et al., 2019, 2018). To address this, as highlighted above, there is a need for **survey data from the POs in their entirety [ACTION]**. To **improve the apportioning of impacts outside the breeding season [OUTPUT]**, there is a need to **collect geolocation data from gannets, common guillemot, razorbill, and kittiwake from Scottish east coast SPAs [ACTION]**, and **consider how these data can be combined with survey data [ACTION]**. Given the resolution of data from geolocation data, there is a need to consider how these can be refined and, in the case of larger species such as kittiwake and gannet, whether it is possible to **develop methodologies for the longer-term deployment of GPS tags [ACTION]** on these species. To **better understand the energetic consequences of displacement**

[OUTPUT] outside the breeding season, **TDRs should be deployed alongside these devices [ACTION]** to assess time-activity budgets.

Given the high level of ornithological constraint associated with the kittiwake population on Orkney and the Scottish east coast, in addition to using careful marine spatial planning to reduce impacts, there is a need to consider effective mitigation options. These may include increasing turbine spacing to mitigate the impact of displacement or raising turbine hub heights to reduce the number of birds at collision risk height. **Assessing the efficacy of these, and other, mitigation options will require the analysis of robust data collected as part of monitoring at existing wind farms. It is also likely to require some inferences to be made in relation to the efficacy of different options [OUTPUT]**. For example, at present, we do not have data to measure whether raising turbine hub height reduces the number of collisions. However, we would be able to **compare flight heights inside and outside [OUTPUT]** operational wind farms using approaches such as GPS tagging, LiDAR, radar, and digital aerial survey. This will offer an indication of how pre- and post-construction flight heights may compare, and therefore, **how effective raising turbine hub height may be in terms of reducing the number of birds at risk of collision [OUTPUT]**.

A1.7.4 Other uncertainties

Whilst not currently constraints to development within NE2 and NE3, the SMP SEA and workshop participants also highlighted uncertainty in relation to several other issues. Firstly, as with NE1, there is uncertainty surrounding the potential for interaction between gannets from the Fair Isle, Noss and other SPAs and POs NE2 and NE3. Consequently, there is also uncertainty surrounding the potential for cumulative impacts on these gannet population in relation to the POs, existing and consented offshore wind farms in the Moray Firth. **GPS tracking of birds from these SPA populations [ACTION]** would help reduce uncertainty surrounding the connectivity between the SPA and NE2 and NE3, and **a strategic cumulative impact assessment for gannets from these SPAs, beyond that which would be expected in relation to individual developments [OUTPUT],** would help to address questions relating to the population level consequences of existing and planned wind farms in the Moray Firth.

In addition to uncertainty surrounding the potential for negative impacts on gannets from the Fair Isle SPA, there is also uncertainty surrounding the potential for significant negative effects on migrating birds. Furthermore, workshop participants also highlighted the potential presence of nocturnally active species such as European storm petrel within the POs. Whilst the ongoing strategic review of migration and development of a migrant collision risk tool is likely to reduce uncertainty surrounding impacts on migrant species, and **a review of the impact of turbine lighting on nocturnally active species [ACTION]** would be beneficial in terms of reducing uncertainty within these POs.

A1.8 NE4 and NE6

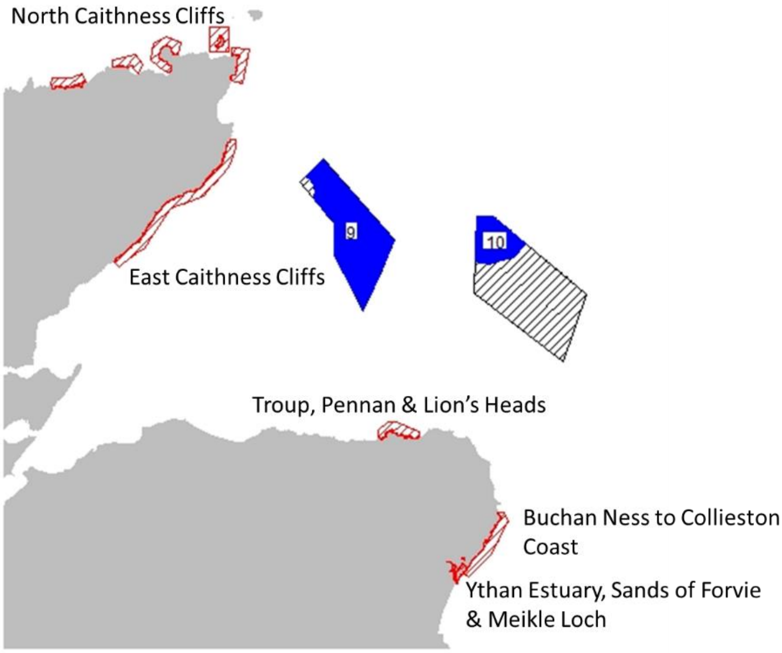

Figure 16 Plan Options NE4 and NE6 (black), including ScotWind Option Agreements 9 and 10 (blue) currently subject to a high level of ornithological constraint as a consequence of potential impacts on designated features of SPAs, including those shown in red.

The SEA of the SMP considered that bird usage of NE4 and NE6 was likely to be high, and likely to include foraging birds from the East Caithness Cliffs SPA (Figure 16). **Consequently, the SMP SEA assessed potential impact of POs NE4 and NE6 as minor negative – major negative. Reflecting this, the SMP HRA concluded that an Adverse Effect on Site Integrity was likely to arise as a consequence of developments within NE4 and NE6 in combination with existing and consented offshore wind farms in the Moray Firth**. As a result, NE4 and NE6 were identified as being subject to higher levels of ornithological constraint, meaning that development within these POs cannot take place until such time that enough evidence on the environmental capacity for seabirds exists to reduce the risk to an acceptable level. This assessment is based on currently predicted levels of impact but, if evidence is presented that would enable these impacts to be revised downwards, it may be possible for development to proceed.

Given the potential for adverse impacts on populations of kittiwake within the North Caithness Cliffs SPA and East Caithness Cliffs SPA, as with NE2 and NE3, the key to unlocking offshore wind potential within these POs will be reducing uncertainty in existing assessments. Consequently, the projects highlighted in relation to NE2 and NE3 to **reduce uncertainty in relation to the predicted impacts of collision and displacement**, **reduce uncertainty surrounding predicted population level effects [ACTION]**, and **reduce uncertainty surrounding the distribution of birds within POs [ACTION]**, are also of relevance here.

Whilst GPS tracking data suggest minimal overlap in foraging areas for common guillemot and razorbill from the East Caithness Cliffs SPA (Wakefield et al., 2017), there is uncertainty over the potential for great black-backed gulls, also a feature of the East Caithness Cliffs SPA, to make use of these POs. Consequently, GPS tracking of great black backed gulls from the East Caithness Cliffs SPA to establish the extent of any connectivity between the SPA and POs NE4 and NE6 would be valuable. This is a license condition for existing Moray Firth wind farms where concerns over the potential for tag effects are a constraint for delivery. Consequently, careful liaison with the Special Methods Technical Panel of the BTO ringing committee will be required in order to deliver this work. Similarly, workshop participants highlighted uncertainty over connectivity between gannets from Fair Isle and these POs, while the SMP HRA also highlights the potential for kittiwakes from the Troup, Pennan and Lion's Heads SPA to interact with NE6. **GPS tracking of these populations [ACTION]** would be valuable to assess the extent of any connectivity with NE4 and NE6. Ideally, in all cases, any tracking should be complemented by **surveys of both POs as a whole [ACTION]** to better understand space use within the POs, and **more accurately apportion impacts back to SPA populations [OUTPUT]**.

As with NE2 and NE3, there is a need to **collect data using geolocators from key seabird species [ACTION]** on the Scottish east coast to improve apportioning outside the breeding season. Alongside this, **TDR data should be collected [ACTION]** to **better understand the energetic consequences of displacement [OUTPUT]**.

As with other POs, the SMP SEA highlighted the potential for significant negative effects on migrating birds, while workshop participants also highlighted the potential presence of nocturnally active species such as European storm petrel within the PO. Whilst the ongoing strategic review of migration and development of a migrant collision risk tool is likely to reduce uncertainty surrounding impacts on migrant species, an assessment of the ability to distinguish between Leach's petrel and European storm petrel, and a **review of the impact of turbine lighting on these species [ACTION]** would be beneficial in terms of reducing uncertainty within this PO. However, such projects would be of a lower priority than those highlighted above in relation to gannets, kittiwakes, and great black-backed gulls.

A1.9 NE7 and NE8

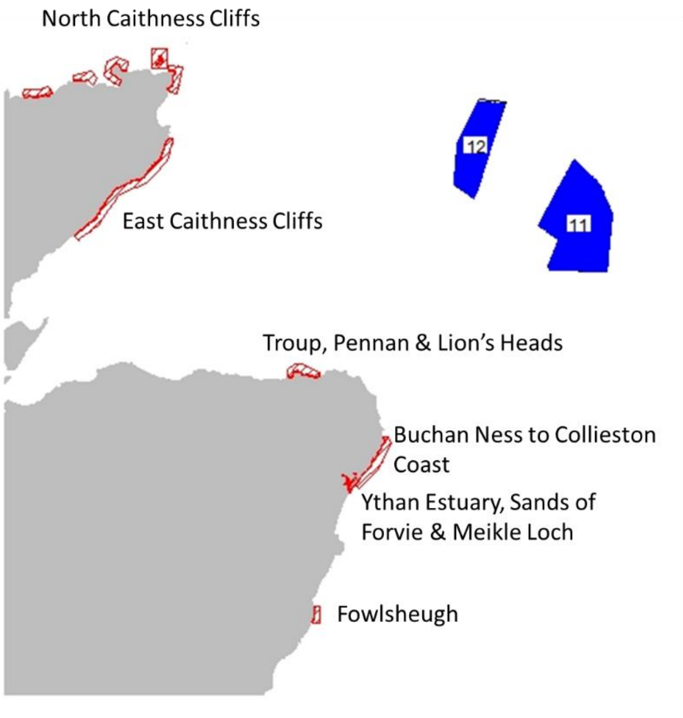

Figure 17 Plan Options NE7 and NE8 (black), including ScotWind Option Agreements 11 and 12. The Strategic Environmental Assessment highlighted the potential for significant negative impacts at SPAs, including those shown in red. Whilst POs NE7 and NE8 are not subject to a high level of ornithological constraint, impacts on the SPAs shown here mean that other POs within this region are subject to a high level of ornithological constraint.

The SMP SEA concluded that the residual effect on key receptors following the construction of wind farms within NE7 and NE8 (Figure 17) was likely to be minor – moderate negative. Analysis of GPS tracking data suggests bird usage of the area is likely to be low (Wakefield et al., 2017). However, the potential for negative effects in-combination with other east coast projects is acknowledged. The SEA also highlights the potential for negative impacts associated with birds migrating from Scandinavia.

Data from surveys and tracking studies indicate that seabird usage of these POs during the breeding season is likely to be low (Waggitt et al., 2019; Wakefield et al., 2017), and, for most species, they are beyond the foraging ranges of key breeding colonies (Woodward et al., 2019). However, there is substantial uncertainty surrounding the distribution of birds within these POs outside the breeding season (Waggitt et al., 2019), particularly during migration periods for species like skuas, and over winter for species like auks. Reducing this uncertainty will require **surveys of the POs as a whole [ACTION]**. Ideally, **these data would be combined with geolocation data collected from auk populations [ACTION]** on the east coast to help **improve the apportioning of impacts outside the breeding season [OUTPUT]**.

Given the water depths in these POs, developments are likely to involve floating turbines. At present, collision risk models have been developed for use with fixed turbines with hub heights measured relative to highest astronomic tide. It will be important to consider how to adapt guidance for use with floating turbines which will remain a constant height above sea-level. Where flight height estimates are based on survey data, these will reflect height above the sea surface, and may be directly transferable to the assessment of collision risk at floating turbines. However, where flight heights have been measured using GPS data, these are likely to be aggregated and reflect height above mean sea-level rather than the height above the sea surface experienced by the birds. Adapting these data for collision risk modelling will require careful consideration. This may also have implications for **assessing the efficacy of raising turbine hub height as a mitigation measure for reducing collision risk [OUTPUT]**.

As with other POs, the SMP SEA highlighted the potential for significant negative effects on migrating birds, while workshop participants also highlighted the potential presence of nocturnally active species such as European storm petrel within the PO. Ongoing strategic review of migration and development of a migrant collision risk tool is likely to reduce uncertainty surrounding impacts on migrant species. However, an assessment of the ability to distinguish between Leach’s petrel and European storm petrel, and **a review of the impact of turbine lighting on these species [ACTION]** would be beneficial in terms of reducing uncertainty within this PO.

A1.10 E1 and E2

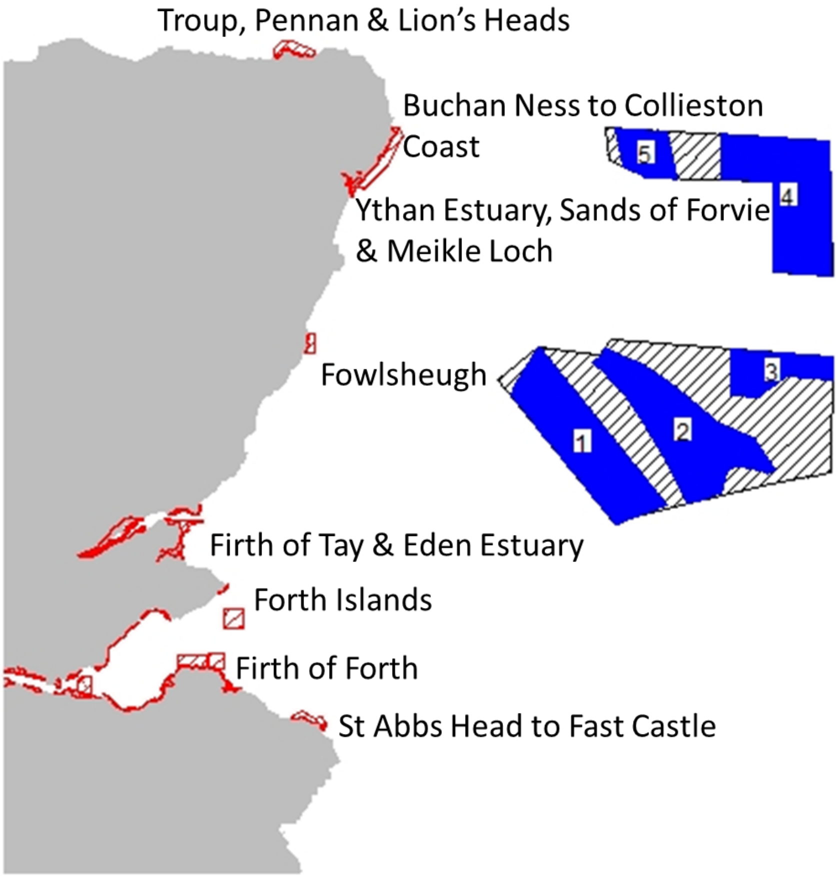

Figure 18 Plan Options E1 and E2 (black), including ScotWind Agreement Offers 1, 2, 3, 4, and 5 (blue), which are subject to additional survey requirements before no adverse effect on site integrity can be concluded. The strategic environmental assessment highlighted potential negative impacts at the SPAs in red.

The SMP SEA suggests that the offshore nature of POs E1 and E2 (Figure 18) mean that they are likely to be areas of lower bird density. Consequently, the SMP SEA considered the likely impact of these POs on designated features of protected sites to be minor negative – moderate negative. However, the SMP HRA highlights the potential for significant negative impacts as a result of the number of built, consented, and planned developments within the region, and the number of important breeding seabird breeding colonies within foraging range. Furthermore, historic data presented in Waggitt et al. (2019) suggests densities may be higher outside the breeding season, though there are uncertainties about these densities. Consequently, the SMP HRA advised that it could not be concluded with certainty that developments within POs E1 and E2 would not have an adverse effect on site integrity. The SMP HRA highlighted two routes to reducing uncertainty surrounding the potential for significant cumulative impacts:

1. Reduce uncertainty regarding the potential scale of cumulative impacts in this region on seabird species (resulting from collision, displacement, and barrier effects)
2. Collect data in relation to seabird densities and behaviours in the offshore region during the non-breeding season.

A1.10.1 Reduce uncertainty regarding the potential scale of cumulative impacts in this region on seabird species

As with NE2-NE6, a key concern within POs E1 and E2 relates to the potential impact of collision on kittiwake. Consequently, **the projects highlighted in relation to reducing uncertainty surrounding collision risk for kittiwake [OUTCOME]**, and **to reduce the uncertainty surrounding distribution and connectivity [OUTCOME]**, in relation to NE2 and NE3 are also relevant here. This should include **GPS tracking studies of populations within the Buchan Ness to Collieston Coast SPA**, **the Fowlsheugh SPA, the Forth Islands SPA, and the St. Abbs Head to Fast Castle SPA [ACTION]**. To ensure optimal layout of turbines, modelled distributions, ideally **combining both survey and GPS data [ACTION]**, should be produced, this would also help to **reduce uncertainty in relation to apportioning [OUTPUT]**. Further analyses of the GPS data should be used to determine the extent to which each PO is used for foraging and commuting, and to **reduce uncertainty surrounding key parameters for collision risk models including flight heights and speeds [OUTPUT]**.

In addition to kittiwake, the SMP HRA also raises concerns about the potential for significant cumulative impacts on razorbills, which are also features of the SPAs listed above. As with kittiwake in relation to NE2 and NE3, reducing uncertainty surrounding the potential for significant cumulative impacts arising as a result of displacement for both species will require **better quantification of the proportion of birds likely to be displaced by offshore wind farms [OUTPUT]**, which could be achieved through the **analysis of post-construction monitoring data from existing wind farms [ACTION]**, and **better quantifying the energetic and demographic consequences of displacement [OUTPUT]**.

As with NE2-NE6, having updated the input parameters and models used to assess the impacts of collision and displacement on kittiwake and razorbills within offshore wind farms on the east coast of Scotland, uncertainty surrounding cumulative impacts could be reduced further by ensuring analyses were **re-run using a consistent approach based on the latest available evidence, using the CEF [ACTION]**.

As with NE2-NE6, uncertainty surrounding the population level consequences of any impacts on kittiwake populations could be reduced further using **a meta-population model for the Orkney and east coast population [OUTPUT]**.

A1.10.2 Collect data in relation to seabird densities and behaviours in the offshore region during the non-breeding season

The SMP HRA highlights uncertainty surrounding the distribution of birds within both E1 and E2, particularly outside the breeding season. Given uncertainty in the distribution of birds outside the breeding season more generally (Waggitt et al., 2019), **regional-level surveys of the Scottish east coast [ACTION]** are required to better understand the relative importance of E1 and E2, particularly in relation to wintering birds. As a minimum, these surveys should include both POs and a 12km buffer around each. Surveys should cover a minimum of 5% of the total area and be carried out on a monthly basis for two years to begin in either March or September to coincide with the start of the start of the breeding or non-breeding season.

Having determined the distribution of birds outside the breeding season, and relative importance of E1 and E2, there is a need to **develop methodologies to apportion impacts back to breeding populations [OUTPUT]**. Initially, this will involve **analysing geolocation data collected from birds at breeding colonies on the east coast of the UK [ACTION]** to infer the likely breeding origins of birds present in E1 and E2. However, given the broad spatial resolution of these data, reducing uncertainty in apportioning further will require **development of analytical methodologies [OUTPUT]** or the **development of longer-term attachment methodologies for GPS tags [ACTION]**.

In addition to understanding the distribution of birds within E1 and E2 outside the breeding season, there is also a need to understand the behaviour of these birds. However, approaches such as HMMs, which are used to classify seabird behaviour, rely on the availability of high-resolution tracking data. In the absence of a methodology for long-term tag deployment, alternative approaches are needed to quantify aspects of birds' behaviour. This should include **deploying TDRs alongside geolocators for auks from east coast SPAs [ACTION]** to estimate species time-activity budgets and the potential consequences of displacement. Similarly, flight height information can be collected as part of surveys using approaches such as LiDAR or digital aerial survey (Largey et al., 2021) in order to better understand species collision risk. However, given the availability of different approaches for estimating species flight heights, **a trial of multiple sensors would be valuable [ACTION]**. This would help to demonstrate how comparable estimates from different platforms are, and identify how any biases, or errors in these estimates may affect outputs from collision risk models.

A1.11 E3

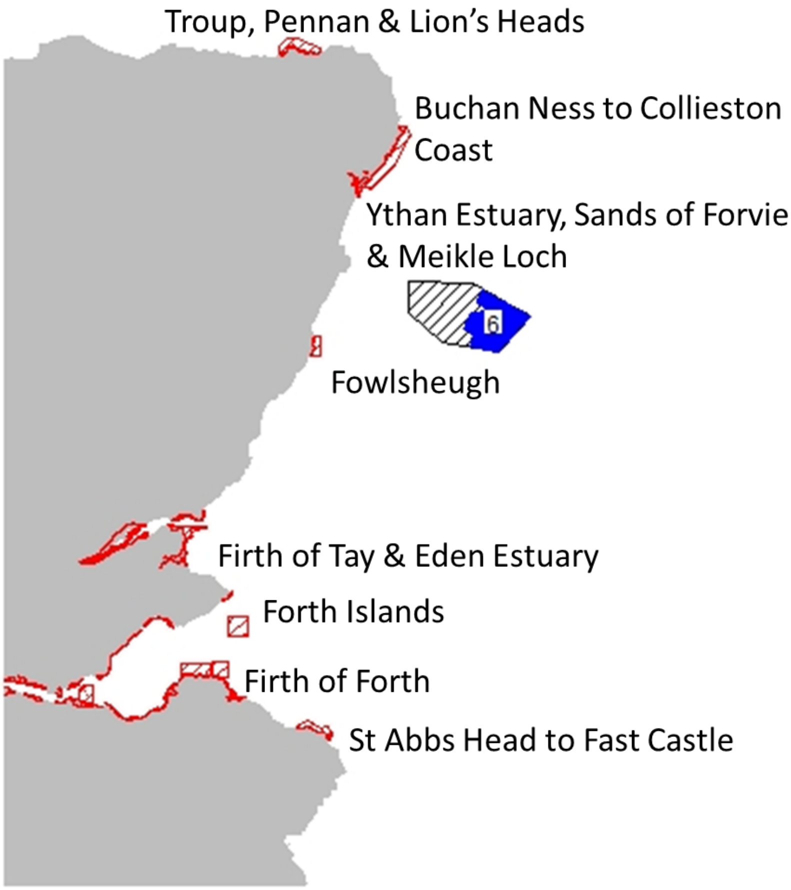

Figure 19 Plan Option E3 (black), including ScotWind Agreement Offer 6, currently subject to a high level of ornithological constraint as a consequence of potential impacts on designated features of SPAs, including those shown in red.

Water depth across PO E3 (Figure 19) is variable with areas of shallower (0-60m) and deeper (>60m) water. Whilst seabird usage of the deeper water areas may be low, the presence of shallower areas, the proximity of SPAs for which seabirds are designated features, and the proximity to several existing and planned projects means that SMP SEA considered that the impacts of E3 were likely to be minor negative – moderate negative. **As a result, E3 was identified as being subject to higher levels of ornithological constraint, meaning that development within this PO cannot take place until such time that enough evidence on the environmental capacity for seabirds exists to reduce the risk to an acceptable level.** This assessment is based on currently predicted levels of impact but, if evidence is presented that would enable these impacts to be revised downwards, it may be possible for development to proceed.

The key to unlocking offshore wind potential within PO E3 will be reducing uncertainty in existing assessments with a view to obtaining evidence that would enable currently predicted levels of impact to be revised downwards. Workshop participants highlighted three key routes to achieving this:

1) **Reduce uncertainty surrounding the distribution of birds in E3 [OUTCOME]**
2) **Reduce uncertainty surrounding the magnitude of the predicted cumulative impacts of collision and displacement within offshore wind farms in Firth of Forth and Moray Firth [OUTCOME]**
3) **Reduce uncertainty surrounding the predicted population level effects of offshore wind farms in the Firth of Forth and Moray Firth [OUTCOME]**

A1.11.1 Reduce uncertainty surrounding the distribution of birds in E3

As with NE2-NE6, there is the potential for developments within PO E3 to have significant in-combination effects on breeding kittiwakes within the Fowlsheugh SPA, Buchan Ness to Collieston Coast SPA and the Troup, Pennan and Lion's Heads SPA as a result of existing and planned developments within the Moray Firth. However, given the more southerly location of this PO, there is also the potential for significant in-combination effects on kittiwakes and other breeding seabirds within the Firth of Forth Islands SPA and the St Abbs Head to Fast Castle SPA as a result of existing and planned developments within the Firth of Forth and Tay region. Consequently, there is a need to better understand the distribution and origin of birds within this PO.

Given the magnitude of impacts predicted as a consequence of in-combination effects on the east coast of Scotland, it is important that any available capacity is developed in an optimal way. This can be informed through **GPS tracking studies of birds from key SPAs including kittiwakes, razorbills, common guillemots, and herring gulls *Larus argentatus* from Buchan Ness to Collieston Coast SPA, Fowlsheugh SPA and Forth Islands SPA, with studies at Fowlsheugh SPA prioritised given the proximity to E3. Given the projected cumulative impacts on kittiwake populations, GPS tracking of birds from St Abbs Head to Fast Castle SPA and Troup, Pennan and Lion's Heads SPA should also be considered. Similarly, given past studies suggesting that gannets from the Forth Islands SPA may forage within PO E3 (Wakefield et al., 2013), GPS tracking of this population should also be considered [ACTION]**. Given the potential for foraging distributions to vary between years, such data should be collected over multiple years (Robertson et al., 2014).

To aid apportioning, and better understand the at sea distribution of birds from SPA populations, it would be valuable to **develop methodologies to combine data from GPS tracking and surveys [ACTION]**. This would help in validating models derived from both GPS data and at sea survey data and would potentially **allow the distribution of non-breeding birds in the breeding season to be quantified [OUTPUT]** – a key missing component of current assessment methodologies. Combining data from GPS tracking and survey data is challenging, because of the mismatches in scale and focus between the data types but could be addressed using modern analytical methods such as data integration. Such analyses should seek to **investigate the influence of oceanographic variables on species distributions [OUTPUT]**.

A1.11.2 Reduce uncertainty surrounding the magnitude of the predicted cumulative impacts of collision and displacement within offshore wind farms in Firth of Forth and Moray Firth

As with NE2-NE6, the key to reducing uncertainty surrounding the predicted cumulative impacts of collision and displacement within existing projects will be the collection of better data to feed into models, and improvements to the models themselves. In relation to collision, this is likely to focus on **analyses of GPS tracking data [ACTION]** to **improve estimates of flight heights and speeds for species such as kittiwake, gannet and herring gull which are vulnerable to collision [OUTPUT]**. As highlighted previously, flight height estimates are available from a variety of platforms and inconsistencies between these can contribute to uncertainty in the applicability of individual datasets. Consequently, **a multi-sensor trial of methods to estimate seabird flight heights [ACTION]** would be valuable. As with NE2-NE6, work to improve collision risk models by validating and/or improving the estimation of PColl and Flux would also help reduce uncertainty.

In relation to displacement, **analysis of data collected from existing offshore wind farms [ACTION]** will help to better quantify the proportion of birds likely to be displaced. As with NE2-NE6, these analyses should also consider whether there is any **evidence that increased turbine spacing may influence displacement rates [OUTPUT]**, and therefore may be an effective mitigation measure. Having improved estimates of the proportion of birds likely to be displaced by offshore wind farms, there is a need to reduce the uncertainty surrounding the consequences of that displacement **through the identification of core foraging areas using GPS and analyses of how the energetic costs of foraging influences survival and productivity [OUTPUT]**.

As previously, having updated the models and parameters input parameters used to assess collision and displacement, **revising the estimated cumulative impacts associated with offshore wind farms in the Firth of Forth and the Moray Firth using the CEF [ACTION]** will help reduce uncertainty surrounding predicted impacts and may help unlock offshore wind potential within E3.

A1.11.3 Reduce uncertainty surrounding the predicted population level effects of offshore wind farms in the Firth of Forth and Moray Firth

The key concern in relation to PO E3 relates to the potential for a significant in-combination effect on kittiwake populations within east coast SPAs as a result of existing and planned developments in the Firth of Forth and Moray Firth. Reducing the uncertainty surrounding the predicted population level effects associated with these developments may help to reduce the ornithological constraints associated with PO E3. As highlighted in relation to NE2-NE6, achieving this will require **support for the collection of demographic data within SPAs on the east coast of Scotland [ACTION]**, and the **development of a meta-population model that better accounts for the demographic processes, such as immigration and emigration, and existing pressures, such as fisheries and climate change, acting on kittiwake populations on the east coast of Scotland [OUTPUT]**

Appendix 2 Full list of projects identified and the Plan Option Areas for which they are relevant

		W1	N1	N2	N3	N4	NE1	NE2	NE3	NE4	NE6	NE7	NE8	E1	E2	E3
Survey Data Collection	Regional survey of Scottish East Coast distribution of seabirds at sea							■	■	■	■	■	■	■	■	■
	Survey PO as a whole	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Determine ability to quantify abundance of, and distinguish between, European storm-petrel & Leach's petrel from Digital Aerial Photography		■		■		■	■								
	Assess proportion of immature/juvenile seabirds from survey data, including but not limited to Digital Aerial photography							■	■	■	■			■	■	■
Demographic data collection & modelling	Support for demographic data collection, especially for kittiwake							■	■	■	■			■	■	■
	Feasibility study for the potential of Motus style tracking study to generate demographic data for seabirds							■	■	■	■			■	■	■
	Collection & collation of colony-specific demographic rates for seabirds from East coast SPAs, especially kittiwake							■	■	■	■			■	■	■
	Quantification of density dependent relationships in kittiwake demographic parameters							■	■	■	■			■	■	■
	Quantify impact of additional pressures (e.g., fisheries, climate change) on kittiwake demography							■	■	■	■			■	■	■
	Meta-population model for Orkney and East Coast kittiwake populations							■	■	■	■			■	■	■
	Cumulative Impact Assessment for Gannet populations, especially Fair Isle						■	■	■	■	■					

Tracking Studies	GLS Tracking of East Coast auk, gannet, and kittiwake populations outside Breeding season															
	Feasibility study for the potential of Motus style tracking study of seabirds to establish connectivity between SPAs and POs in the breeding and non-breeding seasons															
	Development of long-term GPS tag attachment methodology for gannet and kittiwake to improve resolution of winter data															
	GPS tracking of Manx shearwater from Rum SPA															
	GPS Tracking of European Storm-petrel from Sule Skerry and Sule Stack SPA															
	GPS Tracking of European Storm-petrel and Leach's petrel from Sula Sgeir and North Rona SPA															
	GPS tracking of gannet and kittiwake from Shetland colonies															
	GPS Tracking of Fair Isle Gannets															
	GPS tracking of kittiwake from Copinsay SPA															
	GPS Tracking of kittiwake from East Caithness Cliffs SPA															
	GPS Tracking of kittiwake from North Caithness Cliffs SPA															
	GPS Tracking of great black-backed gull from East Caithness Cliffs SPA															
	GPS Tracking of kittiwakes from Troup, Pennan and Lion's Heads SPA															

	GPS Tracking of kittiwake from Buchan Ness to Collieston Coast SPA															
	GPS Tracking of common guillemot from Buchan Ness to Collieston Coast SPA															
	GPS Tracking of herring gull from Buchan Ness to Collieston Coast SPA															
	GPS Tracking of kittiwake from Fowlsheugh SPA															
	GPS Tracking of herring gull from Fowlsheugh SPA															
	GPS Tracking of common guillemot from Fowlsheugh SPA															
	GPS Tracking of razorbill from Fowlsheugh SPA															
	GPS Tracking of gannet from Forth Islands SPA															
	GPS Tracking of razorbill from Forth Islands SPA															
	GPS Tracking of common guillemot from Forth Islands SPA															
	GPS Tracking of kittiwake from Forth Islands SPA															
	GPS Tracking of herring gull from Forth Islands SPA															
	GPS Tracking of kittiwake from St Abbs Head to Fast Castle SPA															
Analys is of tracki	Combine GPS & digital aerial survey data to better understand distribution of seabirds in POs															

	Analysis of Manx shearwater GPS data from Irish Sea region to assess interactions with existing Offshore Wind Farms
	Analysis of GPS data to identify commuting and foraging areas of seabirds
Reduced uncertainty about collision rates	Quantify collisions at existing OWF turbines
	Estimates of commuting and foraging flight height and speed of seabirds from GPS tracking data
	Analysis of existing Manx Shearwater data to provide data on flight height and speed
	Comparison of flight heights of seabirds inside and outside operational wind farms
	Comparison of flight heights of seabirds collected using different methodologies
	Consideration of the implications of using floating turbines to assess overlap between species flight height distributions and turbine collision risk zone
	Consideration of different Collision Risk Model components (e.g., PColl & Flux) and how adjusting those alters estimated avoidance corrections
Reduced uncertainty about displacement	Analyse post-construction monitoring data from Beatrice and Moray East offshore wind farms to reduce uncertainty surrounding displacement rates of seabirds
	Review the potential for nocturnally active seabird species to be attracted to turbine lighting

	Analyse data from existing offshore wind farms to investigate impact of turbine spacing on displacement rates of seabirds			■				■	■	■	■			■	■	■
	Quantify the demographic consequences of displacement and barrier effects for seabirds	■						■	■	■	■			■	■	■
Mitigation & update of existing assessments	Review of the potential to use adaptive management and post-construction mitigation in relation to floating turbines		■	■			■					■	■	■	■	■
	Assess the efficacy of mitigation at existing wind farms							■	■	■	■			■	■	■
	Assess cumulative impacts of collision and displacement using a consistent set of parameters and models							■	■	■	■			■	■	■

Scottish Government
Riaghaltas na h-Alba

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