JNCC Report 823

Advancing knowledge of non-breeding seabirds, in the context of offshore wind impact assessments

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April 2026
(republished with minor amendments in May 2026)

ISSN 0963 8091

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This document should be cited as:

Hall, R. & Ruffino, L. (2026) Advancing knowledge of non-breeding seabirds, in the context of offshore wind impact assessments. *JNCC Report 823*. JNCC, Peterborough, ISSN 0963-8091. https://jncc.gov.uk/resources/ba8df5aa-4e87-48b1-9beb-7084c17efdcd

Please note:

Please note that this report, first published in April 2026, was republished in May 2026 following some minor amendments to Figures 2 and 7.

Acknowledgements:

This work has been undertaken on behalf of the Offshore Wind Strategic Monitoring and Research Forum (OWSMRF) (https://jncc.gov.uk/our-work/owsmrf/). OWSMRF is an industry-led collaborative forum that aims to better understand the impact of large-scale offshore wind development on marine birds.

Evidence Quality Assurance:

This document is compliant with JNCC's Evidence Quality Assurance Policy.

OWSMRF is funded by a consortium of offshore wind developers, and JNCC would like to thank them for ongoing support that enables impartial, expert advice on knowledge gaps to be developed. They are: EDF power solutions UK and Ireland, Equinor, Ørsted, ScottishPower Renewables (SPR), SSE Renewables (Scottish and Southern Electricity) and TotalEnergies.

Summary

This report presents a detailed assessment of non-breeding birds (immatures, sabbaticals and failed breeders) in seabird populations within the context of offshore wind farms. This work has been undertaken on behalf of the Offshore Wind Strategic Monitoring and Research Forum (OWSMRF) Phase III. OWSMRF is an industry-led collaborative partnership, which aims to identify and develop research to fill critical knowledge gaps in our understanding of the impact of offshore wind development on marine bird populations.

Future offshore wind development is dependent on consent, which is underpinned by impact assessments. There is currently a limited understanding of the effects of large-scale offshore wind development on seabirds. Uncertainty in impact assessments can lead to delays in offshore wind project consenting decisions, therefore holding up the rapid roll out of offshore renewable energy that is needed to achieve net zero targets by 2050. During the third phase of OWSMRF (2025–2026), stakeholders identified uncertainty around non-breeding birds (i.e. birds not engaged in reproduction during the breeding season) as a critical issue that is currently posing, or in the near future will likely pose, a constraint or challenge to the offshore wind consenting process. Specifically, there is a lack of knowledge around the ecology and behaviour of non-breeders, their specific level of risk from offshore windfarm impacts, and how they should be considered in offshore wind impact assessments.

This document reports on the current treatment of non-breeders in seabird impact assessments in the UK, highlighting where main areas of uncertainty lie. It then provides a review of the current evidence base around non-breeders in seabird populations, including their at-sea distribution and behaviour, the proportion of the whole population they make up, and their role in population resilience. It finally presents a list of six new Research Opportunities (ROs) identified by experts that could help address identified knowledge gaps, contributing altogether to reduced uncertainty in offshore wind impact assessments. This report follows on from the OWSMRF Pilot Year Knowledge Gaps (KG1, KG2 and KG3) and the Continuation Year Knowledge Gap (KG4), hence these ROs are numbered from five.

The ROs suggested as potentially very useful are listed below (RO 5.1 to RO 5.5) and ordered by topic: distribution, behaviour, proportions within populations, and their role in population resilience. Most of them would need to be undertaken in stages and are structured as sub-ROs. An additional RO (RO 5.6) suggested by experts is presented as a separate appendix to the main report as, although relevant to non-breeders, it was thought to be best achieved through a strategic study targeting both adults and immatures.

RO 5.1 At-sea distribution of immatures

- RO 5.1a Literature review of immature distribution
- RO 5.1b Feasibility of using existing data to improve understanding of immature distribution
- RO 5.1c Planning for new immature tracking deployment and/or Digital Aerial Surveys
- RO 5.1d Tagging immatures and new Digital Aerial Surveys to improve understanding of at-sea distribution
- RO 5.1e Generation of immature distribution maps
- RO 5.1f Comparison of immature and breeding adult distribution
- RO 5.1g Comparison of proportion of immatures from distribution maps, stable age structure and Digital Aerial Surveys

- RO 5.1h Integration of improved understanding of at-sea distribution of immatures into the impact assessment

RO 5.2 At-sea distribution of sabbaticals

- RO 5.2a Feasibility of using existing data to understand sabbatical distribution
- RO 5.2b Planning for new sabbatical tracking deployment
- RO 5.2c Targeted tagging programme to improve understanding of sabbatical at-sea distribution
- RO 5.2d Generation of sabbatical distribution maps
- RO 5.2e Comparison of sabbatical and breeding adult distribution
- RO 5.2f Integration of improved understanding of at-sea distribution of sabbaticals into the impact assessment

RO 5.3 Ecology and behaviour of non-breeders relevant to collision and displacement

- RO 5.3a Strategic review of tracking data on non-breeder collision and displacement parameters
- RO 5.3b Planning for new non-breeder tracking deployment to understand risk of collision and displacement
- RO 5.3c Tagging non-breeders to understand risk of collision and displacement
- RO 5.3d Generation of collision and displacement parameters
- RO 5.3e Comparison of non-breeder and breeder collision and displacement risk
- RO 5.3f Integration of non-breeders into collision and displacement impact assessments

RO 5.4 Better understanding of the proportion of non-breeders within populations

- RO 5.4a Desk-based: Estimating sabbatical rates using population modelling approaches
- RO 5.4b Desk-based: Generation of generic sabbatical rates
- RO 5.4c Field-based: Feasibility of and planning for improving colony monitoring and use of novel technology to understand rates of non-breeding
- RO 5.4d Field-based: Deployment of improved colony monitoring and novel technology to understand rates of non-breeding
- RO 5.4e Field-based: Generation of rates of non-breeding, including variation in rates
- RO 5.4f Integration of rates of non-breeding into population viability analysis

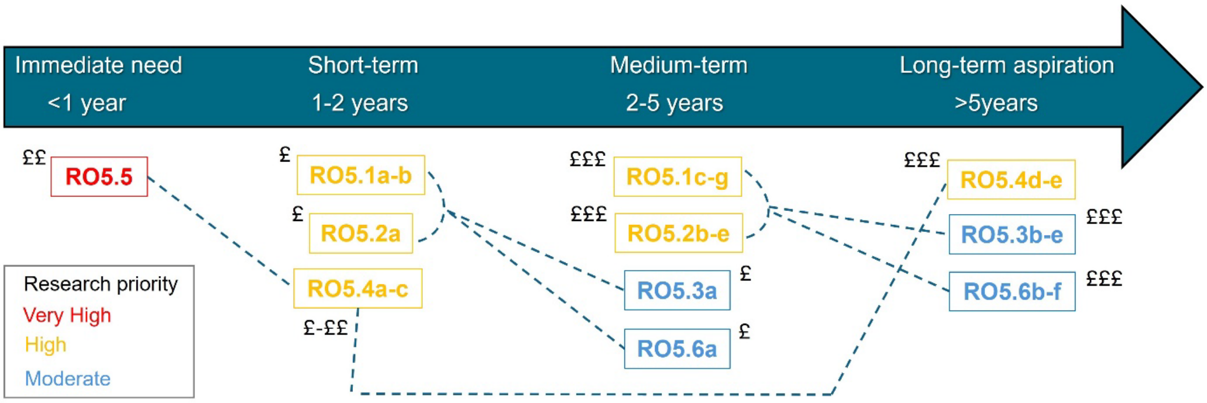
RO 5.5 Role of non-breeders in population persistence and their treatment in population viability analysis

- RO 5.5a Simulation of the role of sabbaticals in seabird populations
- RO 5.5b Sensitivity analyses
- RO 5.5c Targeted collection of demographic data for population viability analyses
- RO 5.5d Integration of non-breeders into population viability analysis

Appendix: RO 5.6 Seabirds’ behavioural response to artificial light

- RO 5.6a Making use of historic datasets to assess seabirds’ behavioural response to light
- RO 5.6b Planning for new studies to understand behavioural response to light
- RO 5.6c Deployment of new studies to understand behavioural response to light
- RO 5.6d Analysis of behavioural response to light
- RO 5.6e Comparison of non-breeder and breeder behavioural response to light
- RO 5.6f Investigate drivers of behavioural response to light
- RO 5.6g Integration of seabirds’ behavioural response to light into impact assessments

Each of the six ROs are presented in the synthetic diagram below in terms of their level of priority (very high, high, moderate), timescale (immediate, short-term, medium-term, longer-term) and indicative budget (low < £150,000, medium £150,000–300,000, high > £300,000). The integration of new evidence into impact assessments (not captured here) is a final and vital step across all ROs and will become possible as/when new evidence is delivered. Dotted lines indicate where synergies between ROs may lie, leading to reductions in overall project costs.



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1. Introduction

In order to meet the ambitious climate targets, set by the UK Government, designed to reduce greenhouse gas emissions by 78% by 2035 and achieve Net Zero by 2050, offshore wind farm (OWF) development will need to be deployed at a large scale. The ambition to increase capacity of offshore wind energy to 43–50 gigawatts (GW) by 2030 has been bolstered by the Offshore Wind Leasing Round 5 in the Celtic Seas, and ScotWind and INTOG (Innovation and Targeted Oil & Gas) in Scottish waters. Such climate change mitigation will have the added benefit of addressing a main driver of biodiversity loss.

Future offshore wind (OW) development is dependent on consent, which is underpinned by impact assessments. There is currently a limited understanding of the effects of large-scale OW development on marine wildlife, particularly seabirds. This is particularly true for protected birds, as there are several ways in which wind farms can potentially negatively impact seabird populations. To inform the planning process of the potential impacts of proposed offshore wind farms, detailed Environmental Impact Assessments (EIAs) and Habitats Regulations Assessment/Appraisal (HRA) are required. EIAs assess potential impacts to the wider environment, whilst HRAs assess whether a plan or project has the potential to have an adverse effect on a site protected under The Conservation of Habitats and Species Regulations (Amendment) (EU Exit) 2019 and The Conservation of Offshore Marine Habitats and Species Regulations 2017 (as amended).

Numbers of renewable energy developments, both offshore and onshore, are increasing globally and their potential ecological impacts will continue to receive growing scrutiny. Cumulative effects of such developments, in addition to existing anthropogenic activities, have the potential to exert pressures on seabird populations (Peschko *et al.* 2024; van der Wal *et al.* 2018). Improving understanding of how seabird populations respond to OWF development in this context is key to facilitate meaningful and precise cumulative impact assessments.

1.1. OWSMRF background

The Offshore Wind Strategic Monitoring and Research Forum (OWSMRF) is an industry-led collaborative partnership that aims to identify and develop research to fill critical knowledge gaps in our understanding of the impact of offshore wind development on marine birds. OWSMRF was initiated by the Joint Nature Conservation Committee (JNCC) and six offshore wind developers who oversaw the Pilot Year (2019–2020) focusing on the black-legged kittiwake (*Rissa tridactyla*, hereafter 'kittiwake'); see Knowledge Gap reports KG1, KG2 and KG3. Building on the success of the Pilot Year, the Continuation phase (2021–2023) funded by seven offshore wind developers delivered work on Procellariiformes (see KG4 report). OWSMRF Phase III began in January 2025 and is running until July 2026. JNCC continues in its secretariat role alongside developers: EDF power solutions UK and Ireland, Equinor, Ørsted, Scottish Power Renewables, SSE Renewables and TotalEnergies, and who together form the Developer Group.

1.2. OWSMRF process

OWSMRF uses a collaborative process to identify knowledge gaps and research opportunities to fill those gaps. The process involves consulting Key Stakeholders, including the four UK government statutory agencies (Natural England, Natural Resources Wales, NatureScot, Department of Agriculture, Environment and Rural Affairs) as well as Scottish Government's Marine Directorate and the Royal Society for the Protection of Birds, on issues for which there is greatest uncertainty on impacts on marine birds from OW development in UK waters. Wider Stakeholders, comprising UK organisations/groups with a strategic role in OW marine planning, or research and evidence delivery, and the OWSMRF Developer Group, are invited to observe the process and comment on potential synergies with existing programmes of work. Altogether, this ensures that OWSMRF outputs are aligned with UK OW consenting priorities, relevant to filling important knowledge gaps and scientifically robust. Once a key issue has been collectively identified to progress to detailed assessment, JNCC undertake an initial review of the evidence base highlighting key knowledge gaps. Following this process, academics and other technical experts are invited to participate to a workshop and suggest high-level research ideas (or Research Opportunities, ROs) that would address those knowledge gaps. ROs are then reviewed by experts and prioritised by Key Stakeholders. Selected high-priority ROs are developed into detailed research proposals, which are actively promoted by JNCC to external funders. Examples of funded projects include the OWEC-ProcBe, OWEC-MOTUS and various ORJIP projects. More details can be found on the OWSMRF webpage.

1.3. OWSMRF Phase III

A workshop with Key Stakeholders, Wider Stakeholders and the Developer Group (DG) was held in April 2025 to identify key areas of ongoing uncertainty in impact assessments for offshore wind and seabirds in the UK, with particular emphasis on issues relevant to both current and future development. The group reached consensus on three topics, including non-breeding birds (i.e. birds not engaged in reproduction during the breeding season, as opposed to birds during the non-breeding season), collision and attraction, and ecological shifts and shocks. Further prioritisation of the topics was based on urgency of the issue, feasibility to deliver useful outcomes within the duration of OWSMRF, and impact on consenting risk if the issue was addressed. It was agreed that the non-breeding bird topic had the largest potential to reduce uncertainty in assessments, with direct benefits to consenting, therefore this topic was selected by the DG to be progressed as part of OWSMRF Phase III.

Non-breeding birds form a large component of populations for most seabird species with late maturity and varying rates of skipped breeding. They likely play an important role in seabird populations, by representing a potentially large pool of future reproductive individuals ready to move in and replace lost breeders, thus helping buffer against sudden losses. Due to their lack of reproductive constraints, non-breeders are expected to represent a relatively larger component of seabirds observed further offshore compared to more nearshore areas, which is relevant to future development in offshore areas. Furthermore, with predicted increased frequencies of extreme weather events, and potentially diseases too, non-breeding rates, as well as non-breeder attendance at colonies and areas at sea, are likely to change. However, a fundamental lack of information regarding non-breeder distribution, behaviour and rates, and their role in population persistence, is posing a challenge to OWF impact assessments.

For the purposes of OWSMRF Phase III, non-breeding birds are classed into two main categories:

1. individuals that have not yet reached sexual maturity (or immatures); and
2. sexually mature adults that skip breeding in a given year due to (e.g. poor condition, lack of mate or nest site (also commonly referred to as “sabbaticals”).

Although not a non-breeding status per se, failed breeders (i.e. adult birds that failed to produce offsprings after committing to nesting) are also considered in this report as their at-sea distribution, behaviour and hence sensitivity to potential offshore wind impacts, may differ to those of breeding birds (breeding birds being the component of seabird populations that impact assessments – within HRAs – typically focus on). We note that birds failing to breed early in the season may make a second breeding attempt; for the purposes of this report we are focussing on individuals that distribute and behave differently to breeders, which is more likely to include birds failing and not attempting a second breeding attempt.

Rather than the specific classification of sabbaticals and failed breeders in terms of breeding phenology, their distribution and behaviour and the consequences these may have on risk from OWFs are all the focus of the present work. Hence, OWSMRF Phase III considers immatures, sabbatical birds and failed breeders (Figure 1).

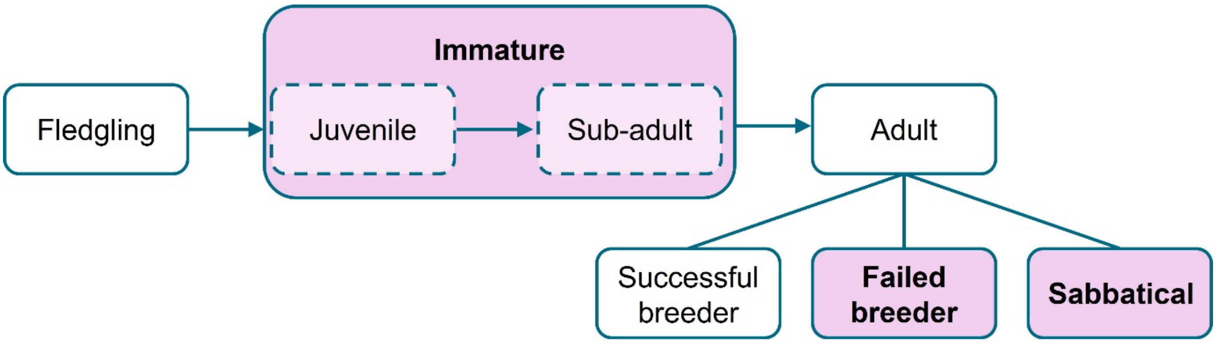

Figure 1. Non-breeding bird diagram (those included in this report in the purple boxes). The purpose of this figure is to present the different categories of non-breeders considered in this report, rather than picturing true reproductive phenological states.

This document reports on the current treatment of non-breeders in impact assessments (Section 2), reviews the existing evidence and understanding of non-breeders (Section 3) and then presents high-level ROs that could help address identified knowledge gaps (Section 4).

2. Current treatment of non-breeders in impact assessments

It is first important to understand how non-breeders are currently treated in offshore wind impact assessments, so that the literature can be interrogated for relevant evidence, and Research Opportunities developed based on knowledge gaps.

2.1. Apportioning birds in surveys to age classes and breeding status

Baseline surveys are a key first step in the assessment, allowing characterisation of a proposed OWF site and its surrounding area in terms of species distribution and abundance. In some species, the age class (immatures versus adults) of birds observed can also be informed from the at-sea data collected pre-construction. Knowledge of population composition within a site can then be used to apportion OWF impacts to relevant age classes.

Digital Aerial Surveys (DAS) provide a means to characterise bird usage of a site but can only differentiate adults from immatures to some extent in a small number of seabird species (e.g. gannet, large gulls) based on plumage characteristics. Alternatively, theoretical assumptions of age class distributions derived from population stable age structures may be used to estimate proportions of adults versus immatures occurring at an OWF site. However, there is uncertainty in how appropriate applying generic population-level age ratios is to specific areas of sea and times of year. NatureScot accept the use of stable age structures to apportion individuals observed at sea to age classes. As advised by NatureScot for HRAs, population composition derived from either stable age structures and/or DAS is used to remove both immatures and sabbaticals from mortality assessments, as breeding adults are the focus of HRAs. On the other hand, Natural England and Natural Resources Wales do not accept the use of stable age structures to apportion individuals observed in surveys to age classes, and except for a small number of species for which DAS apportioning methods could be used, all birds observed in surveys are considered as adults in mortality assessments.

A sabbatical rate may be applied for some species where data is available to estimate proportions of non-breeding adults (sabbatical birds) vs. breeding adults within a proposed OWF site (as advised by NatureScot); otherwise, it is assumed that all adult birds observed at an OWF site are breeders (as advised by Natural England). Sabbatical rates advised by NatureScot are provided in Section 3.2.

2.2. Calculating impact mortalities of non-breeders

Collision Risk Models (CRM) and displacement assessments are assumed to occur through the same mechanisms and using the same tools and input parameters for non-breeders as for breeding adults. CRMs are based on the original deterministic Band model (Band 2012), with the addition of a stochastic model (Caneco & Humphries 2022). The basic premise is to take information around bird body size, flight characteristics and density along with wind turbine parameters, including amount of time operational, to calculate the probability of collision assuming no behavioural response. An avoidance rate is then applied to account for avoidance behaviour, to give an overall estimate of the number of potential collisions. Standard displacement assessments (as per the “displacement matrix” approach) use an abundance of birds within the wind farm and associated buffer area along with a rate of displacement and a rate of mortality of displaced birds to derive an overall estimate of the number of potential displacement mortalities. In addition, the Individual Based Model

SeabORD can be used to model the mortality of displaced birds during the chick rearing period, accounting for energetic costs (Searle *et al.* 2018).

2.3. Apportioning birds in surveys to SPAs for HRA

Within HRA, predicted OWF impacts on Spatial Protection Area (SPA) populations are assessed. For this, birds observed at a development location during baseline surveys are linked back to relevant SPAs. Within the breeding season, the method of doing so is based on breeding adults (using standard breeding foraging range metrics) yet can sometimes (e.g. in Scotland) also be used to apportioning impacts on immatures back to SPAs. Little evidence currently exists to relate the at-sea distributions of immatures and sabbaticals of given species to their relevant colonies and generate immature- and sabbatical-specific SPA apportioning methods.

2.4. PVAs for HRA

The last stage of the impact assessment is Population Viability Analysis (PVA) which, for HRAs, predicts the potential population-level effects of OWFs at single SPAs. Within the currently recommended PVA tool for OW impact assessments in the UK (hereafter, the NE/JNCC PVA tool; Butler *et al.* 2022), age classes are split down to yearly immature classes of individuals transitioning to a single adult age class as they reach breeding age. However, additional mortality (from OWF) can only be assigned to adult and immature age classes separately, as the tool does not currently allow assigning different levels of impact across individual immature age classes (e.g. age 0–1, 1–2, 2–3, etc.). Noting also that it is currently not possible to apportion predicted impacts at this level of granularity either.

As the focus of the HRA assessment is on breeding adults, OWF mortalities are primarily applied to adults. There is however the option within the NE/JNCC PVA tool to specify OWF impact on immatures through adjusting their survival rates. In the absence of robust evidence for age-class specific impacts of OWFs, it can be assumed that immatures have either the same or different (absolute or relative) levels of impact than adults. If the latter, impact levels on immatures can be applied proportionally to adults according to the stable age structure theory (which predicts relative proportions of birds expected to be within each age class in a stable population). In addition, for species where age classes can be identified from plumage characteristics, age ratios derived from DAS data could be considered as a supplementary source of information to refine age-specific mortality estimates.

Sabbaticals are not currently considered as a separate class of adult individuals within the NE/JNCC PVA tool, therefore sabbatical mortality from OWF cannot be modelled at present. A sabbatical rate may be applied however to account for a proportion of adult birds that skip breeding within the population in a year, thereby reducing the number of breeding adults.

2.5. PVAs for EIA

EIAs, on the other hand, assess impacts from OWFs on wider biogeographic populations; this includes therefore both breeding and non-breeding components of seabird populations. Therefore, PVAs carried out for EIAs typically include the mortality of immatures as well as breeding adults. Age class specific mortality estimates are derived from standard apportioning approaches (stable age structure and/DAS). However, as the NE/JNCC PVA tool does not allow sabbaticals to be included in the population structure, additional mortality of sabbaticals cannot be modelled, therefore sabbaticals are currently excluded, as with HRA.

2.6. Summary

In summary, key areas of uncertainty in OW impact assessments in the UK relate to characterising seabird usage of a proposed OWF site by age classes and breeding status (adults versus immatures, breeding adults vs sabbaticals), apportioning predicted OWF mortality to different age classes, apportioning impacts to relevant SPA colonies (for immatures and sabbaticals in HRAs), estimating sabbatical rates across species, and accounting for sabbaticals when assessing population-level impacts through PVA.

Current methods within both EIAs and HRAs do not take account of potential differences in exposure to OWFs and sensitivity to impacts between breeders and non-breeders, and do not consider the mortality of all non-breeders. For example, as described above, the mortality of sabbaticals is not currently modelled within PVAs, and there is a lack of agreement in how to best quantify and account for immature mortality. There are also inconsistencies in advice between UK countries, and there is currently no framework, approved by advisors, regulators and industry, for the treatment of non-breeders in impact assessments. It remains unclear at what stages of the assessment should non-breeding birds be included, and how should they be considered, for both HRAs and EIAs. This lack of clear route for the inclusion of non-breeders in assessments is leading to prolonged conversations during the application stage, creating delays in decision-making, hence increasing risk to OWF consenting. This also creates residual uncertainty in assessments, which have implications for seabird conservation.

It is worth clarifying that there is a process however, in UK impact assessments, for the treatment of “birds during the non-breeding season” (i.e. the period of a bird’s life-cycle when no reproductive activities occur), as opposed to “non-breeders” (i.e. birds of breeding age or not that do not breed in a given year, which this report focuses on), using the Biologically Defined Minimum Population Scales (BDMPS) approach, initially developed by Furness (2015).

3. Existing evidence and understanding

There may be several reasons for birds to take a sabbatical or fail to produce offsprings (Cam *et al.* 1998). Birds may take a sabbatical due to suboptimal body condition (Drent & Daan 1980; Calladine & Harris 2008), or depleted or low-quality food resource (Boekelheide & Ainley 1989; Monaghan *et al.* 1992; Bruinzeel 2007). Failed breeders may have failed due to competition for nesting sites (Kokko *et al.* 2004), loss of nesting site (e.g. through eviction or destruction of nest) (Harris & Wanless 1995; Cam *et al.* 1998), loss of mate (through death or divorce) (Harris & Wanless 1995; Kokko *et al.* 2004; Jeschke *et al.* 2007), loss of egg (egg fail or predation) (Calladine & Harris 2008; Ponchon *et al.* 2015), or loss of a chick (Ashbrook *et al.* 2008). These drivers can occur before or during the breeding season.

Few studies have reviewed various elements of non-breeding, as opposed to solely reporting the results of individual studies. Ainley *et al.* (2024) discussed non-breeders (or at least a subset of non-breeders termed 'floaters', described as adults not breeding due to lack of habitat, mates, or presence of predators, but not regular sabbaticals responding to, for example, food availability) and the consequence of not considering them within population models. They found substantial evidence that there are large proportions of seabird populations not breeding each year, but can provide population resilience, which should be modelled when making management decisions, a proposition supported by Ainley and Johns (2023). Ainley *et al.* (2024) close by proposing a series of unanswered questions, suggesting that even by 2024 there remains many unknowns to even a subset of non-breeders, such as "… what portion of the adult population do floaters represent, and what affects annual variation in that proportion?", "How much time do floaters spend adjacent to active colonies in the absence of nesting habitat versus wandering further to look elsewhere?", and "How can the prevalence of floaters at the metapopulation and sub-population levels be determined, other than by conducting an experiment or intensive colony and at-sea surveys?". Similarly, Penteriani *et al.* (2011) discussed the role of non-breeders in the stability of populations and their importance within populations and conservation. Phillips *et al.* (2017) explored how individual variability may be caused be a range of factors, one of which is whether an individual seabird is a successful breeder, a failed breeder, a sabbatical, or an immature. This study reports spatial segregation and prospecting behaviour of failed breeders, difference in foraging locations of sabbaticals, the timing of returns to colonies, and the difficulties in monitoring non-breeders due to these differences (Phillips *et al.* 2017). Drent and Daan (1980) reviewed topics in relation to the causes of non-breeding, from body condition of females to energy expenditure. Some studies have contemplated how non-breeders may cope with external shocks and shifts, such as climate change and pollution events (Votier *et al.* 2008; Zabala *et al.* 2011; Reed *et al.* 2015; Wood *et al.* 2021). Whilst some studies suggest a buffering effect of non-breeders under climate change (Reed *et al.* 2015; Votier *et al.* 2008), others warn that large environmental shifts may cause declines in non-breeders to the point that there are not sufficient to provide population resilience (Johns *et al.* 2021).

The literature was searched through web searches of Scopus and Google Scholar using terminology for non-breeders (e.g. "fail*", "miss*", "skip*", "sabbatical", "floater", "immature", "juvenile", etc.) along with each of the topics below in turn (e.g. "distribution", "behaviour", "survival", etc.). The Offshore Wind Environmental Evidence Register (OWEER v.06) was searched, however there was no specific mention of ongoing research projects (in the UK) investigating failed, missed or skipped breeders, sabbaticals, or floaters. BirdLife's Seabird Tracking Database and the SEATRACK database were also searched for at-sea distribution data on non-breeders.

In this report, we consider first the risk of non-breeders to OWFs through their distribution and behaviour. This includes whether non-breeders have a different exposure to OWFs due to their distribution and if they have a different risk of collision and/or displacement due to their behaviour, compared to successfully breeding birds. We then regard the vital rates of non-breeders through the rate of non-breeding, survival rate, and likelihood of and success of subsequent breeding. We also consider the importance of non-breeders to populations. In addition, we review methods and difficulties in detecting and monitoring non-breeders. Together, these elements are used to consider how non-breeders should be handled in impact assessments for offshore wind in order to reduce uncertainty in assessment outcomes.

3.1. Distribution and behaviour

To understand whether non-breeders have the same exposure to offshore wind farms as successful breeders, and hence whether current methods of baseline survey and assessments are suitable to apply to non-breeders, it is important to consider their distribution and behaviour.

3.1.1. Distribution

It has been suggested that sabbaticals may have different distributions during both the breeding and non-breeding season compared to breeders, which may mean they are less or more likely to encounter offshore wind farms (Potiek *et al.* 2019). For example, Ainley and Johns (2023) suggest that ‘floaters’ (those able to breed but do not because they are, e.g., awaiting a suitable nest site) remain at sea for virtually the entire breeding season, rarely returning to land except for very occasional prospecting trips to colonies. The at-sea distribution may also differ between sabbaticals, failed breeders and immatures. Here we consider evidence of the distribution of sabbaticals, failed breeders and immatures throughout the year.

Several databases exist which collate available seabird distributional data from bird-borne tracking devices. A search of BirdLife’s Seabird Tracking Database revealed two tracking data entries of a UK seabird species tagged as a “fail” breeding bird; a failed breeding Cory’s shearwater (*Calonectris borealis*) and a sabbatical of the same species, which visits southern UK waters in summer, have been tracked, albeit around the coast of northwest Africa. However, 30 entries of either “fail” or “sabbatical” birds of other species were found from around the globe (BirdLife 2023). The SEATRACK database cannot be filtered by breeding status, and there are no additional details on the data within the distribution maps (SEATRACK 2025). However, it is entirely possible that tracking data from failed breeders and/or sabbaticals has been collected, particularly from multi-year studies, they are just not labelled as such.

3.1.1.1. Sabbaticals

For this report, we consider sabbatical birds as birds that do not attempt breeding in a year (as opposed to failed breeders, which initiate reproductive activities but fail to produce offsprings). Sabbaticals do not have the same constraints as breeders in their foraging; whilst breeders typically act as central-place foragers, repeatedly returning to the colony to attend the nest, eggs and chicks, sabbaticals are free to spend time at sea without the need to return to land.

Sabbatical birds have been known to aggregate and rest at locations away from the breeding colony at sea, often referred to as ‘clubs’ (great skua, *Stercorarius skua*: Klomp & Furness 1992a; northern gannet, *Morus bassanus*, hereafter ‘gannet’: Votier at al. 2011; brown skua, *Stercorarius antarcticus*: Borghello *et al.* 2019 and Lamb *et al.* 2023). These may be on land as well as at sea; sabbatical brown skuas have been observed using ‘club’ sites on land at the opposite side of Amsterdam Island, southern Indian Ocean, to breeding birds (Lamb *et al.* 2023), whilst black-tailed gulls (*Larus crassirostris*) did not return to the colony where they had previously bred, but were found loafing and foraging at sea around the colony (Kazama *et al.* 2013).

In addition, some sabbatical brown skuas attempted to hold territory within the colony but did not attempt breeding (accounting for 25% of the non-breeding individuals identified at the colony) (Lamb *et al.* 2023). These territorial non-breeders and breeders used similar foraging locations and ranges, whilst those from the ‘club’ ranged far more widely. Both sets of non-breeders spent more time foraging and commuting and less time resting compared to successful breeders. Within the non-breeders, non-territorial birds spent comparatively more time commuting whilst territorial birds spent more time foraging or resting. The authors suggest that territorial non-breeders are both able to occupy useful locations within the colony and access more productive foraging areas. Some breeders and territorial non-breeders also spent time within the non-territorial ‘club’, maintaining more than one territory. (Lamb *et al.* 2023).

In black-browed albatrosses (*Thalassarche melanophris*) and Cory’s shearwaters, sabbatical birds utilise different prey to breeding individuals; in fact, sabbatical diet is more closely related to immatures, providing evidence that the central-place foraging strategies of breeders constrain their diet, which is not the case for sabbatical birds (Campioni *et al.* 2016).

In wandering albatrosses (*Diomedea exulans*), which routinely take a non-breeding year, sabbaticals forage in spatially distinct areas compared to breeders (Jaeger *et al.* 2014). Their foraging strategies can be highly complex, with individuals foraging across wide ranges, being largely sedentary, or a combination of the two. The foraging locations and behaviour also appears to differ across colonies, which are situated close to one another. At one specific island, Crozet, in the Antarctic, females tend to remain at or close to the colony and breed every year, compared to the males taking a sabbatical year, which foraged much wider (Weimerskirch *et al.* 2015). Therefore, even within sabbatical birds of the same species, their distributions can be quite different.

After black-tailed gulls skipped breeding, they travelled to similar wintering locations as in previous years (Kazama *et al.* 2013). Before a sabbatical year, birds landed on the water (an indicator of foraging effort) more frequently compared to those that did not go on to take a sabbatical year.

Much of the work on the distribution of sabbaticals is based on species that occur and have been studied outside the UK, such as albatrosses and skuas. It is unknown whether the distribution of sabbaticals from other seabird species follow the same pattern compared to failed breeders, successful breeders or immatures, and hence how transferrable this information is to the UK context.

3.1.1.2. Failed breeders

Kittiwakes have been observed undertaking both small and large prospecting movements to other colonies almost immediately after failed breeding. Ponchon *et al.* (2015) found that failed breeders in Norway prospected colonies from 1 km and up to 40 km away from as little as a week after breeding failed. The more distant colonies were visited more often. As well as prospecting, failed breeders also spent more time resting at non-breeding areas compared to successful breeders.

Failed breeding kittiwakes have also been observed to depart colonies earlier than successful breeders, travel further and to different locations. Geolocator tagged birds from southeast Scotland departed on average 14 days earlier than successful breeders

(Bogdanova *et al.* 2011). More failed breeders travelled over 3,000 km to the west Atlantic, whereas more successful breeders remaining around the east Atlantic around 1,000 km from the colony. However, successful breeders that did travel to the west Atlantic dispersed more widely than failed breeders, whilst those failed breeders that remained in the east Atlantic dispersed more widely than successful breeders. Southern giant petrels (*Macronectes giganteus*) have been observed to have increased foraging ranges in failed breeders compared to successful breeders (González-Solís *et al.* 2007). Similarly, great black-backed gulls (*Larus marinus*) have been observed to take foraging trips up to 2,300 km from the colony after breeding failure (Maynard & Davoren 2018). Spatial segregation in foraging areas of failed wandering albatross has been observed (Jaeger *et al.* 2014).

When analysing solely central-place foraging trips (i.e. excluding prospecting trips), Votier *et al.* (2017) found that failed breeding gannets took much shorter foraging trips compared to successful breeders. Whilst repeatedly travelling to foraging locations, failed breeders also travelled to different locations, showing slightly less foraging route and site fidelity; the authors suggested this could be adult birds taking the opportunity to explore different foraging areas without the constraints of chick provisioning (Votier at al. 2017).

Failed breeders sometimes stay around the colony, supposedly as an attempt to retain territory, but there can also be individual differences as some leave the colony to forage more frequently. This mix of behaviours have been observed in great black-backed gulls, as reported for example by Maynard & Davoren 2018 and Maynard *et al.* 2022). Failed breeding kittiwakes have been observed spending more time at the nest compared to successful breeders. Whilst successful breeders spent comparatively more time foraging, failed breeders spent more time prospecting other colonies or hanging out in non-breeding club sites (Ponchon *et al.* 2015). It has been suggested that there may come a ‘break point’ where failed breeders eventually stop visiting the nest site, presumably after failure is certain, or negative impacts of stress from holding a territory outweighs any benefits (Maynard *et al.* 2022).

There may be temporal and spatial differences between successful and failed breeders too. In black-browed albatross, failed breeders tend to leave breeding grounds earlier, have a longer wintering period, and return to breeding grounds earlier, compared to successful breeders (Desprez *et al.* 2018). Wandering albatross which failed breeding often go on to reproduce the following year, rather than taking a sabbatical year as most successful breeders do. This more frequent reproduction means a much shorter period between breeding attempts (Jaeger *et al.* 2014).

Whilst many of these studies investigate failed breeder distribution, it remains unknown how representative this evidence is, to enable this information to be used within offshore wind impact assessments in the UK.

3.1.1.3. Immatures

Immature birds occasionally distribute and behave similarly to breeders, such as Cory’s shearwater that forage using a central-place foraging strategy, whilst also beginning to show prospecting behaviour by visiting other colonies late in the breeding season (Péron & Grémillet 2013). Immature wandering albatrosses have been seen to travel even shorter distances when behaving as central-place foragers, compared to breeding adults, hypothesised to be due to immatures gaining experience of central place foraging prior to reproductive years (Riotte-Lambert & Weimerskirch 2013). Gradually learning about optimum foraging areas has also been suggested in the case of Manx shearwaters (*Puffinus puffinus*) from Skomer, Wales, which took much shorter trips in both duration (3.7 days) and distance (179 km) compared to incubating (9.3 days and 209 km) and chick-rearing (4.9 days and 221 km) adults (Fayet *et al.* 2015). Immature Manx shearwaters appeared to forage in different locations to adults, despite the distance that immatures flew enabling them to access the same foraging areas as adults. Immatures tended to remain around the Celtic Sea and across to southwest Ireland, whilst adult Manx shearwaters travelled further around the southern Irish coast and up into the Irish Sea. The regions frequented by immatures correlated with lower primary productivity and Chlorophyll a, and whilst all stages spent similar proportions of the days foraging, immatures gained the least weight over the breeding season, suggesting they were foraging in lower quality foraging areas and/or were less efficient foragers (Fayet *et al.* 2015). Immatures gannets have also shown a propensity for exploring different foraging areas, gaining experience of searching for quality foraging areas as they go (Votier *et al.* 2017).

However, immatures can also behave more akin to sabbaticals and are known to frequent the ‘clubs’ which sabbatical attend (Halley *et al.* 1995). Campioni *et al.* (2016) compared isotopic signatures of both Cory’s shearwaters and black-browed albatrosses and found that immatures and sabbaticals were similar, and both differed from breeding adults. This suggests that rather than maturity and experience being the cause of differences in diet and foraging locations, the lack of requirement to regularly return to land allows more freedom of movement.

In addition, immatures may travel to different locations, not for foraging, but prospecting other colonies. Immature gannets from Grassholm, Wales have been tracked ranging much further and for longer periods of time during the breeding season compared to breeding adults, often visiting other colonies; presumably prospecting. Immatures travelled for an average of 114 hours across 1,066 km, whilst breeding adults travelled for an average of 25 hours across 371 km. Even then, despite this wide-ranging travel and visitation of other colonies, immature gannets repeatedly returned to Grassholm and maintained central place foraging behaviour, showing a mix of behaviours (Votier *et al.* 2011).

The reason for travel may therefore explain patterns in distribution of immatures. Furthermore, individual variation has been observed in gannets, with birds each travelling to different locations, which the authors suggested could reduce their vulnerability to mortality due to anthropogenic pressures (Votier *et al.* 2011). Indeed, Votier *et al.* (2008) suggest that younger (age 0–3 years) common guillemots (*Uria aalge*), which also show wide ranging foraging behaviour, were less at risk of encountering oil pollution than older age classes.

Immatures appear to be able to behave both like successful breeders and sabbatical birds, but it is unknown how representative this information is across species, and how frequently they behave in these ways.

3.1.2. Behaviour

The risk of mortalities due to offshore wind farms can be influenced by bird behaviour at sea. For example, flight speeds, flight heights and avoidance rates influence collision risk, and susceptibility to disturbance, foraging habitat specialisation and availability, can impact on mortality due to displacement.

3.1.2.1. Collision risk

Input parameters to Collision Risk Modelling (CRM) are important to consider as these directly impact the number of estimated collisions outputted from the models. These include flight speed, flight height relative to rotor swept zone, nocturnal activity, avoidance rates and macro-avoidance rates. In addition, vulnerability to collision has been characterised by several factors: flight height as a percentage of birds flying at blade height; flight manoeuvrability; percentage of time spent flying; and nocturnal flight activity (Furness *et al.* 2013; Bradbury *et al.* 2014; Wade *et al.* 2016).

This review did not identify any studies investigating whether non-breeders fly at different heights, are more or less active at night, or avoid OWFs at different rates, compared to successful breeders. This can be explained by the fact that flight heights studies are often undertaken with bio-loggers that have short deployment duration, breeders are most targeted due to project needs, and because breeders are easier to catch than non-breeders. There is some evidence that flight speeds may be different; immature Manx shearwaters from Skomer, Wales, flew much slower compared to incubating and chick-rearing adults (18.2 km/h, compared to 20.3 km/h and 23.0 km/h, respectively; Fayet *et al.* 2015). In addition, immatures (including juveniles) may have slightly different body and wing size, and therefore potentially different ability to manoeuvre compared to adults, however the closer to adult-age the more akin to adult morphology (Corbeau *et al.* 2019; Wakefield *et al.* 2019). A study on lesser black-backed gulls (*Larus fuscus*) investigated whether wingspan was correlated with foraging efficiency in both successfully breeding and failed birds but did not report whether there was a difference in wingspan of failed breeders. The authors did find that, whilst successful breeders with longer wings spend more time at sea, no such relationship was found in failed breeders (Camphuysen *et al.* 2015).

Generally, there is an absence of studies looking at attraction to OWFs, such as due to lighting, particularly with relevance to whether attraction is an issue for breeding adults, and whether it is different across ages, for example immatures or inexperienced birds (see e.g. Deakin *et al.* 2022). Deakin *et al.* (2022)'s review of evidence of light attraction indicated that, whilst there is abundant evidence of disorientation due to lighting, there are also knowledge gaps when it comes to assessing how this may influence impacts from offshore wind. Deakin *et al.* (2022) provide recommendations on the specific knowledge gaps and a high-level overview of research avenues.

Most parameters required to estimate collision risk are not known for non-breeders, making non-breeder-specific CRMs currently not possible, should they be required. Much more information about flight parameters is required before collision risk can be fully understood.

3.1.2.2. Displacement risk

Input parameters to displacement assessments are important to consider as these directly impact the number of estimated mortalities outputted from the assessment. These include displacement rate and mortality rate. In addition, sensitivity to displacement has been characterised by several factors: disturbance by structures; disturbance by vessels and/or helicopters; and habitat specialisation (Furness *et al.* 2013; Bradbury *et al.* 2014; Wade *et al.* 2016).

No evidence was found to suggest that non-breeders are displaced from offshore wind farms at different rates to breeders, nor that displacement-induced mortality rates are different. Based on the factors influencing displacement and/or mortality, there also appears to be no evidence for differences in disturbance by different anthropogenic activities. It is important to note however that this apparent absence of evidence likely reflects a crucial lack of research in this area, rather than a true absence of effect.

Non-breeding birds may utilise different foraging areas, and immatures may be less efficient foragers (Fayet *et al.* 2015; Péron & Grémillet 2013; Porter & Sealy 1982). But where breeding status has been used to investigate habitat specialisation, there appears to be no difference among non-breeders in habitat use (Zango *et al.* 2020), and indeed individual specialisation is more likely because of experience rather than breeding status (Votier *et al.* 2017). Non-breeders that act as central-place foragers during the breeding season may have less scope to utilise different areas, akin to breeders, whilst those that range widely may not have the same restriction. Therefore, it could be hypothesised that central-place foragers may be more specialised, but this category can include breeders and non-breeders.

Akin to collision risk, most parameters required to estimate displacement risk are not known for non-breeders, making non-breeder-specific displacement assessments currently not possible, should they be needed. Much more information, such as disturbance by anthropogenic activity and habitat flexibility, is required before displacement risk can be fully understood.

3.2. Proportions of non-breeding adults

Proportions of non-breeding adults in bird populations have been estimated by a range of studies, going back to the 1960s: 14% in common blackbird (*Turdus merula*, Ribaut 1964, cited in Brown 1969); 11% in ring-necked pheasants (*Phasianus colchicus*, Burger 1966, cited in Brown 1969). There are multiple ways to define and calculate the rate of adult non-breeding, methods across the literature are highly variable, and terminology is inconsistent, such as:

- Numbers of breeders not recorded in a year but seen in subsequent years.
- Percentage of adults that were seen not breeding (therefore not including any unseen birds).
- Percentage of known intermittent breeders that failed to breed.
- Probability of non-breeders not returning to breed in the subsequent year.
- Probability of successful and failed breeders not returning to breed in the subsequent year.
- Simulated estimate of the percentage of adults that had previously bred but then skipped breeding.

In addition, adult non-breeding can be reported using different metrics, such as means, ranges, and per year estimates. Rates have been reported as numbers of birds, percentages, and probabilities, using observations and simulated estimates. Rates of adult non-breeders can often solely concentrate on sabbatical birds, but occasionally also include failed breeders. Depending on when and where observations take place during a sabbatical year, it may be difficult to determine whether an attempt at breeding was made (thereby classing birds as failed breeders) or not. The rate of adult non-breeding in seabirds can be incredibly different across species and locations, from 1% in common guillemot (Reed *et al.* 2015) to 79% in Manx shearwater (Wood *et al.* 2021); as noted above, care must be taken when comparing values as they are not always comparable metrics of calculation. The timescales over which rates were calculated also varies. A collation of rates of non-breeding adults is presented in Table 1.

These values have all been calculated or simulated based on data collected at the colony only. With little understanding of where adult non-breeders go when they are not attending colonies, the proportions of adult non-breeders within specific areas of sea have a level of uncertainty associated with them. Whilst many species are coved in Table 1, due to the lack of consistency in terminology, approaches and metrics, these are not comparable values, and caution is warranted in using them to represent a ‘rate of adult non-breeding’ as this can mean many things.

Studies investigating the proportions of adult non-breeders in bird populations, and how they change over time, in a consistent manner is of vital importance to be able to understand their role in population dynamics. This is required before adult non-breeders can be incorporated into impact assessments. Due to the lack of consistency in terminology, approaches and metrics, there is an imminent need to formulate agreed standards to facilitate integration of information.

Table 1. Rates of adult non-breeding in seabirds, all based on information at colonies.

Species	Location	Rate (%)	Numbers	Year	Notes	Reference
Great skua	Foula, Shetland	8.9	-	1989 to 1996	Non-breeders	Catry *et al.* 1998
Arctic skua (*Stercorarius parasiticus*)	Foula, Shetland	5.5	-	1993 to 1994	Non-breeders	Catry *et al.* 1998
Common guillemot	Isle of May, Scotland	7.1	696 of 9,741	-	Skipped breeders (average)	Reed *et al.* 2015
Common guillemot	Isle of May, Scotland	6	599 of 9,741	-	Skipped breeders at colony without territory (average)	Reed *et al.* 2015
Common guillemot	Isle of May, Scotland	1	97 of 9,741	-	Skipped breeders not recorded in a year but seen in subsequent years (average)	Reed *et al.* 2015
Common guillemot	Isle of May, Scotland	5 to 10	-	-	Percentage of birds seen not breeding, therefore does not include any unseen birds	Harris & Wanless 1995
Razorbill (*Alca torda*)	Isle of May, Scotland	3	-	-	Skipped breeders	Harris & Wanless 1989
European shag (*Phalacrocorax aristotelis*)	Isle of May, Scotland	35	1,985	-	Simulated estimate percentage of adults which had previously bred skipped breeding before 1985	Aebischer & Wanless 1992
European shag	Isle of May, Scotland	54	1,976		Simulated estimate percentage of adults which had previously bred skipped breeding before 1976	Aebischer & Wanless 1992
Herring gull (*Larus argentatus*)	Isle of May, Scotland	33	44 of 135	1993	Marked adults seen that did not breed, therefore does not include any unseen birds	Calladine & Harris 2008
Herring gull	Isle of May, Scotland	37	50 of 135	1994	Marked adults seen that did not breed, therefore does not include any unseen birds	Calladine & Harris 2008

Species	Location	Rate (%)	Numbers	Year	Notes	Reference
Lesser black-backed gull	Isle of May, Scotland	34	49 of 143	1993	Marked adults seen that did not breed, therefore does not include any unseen birds	Calladine & Harris 2008
Lesser black-backed gull	Isle of May, Scotland	40	60 of 149	1994	Marked adults seen that did not breed, therefore does not include any unseen birds	Calladine & Harris 2008
Herring gull	Isle of May, Scotland	~50	24	1993 & 1994	Percentage of known intermittent breeders that failed to breed	Calladine & Harris 2008
Lesser black-backed gull	Isle of May, Scotland	~50	26	1993 & 1994	Percentage of known intermittent breeders that failed to breed	Calladine & Harris 2008
Herring gull	North America	15 to 30	-	-	-	Kadlec & Drury 1968
Black-legged kittiwake	Brittany, France	5 to 34 (male) 7 to 24 (female)	-	1984 to 1993	Probability that a breeder becomes a non-breeder	Cam *et al.* 1998
Black-legged kittiwake	Brittany, France	26 to 100 (male) 60 to 100 (female)	-	1984 to 1993	Probability that a non-breeder becomes a breeder	Cam *et al.* 1998
Brown skua	Bahía Esperanza/ Hope Bay, Antarctic Peninsular	-	83	2015 to 2016	Non-breeders (83 individuals) outweighed breeders (23 pairs)	Borghello *et al.* 2019
Manx shearwater	Island of Skomer, Wales	79	-	-	The probability of non-breeders not returning to breed in the subsequent year	Wood *et al.* 2021
Manx shearwater	Island of Skomer, Wales	13	-	-	The probability of successful and failed breeders not returning to breed in the subsequent year	Wood *et al.* 2021
European storm-petrel (*Hydrobates pelagicus*)	Bay of Biscay, northeast Atlantic	31	-	-	Percentage of birds breeding in one year that did not breed in the following year	Hémery *et al.* 1987, cited in Franco *et al.* 2004
European storm-petrel	Marettimo Island, Italy	65	-	-	Probability of an individual having previously bred skipping breeding	Soldatini *et al.* 2016

Here we provide an overview of the sabbatical rates currently advised by NatureScot (as of February 2026), noting that NatureScot are continuously reviewing their guidance, therefore recommended sabbatical rates are subject to change in the future based on available evidence (Table 2). The rates below are based on rates generated from expert opinion for use by Moray West and other Forth and Tay OWF projects.

Table 2. Sabbatical rates advised by NatureScot (as of February 2026).

Species	**Recommended sabbatical rate (as advised by NatureScot as of February 2026)**	**Supporting evidence**
Auks	7% for common guillemot, and in absence of species-specific data, other auk species	On the Isle of May, an annual average of 7.1% of guillemots that had bred at least once before did not hold a site (Reed *et al.* 2015). Between 5% and 10% of guillemots on the Isle of May were seen not breeding Harris and Wanless (1995)
Black-legged kittiwake	10%	Coulson (2011) assessed missed breeding years in male and female kittiwakes. Between 4% and 14% of females skip a year of breeding, as compared to between 4 and 7% of males.
Gannet	10%	There is little data concerning gannet sabbatical rates.
Shag	35%	Aebischer and Wanless *et al.* (1992) found that between 10% and 60% of shags were non-breeding, with 25% of birds exhibiting breeding skipping at least once in their lifetime.
Large gulls	35%	The proportion of sabbatical adults in the populations of great black backed and herring gull was discussed and a rate of 35% agreed for the MORL and BOWL applications. Calladine and Harris (2008) found 33–37% of marked adult Herring gulls, and 34–40% of marked adult lesser black-backed gulls on the Isle of May that were seen not breeding.

3.2.1. Detecting and monitoring

Recommendations have been given for many years now that improvements need to be made in seabird population survey methods in order to detect non-breeders and be able to distinguish them from breeders, successful or otherwise (e.g. Manuwal 1974; Cam *et al.* 1998), but as yet improved methods do not appear to be widely implemented, nor is there best practice guidance for these changes. Ainley and Johns (2023) make a case for better and innovative methods of monitoring non-breeding seabirds given their propensity to remain either at sea or out of reach from land for most of the year, and for purposefully targeting non-breeders to fill knowledge gaps. In the following sections we describe the current methods for detecting and monitoring non-breeders at sea and at the colony in the UK.

3.2.1.1. At sea

At-sea monitoring currently and historically carried out can be classified into snapshot surveys and continuous monitoring over a period. In the minority of species, snapshot surveys using boat-based or aerial surveys may be able to distinguish immatures, if plumage can be used as an identifying feature. However, it is not possible to categorically state whether an adult-plumage bird at sea is a failed breeder or a sabbatical from boat-based or aerial surveys, nor at the colony. Alternatively, it is possible to monitor the at-sea movements and behaviour of non-breeders using longer-term movement tracking techniques such as attachment of data loggers. The very nature of having to attach a data logger to a bird means that failed breeders, sabbaticals and immatures can be selected and tags attached. This is, of course, providing observations of their breeding status have taken place at the colony and these birds are present at the colony or could be caught at sea. One major caveat however is that distinguishing between failed breeders, sabbaticals and immatures requires extensive time in the field, and in many species, sabbaticals and immatures cannot be distinguished. Furthermore, as these birds are not tied to a nest, they will also be more difficult to catch at the colony.

Targeted tagging of non-breeders might need to consider their distribution throughout the year. In particular, certain species where non-breeders are known to spend long amounts of time at sea and not return to colonies would benefit from use of tagging systems allowing remote at-sea locations to be automatically downloaded through satellite systems such as Argos, rather than those where data need to be retrieved or relayed to receiver stations on land (although the latter would help capture coastal locations). Crucially, suitable tags (e.g. Argos) do not exist for most smaller species due to tag weight. The MOTUS system has the advantage of making use of small tags and may be helpful in this context if receiver stations can be placed at sea.

3.2.1.2. At colony

Current methods for monitoring at colony

Current population and productivity monitoring, as described by the Seabird Monitoring Handbook, describes how to most accurately count the breeding population of most (not all) UK-breeding seabird species, specifically excluding non-breeders as far as possible (Walsh *et al.* 1995). In addition, for some species only, it details how additional information on non-breeders, such as those at club sites, may be collected.

In general terms, population monitoring methods attempt to exclude sabbaticals and immatures, but include breeders which may or may not fail that year. A breeding population is defined by the Seabird Monitoring Handbook as "…the total number of adult birds (or number of pairs), in a defined study area, which make a breeding attempt (i.e. produce an egg) in a particular year", though the exact metric is often species-specific, such as number of individuals or the number of apparently occupied sites, nests, or territories as specified (Walsh *et al.* 1995).

Walsh *et al.* (1995) define productivity as "chicks fledged per breeding pair". Failed breeders can therefore be included within this metric, if the count is conducted before failure occurs. Both population and productivity therefore aim to include failed birds but discount immatures and sabbaticals.

The time of day during which counts should be undertaken is often specified (Walsh *et al.* 1995). In the case of Manx shearwater population estimates, it is advised that counts using burrows are made during the daytime when fewer non-breeding immatures or prospecting birds are present in burrows. For tern species (*Sterninae*), counts should ideally be done between 10 am and 12 noon as non-breeders tend to be absent at this time. Numbers of skuas at club sites can vary throughout the day, therefore if recording birds at these areas, the time of day should also be noted.

Similarly, the timing within the breeding season can be optimised to exclude non-breeders. In gulls, counts are undertaken midway through the incubation period, usually late May to early June. If counts are also done later in June, not only is it harder to determine active nests with chicks and adults outside of the nest, but failed adults may have already left. Northern fulmars (*Fulmarus glacialis*) have a relatively long breeding season, and sites become occupied for a period by individuals or pairs that do not breed, meaning that getting accurate counts excluding non-breeders is more difficult in this species. Failed birds, or where breeding has not begun, may be missed; in kittiwakes, counts may additionally be done later in the season to account for this. However, later counts should not be averaged with earlier counts as later counts may be lower due to breeding failure. In many species, failed breeders may re-lay, and sometimes this re-laying happens in a new location within the colony, therefore peak counts are advised rather and an average to reduce the likelihood of double-counting.

Weather conditions can also be important; it is recommended that population counts of northern fulmar, common guillemot, black guillemot (*Cepphus grylle*) and razorbill are only undertaken when winds are less than Beaufort force 4 and not during heavy or continuous rain. In addition, counting or visiting gull or tern colonies should not be undertaken in strong wind or rain. Non-breeders and failed breeders may leave the colony during windy conditions as they may have less investment in remaining at their breeding sites, so comparisons with counts undertaken in calm conditions cannot be made (Walsh *et al.* 1995).

It is advised that separate counts are kept of, for example, well-built nests in which eggs may not yet have been laid and nests which may already have failed. In addition, it is recommended to log poorly built or trace nests as, although they may by visited by non-breeders, they may also indicate late breeding or declines in the breeding population.

Productivity monitoring is far more intensive than population monitoring due to the need to visit the colony on multiple occasions and estimate hatch dates, chick ages and fledgling rate. More frequent visits and more detailed reports will make for more accurate productivity, which may also include determining the timing of failed breeding. This is particularly relevant in some species, such as terns, whereby failed breeders may re-lay in another area of the colony or emigrate to a different colony to try a second breeding attempt.

Areas of the colony that are likely to contain non-breeders, mostly sabbaticals, are described by the Seabird Monitoring Handbook, such as terns resting outside the colony, or common guillemots at the base of the cliffs or on the sea. Unlike terns, it is specifically advised that non-breeding areas of common guillemots are not excluded from population counts due to the difficulty in making firm and consistent judgments as to what is a breeding area and what is a non-breeding area.

For some species, non-breeders may be dispersed within a colony alongside breeders, therefore certain type of counts can help improve accuracy of a population census. For example, at certain gannet colonies non-breeders occur within the colony therefore Apparently Occupied Nests (AON) are recommended as the metric, rather than Apparently Occupied Sites (AOS).

In common guillemots and razorbills, breeding and non-breeding areas are particularly difficult to define due to the lack of a nest, therefore active sites (birds with an egg; birds with a chick; and birds apparently incubating) are counted, as well inactive sites (pairs in a location which is capable of supporting an egg) which may include late breeders, failed breeders or sabbaticals if they are present at these sites.

Where there are distinct non-breeding ‘club’ sites, these can be recorded, but they do not form part of colony or productivity counts, and these cannot currently be recorded on the Seabird Monitoring Programme database. However, they may be useful for subsequent years surveys or monitoring of non-breeding populations and the health of the wider population, though there is no standard protocol for this at present.

Evidence of non-breeders at colony

The absence of immatures and sabbatical birds at the colony can severely limit both monitoring of these birds using established colony methods and the ability to place tracking devices on them to better understand their movements and at-sea distributions (Calladine & Harris 2008; Phillips *et al.* 2017).

Immature Mediterranean storm petrels (*Hydrobates pelagicus melitensis*) were found to be present in higher numbers early during the breeding season, to the point that 50% of the birds at the colony were immatures, the other half being breeders. Over the course of the breeding season, a larger proportion of the birds present were breeders (Amengual *et al.* 1999). An in-depth study into the number of non-breeding great skuas visiting Foula, Shetland revealed that individuals were only present for an average of 16 to 21 days (Klomp & Furness 1992b). The peak in non-breeding brown skua occurred in the middle of the breeding season, when immatures, failed breeders and sabbaticals were all present (Borghello *et al.* 2019). Conversely, Boulinier *et al.* (1996) found that more non-breeding kittiwake were present at colonies later in the breeding season compared to earlier, with a peak in numbers between the end of June and the end of July. Therefore, at the colony, careful consideration is required as to when monitoring and/or tagging is carried out. For example, breeding kittiwakes were captured during the incubation period when the adults were still at the nest to fit tags, such that any potential failed breeders were tagged before they left the colony. Tags were retrieved ten days later, before they departed for winter (Ponchon *et al.* 2015). Note, however, that this study experimentally induced failure, rather than capturing natural breeding failures, therefore results are not necessarily applicable to other occurrences of failure.

Where monitoring is undertaken is also a key concern. Non-breeding great skuas at Foula, Shetland were found to frequent ‘clubs’ but not all non-breeding birds visited the breeding colony itself (Klomp & Furness 1992a); monitoring of the colony alone may not be sufficient to fully capture the number of non-breeding birds. Club sites may be on land or at sea; sabbatical brown skuas have been observed using ‘club’ sites on the opposite side of Amsterdam Island, southern Indian Ocean, to breeding birds (Lamb *et al.* 2023). Immature gannets at Grassholm, Wales, present at ‘club sites’, were identified based on plumage of two- to four-year olds and caught for tagging (using an Argos system to relay GPS fixes every 48 hours). These tags allowed remote download of the data, providing the dual benefit of not having to return to the colony to collect the data and securing data in case the tagged birds do not return to the colony (Votier *et al.* 2011).

It must be noted that, where tagging of birds is used, careful consideration must be given to tag effects, which may affect observed patterns of at-sea distribution, behaviour, breeding success and survival of individuals (e.g. Kentie *et al.* 2024; Langlois Lopez *et al.* 2024; Maynard *et al.* 2022).

3.3. Vital rates

In order to understand the impact of non-breeders on populations, it is important to consider their vital rates and whether these are different compared to breeders. Here we review the vital rates of non-breeders through survival rates and the likelihood of and success of subsequent breeding. Given the varied reasons for non-breeding, it may be that demographic parameters are specific to the reason for non-breeding (Cam *et al.* 1998).

3.3.1. Survival

Two hypotheses on the survival of non-breeders are often described throughout the literature, one related to the effects of energy-intensive breeding, and the other related to other factors not related to breeding.

The first is that non-breeders are in a better condition than breeders due to them not participating in energy-intensive breeding activities. This has been observed in Bulwer's petrel (*Bulweria bulwerii*), whereby non-breeding females had a higher probability of surviving over winter to the next breeding season compared to breeding females, which was thought to be attributed to the costs of reproduction. However, the opposite was seen in males, with non-breeders having a lower chance of survival, suggesting sex-specific costs of reproduction (Cruz-Flores *et al.* 2021). It may also be the case that survival is higher in non-breeders if their distribution is different to breeders and not limited by central-place foraging, increasing their ability to access other food resources and avoid potential threats such as oil pollution (Votier *et al.* 2008).

Conversely, non-breeding status can be associated with low survival rates if poor body condition prevents birds from engaging in reproduction. For example, in herring gulls, non-breeding birds were found to have a lower survival rate the following year, compared to breeding birds (Calladine & Harris 2008); the same trend has been seen in kittiwakes (Cam *et al.* 1998) and common guillemots: those that did not breed had lower survival rates (87%) than successful breeders (95%) (Harris & Wanless 1995).

It may be that the reason for non-breeding plays a role in the relative survival of non-breeders. Ecological theory would suggest that those which do not breed due to poor condition have a lower chance of survival than breeders, whilst birds which do not breed due to factors not related to body condition (e.g. lack of mate, lack of nest) have a higher chance of survival (as they are not constrained by breeding). This may mean that generating a generic survival rate for all occurrences of non-breeders may not be appropriate if the reasons for not breeding are different.

Better estimates of non-breeder survival rates, and how they may vary across immatures, failed breeders and sabbaticals, is required before population models can be accurately parameterised, and used in impact assessments.

3.3.2. Likelihood of and success of subsequent breeding

Akin to survival rates, there may be differences in the likelihood of a subsequent breeding attempt and the success of any attempt between breeders and non-breeders.

3.3.2.1. Likelihood of subsequent breeding

Few studies have analysed whether non-breeders are more or less likely to skip breeding in a subsequent year, but those which have showed mixed results. Two studies of Manx shearwaters on Skomer Island showed opposing results. Wood *et al.* (2021) found that non-breeding birds were less likely to attempt breeding in the year after a sabbatical year. In comparison, Shoji *et al.* (2015) observed that non-breeders were less likely to skip or fail to breed in the subsequent year compared to successful breeders. It should be noted that these studies were carried out on different parts of the island, with different surrounding conditions; Wood *et al.* (2021) notes that their study plot is surrounded by Atlantic puffin (*Fratercula arctica*, hereafter 'puffin') burrows and that competition may occur, which was not the case in the Shoji *et al.* (2015) study. In addition, Shoji *et al.* (2015) studied birds which had all successfully bred, some of which then went on to take a sabbatical year. In contrast, Wood *et al.* (2021) did not select successful breeders, but instead took a wider view across the colony, therefore was more likely to pick up both one-off sabbatical and regular sabbaticals. This highlights several important factors to consider, and which may influence results, when studying non-breeders; other factors impacting breeding, such as competition, and the pool of birds which are being studied.

A further factor to consider is how a change in nest site itself may influence the likelihood of subsequent breeding. In kittiwake, non-breeding birds returning to breed in a new nest site were more likely to skip breeding again, and much more likely to attempt nesting on a different cliff within the colony when they did return to breed, compared to continuous breeders (Cam *et al.* 1998; Danchin & Cam 2002).

Furthermore, it is possible that, in some species, the propensity for skipping breeding changes with age and/or experience. For example, kittiwakes at a colony in Brittany, France were found to be more likely to skip breeding when young and inexperienced, compared to older more experience individuals (Desprez *et al.* 2011). Conversely, no such relationship was found in common guillemots at the Isle of May, Firth of Forth, Scotland, where the likelihood that a bird does not breed after a successful breeding attempt was found to not change with age (Harris *et al.* 2016).

The quality of individuals, and the continuity of quality, has also been suggested to have a role to play as to whether subsequent breeding attempts are made, as well as their survival; the theory being that lower quality individuals are less successful at breeding and have higher mortality rates (Bergeron *et al.* 2010; Cam *et al.* 1998; Lescroël *et al.* 2009).

3.3.2.2. Success of subsequent breeding

As with the likelihood of subsequent breeding, success differed between the Shoji *et al.* (2015) and Wood *et al.* (2021) studies, likely due to the same reasons mentioned above. Shoji *et al.* (2015) found that birds taking a sabbatical had the highest chance of successful breeding (0.79), followed by failed breeders (0.61), above successful breeders (0.57). Meanwhile Wood *et al.* (2021) found that subsequent breeding after a sabbatical was less likely to be successful, compared to previously successful breeders.

In black-browed albatross, failed breeders had a higher risk of failing in the subsequent year, despite spending more time at wintering grounds (Desprez *et al.* 2018). The authors suggested that these were individuals of lower quality, as evidenced by the longer time spent foraging and increased time spent taking off and landing, and therefore prioritised increasing their own physical condition rather than breeding.

Calladine and Harris (2008) investigated sabbatical herring gulls and found that, despite having similar clutch size and laying date, frequent sabbaticals tended to have lower chick survival and lower chick growth compared to continuous breeders, suggesting legacy effects of potentially lower quality individuals.

3.3.2.3. Quality of nest site

The relative quality of a nesting site may also influence the propensity for and success of subsequent breeding. Nest sites that provide protection against predators and bad weather, for example, can lead to increase breeding success (Burke *et al.* 2022; Mariné & Cadiou 2019; Michielsen *et al.* 2019).

Common guillemots generally use the same nest site from year to year, but in rare cases they can move between breeding seasons. On the Isle of May, Kokko *et al.* (2004) found that birds that had to change nest site from the previous year (as occupied by a new bird) tended to spend several years as non-breeders and then returned to breed on lower-quality sites. Conversely, birds that moved to a new nest site that was not occupied improved their nest site quality.

In Eurasian oystercatcher (*Haematopus ostralegus*), Bruinzeel (2007) found that, for the majority, sabbatical birds returned to the same quality site as they previously occupied, and reasonably close by. Those that did return to a site of a different quality, this appeared to be influenced by the duration of the sabbatical and differed between sexes. Non-breeding bouts could last anywhere from two to nine years. Males taking a longer period off from breeding returned to a low-quality site, while those with a shorter sabbatical duration returned to a high-quality site. Conversely, the opposite was seen in females, where a longer sabbatical was more likely to result in a higher quality site (Bruinzeel 2007).

Many factors appear to potentially play a role in why a bird may not successfully breed, whether subsequent breeding is attempted, and whether it is successful. These may change with age, sex and nest site quality, among other factors. It remains unknown how representative this is across species of relevance to the UK, how important these factors are, and how relevant they are to an impact assessment for offshore wind. More generally, better understanding why birds do not breed, and what influences their probability of successfully breeding the following year, is required.

3.4. Importance of non-breeders in populations

Non-breeding birds play an important role in population dynamics, with the ability to rapidly take the place of lost, or sabbatical breeders. Indeed, it has been evidenced that relatively stable populations may have differences in recruitment year on year due to a sufficiently large pool of non-breeders which are able to rapidly fill gaps left by other non-breeders, mortalities, or divorces (Cam *et al.* 1998; Penteriani *et al.* 2011; Johns *et al.* 2021). This can be particularly important during mass mortality events, such as pollution (Votier *et al.* 2008).

Yet it has also been seen that large declines in populations have coincided with larger proportions of numbers of non-breeders, suggesting that birds deciding not to breed may sometimes outweigh non-breeders being recruited into the breeding population. This was seen in shags, whereby simulations suggested that a 60% non-breeding rate caused a 54% decline in the population of over the following years, and several years later 35% non-breeders occurred shortly before a 79% drop in the population (Aebischer & Wanless 1992). The same authors estimated that 12% to 25% of shags may undertake skipped breeding in their lifetime.

Penteriani *et al.* (2005) warn that large numbers of mortalities of non-breeders may not be immediately observed, and may take several years to influence population stability, by which time little can be done to prevent further decline. Penteriani *et al.* (2005) generated an individual-based model to simulate the impact of a range of mortality rates on a population of Spanish imperial eagles (*Aquila adalberti*), which included non-breeders in the model. In this scenario, productivity was density-dependant, therefore initial mortalities of non-breeders had little impact on the population, but after 20 years massive declines were predicted. Worse outcomes were associated with a younger age of recruitment and higher mortality rates of non-breeders. Under some scenarios, populations were predicted to become extinct in less than 100 years (Penteriani *et al.* 2005). Indeed, the Allee effect (the correlation between population size and fitness, and hence the potential for extinction at low numbers and low productivity and/or survival) has been demonstrated to be due, at least in part, to non-breeder mortality (Penteriani *et al.* 2008). Similarly, a decrease in the average age of recruitment could suggest instability of a population as more younger immatures become part of the breeding population (Ferrer *et al.* 2003).

Modelling populations without including non-breeders can vastly overestimate population growth rates, potentially hiding lower growth rates, or even declines (Lee *et al.* 2017). In modelling population change, it has been suggested that recruitment had a much greater impact than survival rates of breeders on the resulting population size of northern fulmar (Ollason & Dunnet 1983). Conversely, Potiek *et al.* (2022) carried out a sensitivity analysis and found that population growth rate was less sensitive to sabbatical rates than breeding adult survival rates for all 18 seabird species modelled across the North Sea.

It is clear from studies that non-breeders do have an important role to play in seabird population dynamics, and that it is possible to model populations including non-breeders. Further investigation is required around the sensitivity of models to different parameters related to non-breeders, and where future data collection should be targeted. A feedback loop, where data is collected, fed into population models, and data reviewed to inform further data requirement needs would also be useful to inform efficient data collection.

4. Research Opportunities

These Research Opportunities (ROs) have been developed in collaboration with a consortium of key scientific expertise from species and industry experts. Discussions mainly focussed on collating existing data, making assessments of that data with a view to undertaking gap analyses, which will then inform the expansion of monitoring to new sites or scaling up of existing studies. These ROs are designed to consider multiple species; some ROs propose a case study of a particular species, then investigate the applicability to other species.

A summary of the issues with evidence, data at and methods in different parts of the impact assessment, and the improvements required are provided in Table 3. The ROs described in this section have been specifically developed to feed directly into seabird impact assessments for offshore wind, targeting multiple parts of the process to ensure non-breeders are considered at each relevant stage.

Table 3. A summary of issues with currently available data and methods, and improvements required for non-breeder inclusion in offshore wind impact assessments.

Part of assessment	Issues with currently available data and methods	Improvement required
The proportions of non-breeders observed in baseline at-sea surveys	- Reasonably likely that immatures and sabbaticals distribute differently to breeding adults. - Very unlikely that all birds observed at a proposed OWF site are breeding adults, especially far offshore. - Uncertainty over the appropriateness of applying theoretical assumptions from population stable age structures to derive age class compositions in specific areas of sea and times of year. - Uncertainty over the appropriateness of applying generic sabbatical rates to estimate relative proportions of sabbaticals vs. breeding adults at sea. - Low confidence in sabbatical rates across species. - Uncertainty over how accurate DAS data are for deriving age class distributions at sea	Improved understanding of year-round immature and sabbatical at-sea distributions.
The assessment of collision and displacement mortality	- Reasonable to assume that sabbaticals behave similarly to breeding adults, in relation to collision and displacement risk. - Likely that immatures behave differently to breeders due to lack of experience and lack of reproductive constraints.	Improved understanding of at-sea behavioural parameters informing sensitivity to collision and displacement.

Part of assessment	Issues with currently available data and methods	Improvement required
The apportioning of impacts back to SPA colonies	- Uncertainty over attendance of sabbaticals and immatures at colonies during the breeding season. - As immatures and sabbaticals may distribute differently to breeding adults and may not need to regularly return to colonies, reasonably likely that current methods of apportioning (based on central-place foraging assumptions) are not appropriate. - Inability to apportion birds observed at an OWF site far offshore during the breeding season to relevant SPAs.	Improved understanding of the at-sea distribution of immatures and sabbaticals, and their colony attendance.
The assessment of impacts on populations (PVA)	- Large uncertainty in sabbatical rates across species. - Inability to apply additional mortality from OWFs to sabbaticals within the NE/JNCC PVA tool. - Uncertainty over whether the inclusion of sabbaticals (either as a rate or a separate class of individuals) in PVA influences population trajectories. - Where it is done, applying mortalities to breeding adults only at the PVA stage ignores risks to immatures and sabbaticals. - Assigning equal mortality estimates to adults and immatures, without supporting evidence, may influence population trajectories. - Apportioning impacts to immatures and adults using stable age structures relies on unverified, potentially strong assumptions. - Inability to apply differential levels of mortality to specific immature age classes (age 0–1, 1–2, 2–3, etc.) within the NE/JNCC PVA tool (which is dependent on being able to age birds present in baseline surveys to this level of granularity).	Improved understanding of the proportion of sabbaticals in populations and their role in population persistence. Better estimates of sabbatical rates, including variation across species and between years. Clarity in the application of immature mortality to PVA.

The relationship between each RO and the stages of the impact assessment that it feeds into is outlined in Figure 2, summarised below, and described in detail in the subsequent sections. The ROs below are presented in no order of priority, rather they are structured to reflect the main knowledge gap themes covered in the review of evidence section above and maximise relevance to the different stages of the impact assessment process.

The ROs that have been developed aim to better understand the at-sea distribution of non-breeders to assess their exposure to offshore wind farms. Research is then proposed to investigate non-breeder behaviour at sea to evaluate their sensitivity to collision and displacement from offshore wind farms. Other ROs explore the rate of non-breeding within populations, a core part of the research required, which will aid with modelling the importance of non-breeders in population, and population-level impacts. In total, this will provide information to enable non-breeders to be brought into impact assessments at all relevant stages, ensuring that HRAs and EIAs fully consider all relevant constituent parts of seabird populations.

Apportioning birds to age class or breeding status	Collision Risk Model	Displacement assessment	Apportioning impacts to SPAs	Population Viability Analysis
RO 5.1 At-sea distribution of immatures	RO 5.3 Ecology and behaviour of non-breeders relevant to collision and displacement	RO 5.3 Ecology and behaviour of non-breeders relevant to collision and displacement	RO 5.1 At-sea distribution of immatures	RO 5.4 Better understanding of the proportion of non-breeders within populations
RO 5.2 At-sea distribution of sabbaticals	RO 5.6 Seabirds' behavioural response to light	RO 5.6 Seabirds' behavioural response to light	RO 5.2 At-sea distribution of sabbaticals	RO 5.5 The role of non-breeders in population persistence and their treatment in PVAs
RO 5.5 The role of non-breeders in population persistence and their treatment in PVAs				

Figure 2. Summary of Research Opportunities identified through OWSMRF Phase III and how these link to the stages of an offshore wind impact assessment.

4.1. RO 5.1 At-sea distribution of immatures

4.1.1. Rationale

There are limitations in the approaches currently used to apportion predicted impacts of OWFs to age classes. Digital Aerial Surveys (DAS) can only be used to distinguish between immatures and adults observed at a proposed development for those species with age-specific plumage characteristics (e.g. gannet, large gulls) and is also dependent on the quality of the images produced. Alternatively, classical population theory, using stable age structures in population modelling, can be applied to estimate age class compositions in seabird populations. A key limitation of this approach is that its underlying theoretical population modelling assumptions may not necessarily reflect variations in age class distributions across areas of seas and times of year, and therefore not represent age ratios at a specific OWF site. Indeed, in some species such as gannet, estimated population-level age class proportions derived from stable age population structure have been shown to differ from site-specific age ratios observed at sea. Better understanding of immature at-sea distributions in UK waters is crucially needed to validate age class apportioning assumptions.

For those limited seabird species for which there are data on the relative at-sea distribution of immatures compared to adults, distributions appear to differ between both groups. Therefore, their exposure to offshore wind farms may also differ, particularly in the context of future windfarm developments further offshore, which may overlap with immature distributions. In addition, it is unclear whether this difference in age class distribution can be generalised across species and times of year. This RO aims to obtain a better understanding of immature distributions year-round for several key species breeding in the UK. It will test the hypothesis that immatures have a different exposure to OWF compared to breeders, and test assumptions from multiple approaches for estimating age class proportions observed at sea (e.g. DAS, stable age structure, tracking data).

In addition, there are limitations in the approach currently used in impact assessments to apportion birds observed at sea back to colonies. The method developed for the breeding season is based on central-placed foraging theory, which presents a challenge when apportioning birds observed at a far offshore OWF site, outside typical foraging ranges. This RO will test how suitable the current apportioning method is for determining the colonies which immatures are associated with.

To do this, new at-sea distribution maps of immatures will be generated, and compared to distribution of breeding adults, from which proportion of immatures in at-sea surveys can be determined. A method will be developed to allow impact assessments to calculate relative numbers of immatures vs adults observed in OWF areas. At-sea distribution maps of immatures obtained through tracking of individual movements will also be used to improve the existing process of apportioning birds back to SPAs. This RO will generate a novel approach for estimating proportions of age classes observed in OWF survey areas and identifying colonies they are associated with.

4.1.2. Work required and predicted resources

This RO focuses on understanding the distribution of immatures at sea and how this differs from breeding birds. There is a particular order to these sub-ROs based on the outcome of the RO 5.1b. This sub-RO investigates whether existing data can be used to generate at-sea distribution maps of immatures; if this is possible then distribution maps are generated, if not then new data collection is recommended to produce distribution maps, then continuing through the remaining sub-ROs. This process is explained in Figure 3.

Part of this RO involves the comparison of the proportion of immatures at-sea generated from new distribution maps with those generated from stable age structures and DAS. It is suggested that this process is first followed using gannet as a case study, working to aid and inform work generating distribution maps for other species. Gannet is likely to have the most immature tracking data available, and immature gannets can be differentiated from adults in DAS. For other species which ages cannot be identified from DAS, this process can also be followed but only a comparison with stable age structures will be possible.

While it may be sensible to focus this RO on gannet in the first instance, the same process could be followed for other species or groups of species. RO 5.1b is a key first step in the process, helping identify candidate species for which this work would be most feasible.

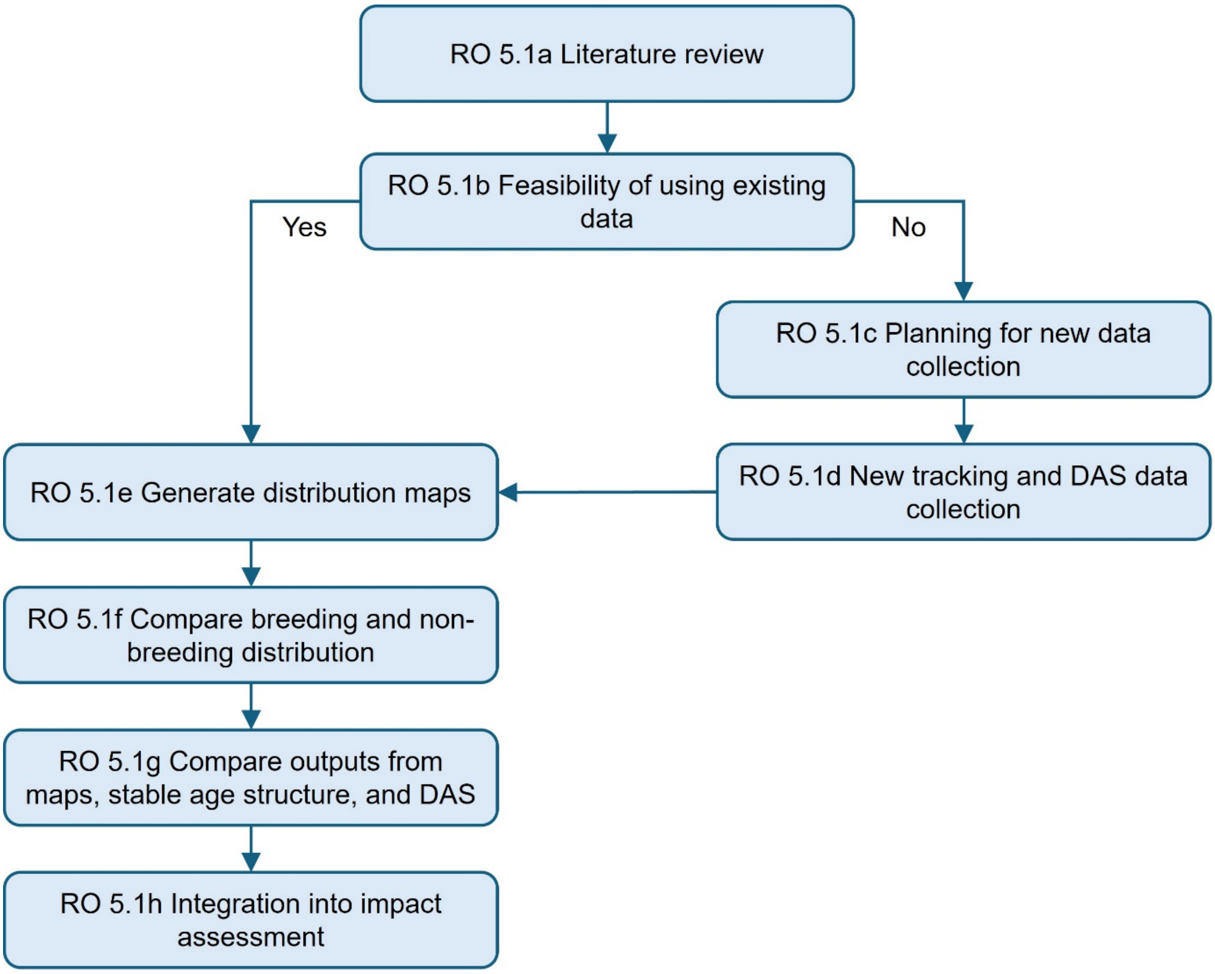

Figure 3. Order of RO 5.1 research.

4.1.2.1. RO 5.1a Literature review of immature distribution

This RO would begin with a thorough review of literature on the distribution of immatures in seabird species, expanding on that undertaken in this report. The work would involve assessing the extent to which at-sea distributions differ between age classes, and at various times of year. It would also identify potential drivers of immature distribution, including for example environmental factors, fishing vessel distribution, distance to coast. This sub-RO would include a range of seabird species.

As this is desk based, the resource requirements will be restricted in terms of time and cost.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.1.2.2. RO 5.1b Feasibility of using existing data to improve understanding of immature at-sea distribution

This work would identify tracking and DAS datasets that could be made available to map out at-sea distribution of immatures for a range of priority species breeding in the UK. This would include searching existing tracking databases such as SEATRACK, Movebank, BirdLife's Seabird Tracking Database, etc., but also engaging with experts and data holders to discuss existing evidence, identify gaps (spatial, temporal, species) and explore collaboration opportunities. Crucially, this feasibility assessment would need to include a thorough investigation of any risks related to obtaining access to data including legal implications of sharing data, as well as challenges associated to processing data, and potential biases such as tag effects, data resolutions or sample sizes, for example. As an output, species for which immature at-sea distribution data could be made available for future distribution mapping work would be identified, as well as any opportunities and barriers for obtaining access to additional data. For those species which it is deemed feasible to access and use existing data to generate distribution maps, work can progress directly to RO 5.1e and the subsequent sub-ROs. If it is not feasible on the other hand, then RO 5.1c and RO 5.1d are progressed first, followed by the subsequent sub-ROs as outlined in Figure 3.

There may be several species for which immature at-sea distribution data is readily available and accessible for further mapping work, especially from tracking data only. Gannet would seem to be a good case study that this RO could tackle in the first instance, due to the reasonable confidence in age class identification in this species, which will allow including age class distribution data obtained from DAS. Tracking of both immature and adult gannets has been carried out, and DAS have collected data on various gannet age classes (e.g. through the OWEC-funded POSEIDON project). This will provide an evidence base from which to investigate the feasibility of using multiple sources of information to map out current understanding of gannet immature distributions around the UK at various times of year. Comparisons to adult distributions will be required in subsequent sub-ROs, therefore the feasibility of obtaining concurrent adult tracking data, and identification of gaps, will also be included.

This feasibility assessment represents a vital first step, providing the foundations for subsequent work (e.g. identifying species for which data are available and accessible, as well as most relevant datasets that could be used to improve understanding of at-sea distribution).

As this is desk based, the resource requirements will be restricted in terms of time and cost.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.1.2.3. RO 5.1c Planning for new immature tracking deployment and/or Digital Aerial Surveys

Building on the data gaps identified in RO 5.1b, this work will provide detailed recommendations to fill those gaps through additional data collection, focusing on immature gannets in the first instance, but also considering what is required for other species. This may include, for example, further monitoring through tagging, where to tag and/or survey, how many individuals to tag, which tags to use, and any technological, resource, health and safety and ethical/welfare considerations. If GPS is being considered for long-term attachment, currently a key barrier is the attachment method and related welfare concerns (i.e. if using harnesses). The feasibility of collating tracking data for several candidate species would be investigated. Considerations will be given to the feasibility of tagging immatures caught at colonies. In a number of seabird species, immature birds do not return to the colony at all, therefore alternative methods through, for example., remote download technology and tagging of chicks/fledglings may be required (in which case the feasibility of tag development would also need to be considered). Novel technologies, such as cameras mounted on structures at sea and AI-aided data analysis, could also be explored.

If DAS is identified as a potentially useful and complementary source of information (as per the outputs of RO 5.1b), then the feasibility of undertaking further DAS will also be explored. Comparisons to adult distributions will be required in subsequent sub-ROs, therefore the feasibility of undertaking new adult tracking and identification of gaps will also be included.

As this is desk based, the resource requirements will be restricted in terms of time and cost. Familiarity with tracking deployment and experience of power analysis is required.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.1.2.4. RO 5.1d Tagging immatures and new Digital Aerial Surveys to improve understanding of at-sea distribution

This sub-RO focusses on undertaking further data collection to fill gaps. If the result of earlier sub-ROs is that either there is not sufficient evidence to generate a robust understanding of seasonal immature gannet distribution in the UK, and/or other species are likely to be significantly different to gannet, then additional work would be required. This work will seek to deploy new tagging of immatures, as informed by RO 5.1c; first for gannet, then other species of importance as identified in RO 5.1b and RO 5.1c. If RO 5.1c identifies that DAS would also be a useful source of further data, then this RO may also undertake new DAS campaigns. Either new or refined immature distribution maps would subsequently be generated following this additional data collection.

Resources required will be better understood based on the outcomes of RO 5.1c.

Predicted resources for this sub-RO are high (several years and over £500,000), best achieved through a collaborative approach.

4.1.2.5. RO 5.1e Generation of immature distribution maps

Using tracking data that have been made available and are accessible for a given species, distribution maps for immatures in the UK will be produced, investigating seasonal and yearly patterns if deemed feasible. Provided sufficient data is available, effects of likely important covariates (as identified under RO 5.1a) could be modelled. For example, periodic mass mortality events such as HPAI may lead to changes in the extent to which immatures are tied to colonies during the breeding season and acting as central-place foragers, therefore potentially changing how they use the marine environment.

For species for which DAS data can be used to age birds, such as gannet, this sub-RO will then explore feasibility of combining tracking and DAS datasets to refine relationships between covariates and distributions. This work could build on the modelling framework developed by the ORJIP Integration of tracking and at-sea survey data (InTAS) project, which has developed a framework for making use of at-sea survey and telemetry data to improve understanding of seabird distributions.

The work would investigate the drivers of immature distribution to gain better understanding of the variability in distribution. As well as environmental drivers, this may also include periodic events, such as HPAI, and how these may influence at-sea distribution.

As this is desk based, the resource requirements will be restricted in terms of time and cost. Familiarity with data of various types and format is required and experience of extracting, manipulating and combining datasets from disparate sources and in various formats is required.

Therefore, predicted resources for this sub-RO (per species) are low, with updated maps produced as/when new data becomes available (less than one year and less than £100,000 per iteration). Cost will increase as the number of species considered increases

4.1.2.6. RO 5.1f Comparison of immature and breeding adult distributions

Seasonal distributions of immature birds would subsequently be compared to the distributions of breeding adults. This may be through known distributions of breeding adults, such as for gannet: Wakefield *et al.* (2013), Grecian *et al.* (2012) or Niven *et al.* (2025). Alternatively, contemporaneous immature and breeding adult tracking data, possibly DAS data too if available, could be interrogated as these would have similar environmental conditions to the immature data that was used to generate distribution maps under RO 5.1e.

As this is desk based, the resource requirements will be restricted in terms of time and cost.

Therefore, predicted resources for this sub-RO (per species) are low (less than one year and less than £100,000).

4.1.2.7. RO 5.1g Comparison of proportion of immatures from distribution maps, stable age structure and Digital Aerial Surveys

For a range of locations and times of year, estimated proportions of immature gannets derived from tracking data, a population stable age structure and DAS will be compared. This will allow an investigation of differences in approaches to apportion OWF impacts to age classes and identify circumstances where some methods may be more suitable than others. For those species for which DAS cannot be used to age birds with confidence, only comparisons between tracking data and stable age structures could be undertaken.

As this is desk based, the resource requirements will be restricted in terms of time and cost.

Therefore, predicted resources for this sub-RO (per species) are low (less than one year and less than £100,000).

4.1.2.8. RO 5.1h Integration of improved understanding of at-sea distribution of immatures into the impact assessment

This work is to synthesise the work of RO 5.1a to 5.1g on immature distribution to ensure that the outputs can be utilised within impact assessments. Better understanding of at-sea distribution is likely to influence at least two separate parts of the impact assessment: apportioning birds to age classes or breeding status and apportioning of impacts to SPAs. To understand how distribution of immatures affects their level of risk from OWFs, a method of quantifying the proportions of immatures at specific areas of sea is required. This may need to be defined and agreed with experts, including relevant UK country agencies, early in the project. This may be, for example, through distribution maps of relative density of breeding adults and immatures from which a value of the proportion of immatures can be extracted for a particular area. Depending on the temporal resolution of the data, these may be monthly, seasonal or annual values. An analysis of values at various at-sea locations, varying in distance to shore, distance to colonies, size of nearest colonies, among other factors may aid in producing tools to predict proportions of non-breeders at sea. To apportion impacts back to SPAs, a method of assigning immatures to a colony is required. An assessment of the suitability of existing apportioning methods will be undertaken, followed by any necessary amendments, or the development of new methods.

As this is desk based, the resource requirements will be restricted in terms of time and cost.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.1.3. Benefits and outcomes

The aim of this RO is to gradually produce an up-to-date, and as comprehensive as possible, understanding of the distribution of immatures at sea, focusing on gannet first. However, this RO could be applicable to other priority species (as identified in RO 5.1b). From this, the risk of immatures interacting with existing and future offshore wind developments can be analysed, to help inform both project-level and plan-level assessments, as well as future leasing. The information provided by this RO will enable estimates to be made of the proportion of birds observed in baseline surveys to be characterised as immatures and assessed as immatures in subsequent stages of an impact assessment. In addition, using at-sea movement tracking evidence, colonies of origin of immatures will also be better understood, allowing for improvements in apportioning of impacts back to SPAs as well as considering impacts to the whole population.

4.1.4. Existing work, synergies, and risks

Tracking immatures of several species is undertaken, or being considered further, by the SEATRACK programme in the North Sea. Further discussions with the project team would be needed to understand opportunities and maximise benefits of any future work.

The OWEC-funded POSEIDON project has collected distribution data on gannets using DAS, which may be useful to interrogate further. Several gannet tracking studies have been undertaken across south Wales, eastern Scotland and around the southern coast of Ireland, which may offer data on immature distribution. The integration of tracking and at-sea datasets has been investigated previously through the ORJIP II project InTAS; the outcome of which provides an analytical framework for improving understanding of age-class and season specific at-sea usage.

Furthermore, as the behaviour of immatures may be different to breeders, any future tracking study of immatures could investigate options for collecting additional data on at-sea behaviour, for example collision risk parameters such as flight heights, flight speeds and nocturnal activity, provided suitable technology is deployed (see RO 5.3 and RO 5.6).

Synergies also exist between immature and sabbatical tracking research, whereby RO 5.1b and RO 5.2a could be jointly considered as part of the same data collation initiative (as likely involving sourcing and interrogating similar datasets and liaising with the same network of data holders). This would also provide a financial benefit, leading to reductions in overall project cost (approximately £30,000–40,000).

It may be that desk-based solutions are not possible to generate immature distribution maps for each relevant species, in which case additional tagging and DAS (RO 5.1d) would be required. Tagging is likely to involve expensive and intensive monitoring, which would result in very good quality data, but only after many years-worth of data collection. Inferences made from tracking would also be limited to the ability of tagging a sufficiently high number of individuals within each population. Biases associated with tagging data, such as tag effects, and from different types of tags, also need to be considered. DAS is also very expensive; however, it is complementary to tracking in terms of the spatial and temporal resolutions of the data acquired and may obtain data in a shorter time frame. A combined approach would therefore be desirable.

4.2. RO 5.2 At-sea distribution of sabbaticals

4.2.1. Rationale

Not much is known about how sabbatical birds use the marine environment (e.g. how much time they spend further offshore rather than close to colonies). As with immature birds, the at-sea distribution of sabbaticals may differ from breeders, therefore changing their exposure to offshore wind. This is particularly the case if sabbaticals do not behave akin to central-place foragers as breeders do. With the on-going impacts of climate change, and more frequent mass mortality events of adult breeding birds (from e.g. HPAI), numbers of birds skipping breeding in a year is likely becoming more variable (and potentially increase), therefore influencing breeders/non-breeders ratios observed at sea, particularly near colonies.

A key issue in offshore wind impact assessments is the difficulty to apportion OWF impacts to non-breeding components of seabird populations, and back to relevant SPAs. This is becoming increasingly relevant to future developments further offshore, which may have larger overlaps with sabbatical distributions. Within the breeding season, the current method for apportioning OWF impacts to SPAs is based on central-placed foraging theory, which may not apply to individuals with no reproductive constraints such as sabbaticals. This represents a challenge when apportioning birds observed at a far offshore OWF site, outside typical foraging ranges, to relevant SPAs (e.g. are these birds breeding adults with extended foraging ranges or sabbaticals?). This RO will test how suitable the current apportioning method is for determining the colonies which sabbaticals are associated with.

Non-breeding adults such as sabbaticals may not be differentiated from breeding adults or immatures by their plumage; therefore, only telemetry data offers a means to track their movements at sea and link these distributions back to those colonies they relate to. One of the difficulties with tracking sabbaticals is being able to identify sabbaticals at colonies or at sea to place a tag on them to follow their movements. Furthermore, many sabbaticals do not return to the colony during the breeding season, therefore, unless these birds are caught at sea, they cannot be fitted with a tag during their sabbatical year. Birds could be caught at sea beyond typical foraging ranges under the assumption that these are sabbatical birds, but there is a risk that these individuals are breeding birds foraging further offshore. Routine tagging of birds at colonies could shed some light if, during the period that the tag is deployed, the individual takes a sabbatical year.

New tagging work to get information on the at-sea distribution of sabbaticals could take many years, particularly if tags are put on breeding individuals assuming they will at some point take a sabbatical year. Sample sizes and the number of years to collect movement and at-sea distribution data could be large for species that have low sabbatical rates. However, a large volume of tracking data has been collected across species in UK waters, some of which may have covered sabbatical periods, even if this was not the primary aim of the original study.

This RO will investigate the feasibility of generating distribution maps of sabbaticals, which will be compared to the distribution of breeding adults. This will help estimating with more confidence the likelihood of sabbatical at-sea usage in various marine regions, for example at various distance bands from the coast. A method will be developed to allow impact assessments to calculate relative numbers of sabbaticals vs breeding adults observed in OWF areas. The distribution of sabbaticals at-sea will also be used to improve the process of apportioning birds back to SPAs; this RO will generate a method of relating proportions of sabbatical birds observed in OWF survey areas to relevant SPA colonies.

4.2.2. Work required and predicted resources

This RO would focus on understanding the distribution of sabbaticals at sea, how this differs from breeding birds, and the colony of origin of sabbatical birds at sea. There is a particular order to these sub-ROs based on the outcome of the RO 5.2a. This sub-RO investigates whether existing data can be used to generate distribution maps of sabbaticals; if this is possible then distribution maps are generated, if not then new data collection is recommended to produce distribution maps, then continuing through the remaining sub-ROs. This process is explained in Figure 4.

This work may also be considered for failed breeders; part of the feasibility of using existing data may also include searching for failed breeders, and new tracking studies could also be undertaken.

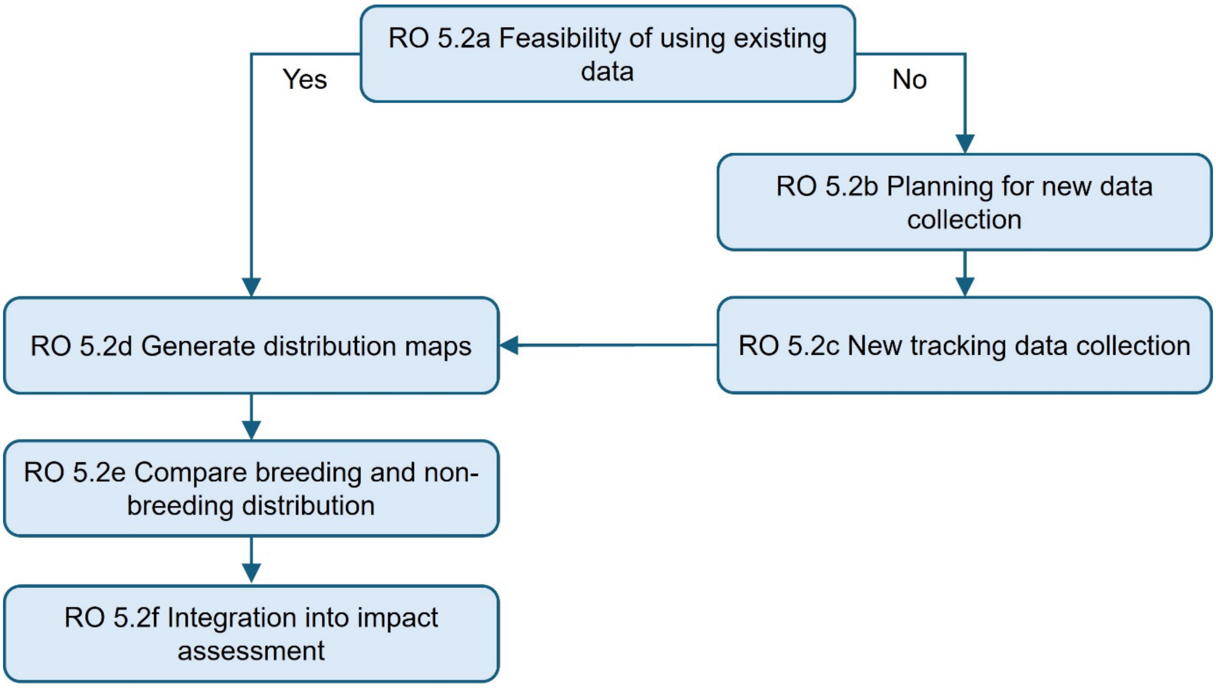

Figure 4. Order of RO 5.2 research.

4.2.2.1. RO 5.2a Feasibility of using existing data to understand sabbatical distribution

There is a wealth of existing tracking data available across seabird species and years from UK colonies, which may include adult birds taking a sabbatical year. The first part of this work is to explore whether existing tracking data covers sabbatical years, and whether a bird is a sabbatical or not can be understood from tracking data. Concurrent colony monitoring, where available, would provide context on the population, confirm the status of individuals, and assess at what point in time a bird becomes a sabbatical. This work would include reaching out to seabird tracking and colony monitoring programme managers to discuss existing evidence, identify gaps (spatial, temporal, species) and explore collaboration opportunities. A range of tagging and data collection methods will be considered, including remote tracking technology. These will also include light detection to determine if a bird enters a burrow, or saltwater immersion to determine if they are on land, and therefore more likely to be breeding, with the caveat that these may be failed breeders or sabbaticals holding territory.

Crucially, this feasibility assessment would need to include a thorough investigation of any risks related to obtaining access to data including legal implications of sharing data, as well as challenges associated to processing data, and potential biases such as tag effects, data resolutions or sample sizes, for example. Candidate species and sites where this may be possible will be identified, likely including those species with higher sabbatical rates and those sites with long-term colony monitoring.

As this is desk based, the resource requirements will be restricted in terms of time and cost.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.2.2.2. RO 5.2b Planning for new sabbatical tracking deployment

If existing tracking data provides insufficient evidence on the at-sea distribution of sabbaticals, or is not available for certain key species, then consideration would be given to new tagging studies. This would likely require a long timeframe for data collection to build up a significant population of marked birds (ideally with colour rings), to pick out non-breeders, and then identify targets for tagging, and to do this across a number of candidate species. Rather than designing new tracking programmes on sabbatical birds only, particular emphasis should be given to incorporating sabbatical tracking into other tracking programmes. This work would make use of the sabbatical tracking data which does exist and is accessible to identify candidate species and sites where sabbatical tagging would be most feasible, as well as identify possible limitations, including any technological, resource, health and safety and ethical/welfare constraints. Feasibility of tag development would also need to be considered.

If further tracking is deemed practically feasible for some species, further work would involve a power analysis to determine both logger deployment and tag retrieval efforts needed to achieve a robust understanding of at-sea distribution of sabbaticals, capturing inter-individual/colony/annual variation. This would include, for selected species, initial colour ringing to identify non-breeders at colonies, potential monitoring of sites, sample sizes, and duration of study. A significant part of the power analysis will be estimating rates of non-breeding in a population to determine how many nests to monitor a year to obtain a sufficient sample of non-breeders. Logger type will also be considered; this may include a combination of logger types to obtain sufficient information, such as GLS or GPS for locations, as well as light-level loggers to determine whether an individual is in a burrow and is a breeding individual or not, for example. Recommendations for any new tag development would be provided, as required.

As this is desk based the resource requirements will be restricted in terms of time and cost. Familiarity with tracking deployment and experience of power analysis is required.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.2.2.3. RO 5.2c Targeted tagging programme to improve understanding of sabbatical at-sea distribution

If the outcome of RO 5.2b is that deployment of new loggers is feasible, then this next phase of work would be to undertake such a deployment of loggers, noting the difficulties in identifying non-breeders, large sample sizes likely required, and the long duration of any study. This work may involve new tag development.

Resources required will be better understood based on the outcomes of RO 5.2b but are likely to be on the higher range.

Predicted resources for this sub-RO are high (several years and over £500,000), best achieved through a collaborative approach.

4.2.2.4. RO 5.2d Generation of sabbatical distribution maps

Using data that have been made available and are accessible, or new data collection, this work will attempt to produce sabbatical at-sea distribution maps and highlight any spatial and temporal gaps in distributions in the UK for several species. Noting the risks associated with accessing sufficient existing data and collecting new data, there is uncertainty as to whether the generation of sabbatical distribution maps will be attainable. If possible, the work would also investigate the drivers of sabbatical distribution to gain better understanding of the variability in distribution and enable variables to be accounted for when predicting distributions in areas where no tracking data is available. As well as environmental driver, this may also include one-off events, such as HPAI, and how these may influence distribution.

As this is desk based, the resource requirements will be restricted in terms of time and cost. Familiarity with data of various types and format is required and experience of extracting, manipulating and combining datasets from disparate sources and in various formats is required.

Therefore, predicted resources for this sub-RO (per species) are low (less than one year and less than £100,000). Cost will increase as the number of species considered increases.

4.2.2.5. RO 5.2e Comparison of sabbatical and breeding adult distribution

Comparisons to breeder distributions will be required to determine if and how distributions differ between breeders and sabbaticals. This work would investigate the best breeding distribution data to compare to sabbatical distributions, before carrying out such a comparison. In addition, the colony of origin of sabbaticals will be interrogated, and compared to what is assumed for breeders, which is currently based on standard foraging range metrics. Resolutions achieved through various logger types (e.g. GLS vs GPS) would also need to be compared and discussed to determine the caveats and uncertainties associated with different methods, with implications for comparing distribution patterns between sabbaticals and breeding adults in a robust manner.

As this is desk based, the resource requirements will be restricted in terms of time and cost.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.2.2.6. RO 5.2f Integration of improved understanding of at-sea distribution of sabbaticals into the impact assessment

This sub-RO is to synthesise the work of RO 5.2a to 5.2e on sabbatical distribution to ensure that the outputs can be utilised within impact assessments. Better understanding of at-sea distribution is likely to influence at least two separate parts of the impact assessment: apportioning birds to age class or breeding status and apportioning of impacts to SPAs. To understand how distribution of sabbaticals affects their level of risk from OWFs, a method of quantifying the proportions of sabbaticals at specific areas of sea is required. This may be, for example, through distribution maps of relative density of adult breeders and sabbaticals from which a value of the proportion of sabbaticals can be extracted for a particular area. Depending on the temporal resolution of the data, these may be monthly, seasonal or annual values. An analysis of values at various at-sea locations, varying in distance to shore, distance to colonies, size of nearest colonies, among other factors may aid in making tools to predict proportions of sabbaticals at sea. To apportion impacts back to SPAs, a method of assigning sabbaticals to a colony is required. An assessment of the suitability of existing apportioning methods will be undertaken, followed by any necessary amendments, or the development of new methods.

As this is desk based, the resource requirements will be restricted in terms of time and cost.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.2.3. Benefits and outcomes

This RO should provide direct information on the distribution of sabbaticals at sea. From this, the risk of sabbaticals interacting with existing and future offshore wind developments can be analysed, to help inform both project-level and plan-level assessments, as well as future leasing particularly in areas further offshore. The information provided by this RO will enable estimates to be made of the proportion of birds observed in baseline surveys to be characterised as sabbaticals and assessed as sabbaticals in subsequent stages of an impact assessment. In addition, colonies of origin of sabbaticals will also be better understood, allowing for improvements in apportioning of impacts back to SPAs as well as considering impacts to the whole population.

4.2.4. Existing work, synergies, and risks

There is no known seabird tracking programmes specifically targeting sabbaticals or investigating their at-sea distribution. However, tracking data is available through various long-term programmes, such as SEATRACK in the North Sea, which may include data on sabbaticals. Routine tracking around the UK such as that on as on the Isle of May (kittiwake, common guillemot, razorbill, puffin, shag), Skomer, Skokholm, Rum and Copeland (Manx shearwater), Grassholm, Bass Rock and Ailsa Craig (gannet), Shiants and Canna (common guillemot, razorbill, puffin), east coast of Scotland (kittiwake, common guillemot, razorbill), and Eynhallow (northern fulmar) may also have collected data on sabbaticals.

To estimate the feasibility of new tagging efforts on sabbaticals (RO 5.2b), a good estimate of rates of sabbaticals would be useful, therefore there is a dependency on RO 5.4.

Synergies also exist between immature and sabbatical tracking research, whereby RO 5.1b and RO 5.2a could be jointly considered as part of the same data collation initiative (as likely involving sourcing and interrogating similar datasets and liaising with the same network of data holders). This would also provide a financial benefit, leading to reductions in overall project cost (approximately £30,000–40,000).

It may be that desk-based solutions are not possible to obtain distribution maps for relevant species, in which case additional tagging effort would be required. Tagging is likely to involve expensive and intensive monitoring which, whilst resulting in good quality data, is only possible after many years-worth of data collection. There remains uncertainty as to the feasibility of deploying sufficient tags to answer sabbatical birds research questions.

4.3. RO 5.3 Ecology and behaviour of non-breeders relevant to collision and displacement

4.3.1. Rationale

There are differences in how seabird species use the at-sea environment between incubation and chick rearing, due to the need for chick provisioning, so it is likely that there is also a difference in at-sea behaviour between birds that are engaged in breeding activities and those that are not. These differences may be due to, for example, absence of reproductive constraints, lack of experience, flexibility in habitat use or diet breadth. Therefore, we may expect that non-breeder sensitivity to collision and displacement may also differ to active breeders. Consequently, the methods currently used to assess displacement and collision of breeders may not be directly applicable to non-breeders, and need updating. The outcomes of this RO will be, where required, updated input parameters for collision and displacement assessments.

4.3.2. Work required and predicted resources

This RO would focus on understanding non-breeder behaviours relevant to collision and displacement, and how this differs from breeding birds. This includes investigating parameters influencing collision risk such as flight heights, flight speeds and nocturnal activity, as well as those influencing displacement risk such as foraging habitat flexibility and disturbance caused by anthropogenic activity. There is a particular order to these sub-ROs based on the outcome of the RO 5.3a. This sub-RO investigates whether existing data can be used to understand collision and displacement parameters of non-breeders; if this is possible then this is used, if not then a series of data collection is recommended, before returning to continue through the remaining sub-ROs. This process is explained in Figure 5.

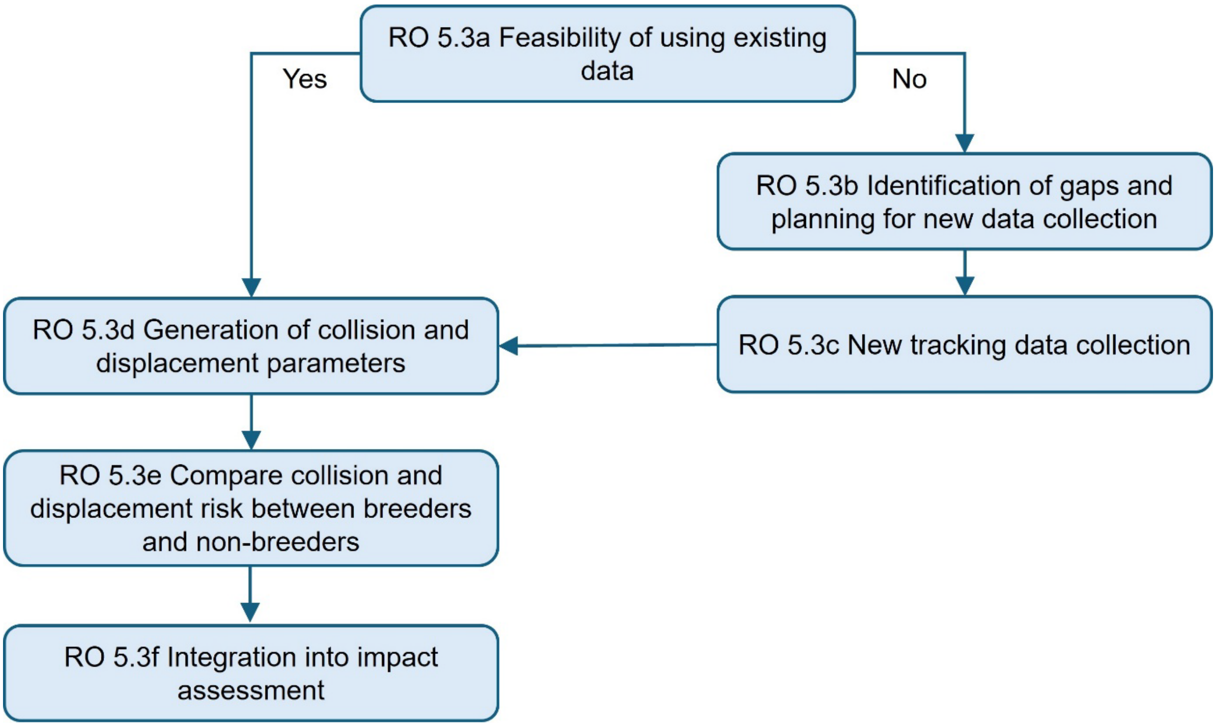

Figure 5. Order of RO 5.3 research.

4.3.2.1. RO 5.3a Strategic review of tracking data on non-breeder collision and displacement parameters

Akin to RO 5.1 and RO 5.2, there may be a wealth of existing data that may be interrogated in terms of risk of collision and displacement of non-breeders across different species, potentially more for immatures than sabbaticals. Therefore, for several priority species agreed by experts, this work would include a strategic review of available tracking data, and feasibility assessment of obtaining behavioural information relevant to collision and displacement of non-breeders, such as flight heights, flight speeds and nocturnal activity (relevant to collision), and foraging habitat flexibility and susceptibility to disturbance from anthropogenic activity (relevant to displacement). Priority species would ideally include those species known at high risk of OWF collision and displacement, but also other species potentially at risk but where evidence is currently limited. Emphasis will be put on the quality and resolution of tracking data available, and whether they would allow for accurate estimation of collision risk parameters. It will also consider challenges related to obtaining access to data including legal implications of sharing data, processing data, and biases, for example. As comparisons with breeders are to be undertaken in a subsequent sub-RO, the feasibility of collating and using tracking data on breeders is also included in this work.

Resource requirements will vary depending on the scope of this work. Familiarity with data of various types and formats is required and experience of extracting, manipulating and combining data from disparate sources and in various formats is required.

Therefore, predicted resources for this sub-RO are low to medium, depending on the number of species studied and volume of data retrieved (up to £150,000–200,000).

4.3.2.2. RO 5.3b Planning for new non-breeder tracking deployment to understand risk of collision and displacement

If existing tracking data provides insufficient evidence to infer sensitivity of non-breeders to collision and displacement, or is not available for certain key species, then consideration would be given to new tagging studies. This work would use the non-breeder tracking data which does exist and is accessible to perform a power analysis to determine both logger deployment and tag retrieval efforts needed to achieve a robust understanding of behaviour, capturing inter-individual/colony/annual variation. This would include, for selected species, potential monitoring sites, sample sizes, duration of study, and logger type, and if required, new tag development. This may include a combination of logger types to obtain sufficient information. As comparisons with breeders are to be undertaken in a subsequent sub-RO, the feasibility of collecting new tracking data on breeders is also included in this work.

As this is desk based, the resource requirements will be restricted in terms of time and cost. Familiarity with tracking deployment and experience of power analysis is required.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.3.2.3. RO 5.3c Tagging non-breeders to understand risk of collision and displacement

If the outcome of RO 5.3b is that deployment of new loggers is feasible, then this next phase of work would be to undertake targeted deployment of loggers, allowing estimations of at-sea behaviour such as flight heights, flight speeds and nocturnal activity. The type of logger to be used as determined by RO 5.3b would be deployed at locations also determined by this RO. The resulting behavioural data would be interrogated to assess collision and displacement risk. Comparisons to breeder risk may also be required to determine whether and to what extent risks differ, therefore the tagging of breeders is also included in this work, if not available from existing studies.

Resources required will be better understood based on the outcomes of RO 5.3b but are likely to be on the higher range.

Therefore, predicted resources for this sub-RO are high (several years and over £500,000), best achieved through a collaborative approach, for example, combining elements from RO 5.1d (tagging immatures) and RO 5.2c (tagging sabbaticals).

4.3.2.4. RO 5.3d Generation of collision and displacement parameters

Using data that have been collated, collected, or both, this work will synthesise the data to produce estimates of collision and displacement parameters for non-breeders (likely immatures only), per species, highlighting any spatial and temporal trends and uncertainties. Variation in behaviour and parameters due to different conditions, such as environmental variables, or periodic events such as HPAI, will also be considered in the generation of rates and uncertainties.

As this is desk based, the resource requirements will be restricted in terms of time and cost.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.3.2.5. RO 5.3e Comparison of non-breeder and breeder collision and displacement risk

If data exist on non-breeder behaviour, are available and accessible, and data quality is suitable for the purpose of this RO, this phase of work would explore these differences in terms of collision and displacement, and how behaviours differ between adults and immatures. Breeder behavioural information is also required to make this comparison.

As this is desk based, the resource requirements will be restricted in terms of time and cost.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.3.2.6. RO 5.3f Integration of non-breeders into collision and displacement impact assessments

This work is to synthesise the work of RO 5.3a to 5.3e on the ecology and behaviour of non-breeders to ensure the outputs can be utilised within impact assessments. This work will consider if current collision risk models and displacement assessments require adjusting to account for non-breeder behaviour, and if so, how. Required modifications will be made to assessment methods and tools.

As this is desk based, the resource requirements will be restricted in terms of time and cost.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.3.3. Benefits and outcomes

This RO should provide information on the behaviour of non-breeders (likely immatures only) relevant to collision and displacement. From this, the risk of non-breeders interacting with offshore wind developments can be analysed. It will inform whether changes to existing collision and displacement assessment methods are required, what these changes should be, or whether new non-breeder-specific models are needed. The relative risk of collision and displacement to non-breeders, compared to breeders, can be analysed from this, which will then inform how mortalities of non-breeders should be treated within PVAs.

4.3.4. Existing work, synergies, and risks

Multiple studies have been carried out and are ongoing to investigate behaviour of birds in response to offshore wind farms. Both the methods and outputs of such studies may be useful to review and explore how these may be adapted for non-breeders.

Work from this RO on increasing the accuracy of collision and displacement mortalities of non-breeders will inform how non-breeder mortalities are treated within PVA and hence has synergies with RO 5.5.

Synergies also exist with immature and sabbatical tracking research, whereby RO 5.1b, RO 5.2a and RO 5.3a could be jointly considered as part of the same data collation initiative (as likely involving sourcing and interrogating similar datasets and liaising with the same network of data holders). This would also provide a financial benefit, leading to reductions in overall project cost (approximately £30,000–40,000).

RO 5.3b and RO 5.3c on the feasibility and deployment of new tracking to better understand collision and displacement may be combined with RO 5.1c, RO 5.1d, RO 5.2b, and RO 5.2c on feasibility of and tagging of immature and sabbaticals to better understand distribution, should tagging for the purposes of distribution and behaviour be aligned.

Due to the challenges of acquiring data on sabbaticals at sea, it is likely that this RO will only be feasible for immatures only.

4.4. RO 5.4 Better understanding of the proportion of non-breeders within populations

4.4.1. Rationale

To understand the role that non-breeders play in populations, how this varies over time, and how they may be incorporated into impact assessments, a robust estimate of the proportion of non-breeders is crucial. Sabbatical rates are required to estimate the proportion of non-breeders at sea (as part of the baseline abundance stage of the impact assessment) and when estimating impacts on SPA populations (as part of the PVA stage). Not all UK-based species have estimates of sabbatical rates. Current understanding of the rates of non-breeding within adult populations is based on data obtained through different methods, using different definitions, and often based on locations outside of the UK.

At present, colony monitoring in the UK is focussed on breeding adults, and for most species actively excludes individuals that are not adults or apparently breeding. Information on non-breeders is sometimes noted, but current databases (such as the Seabird Monitoring Programme) do not allow for input of this data. Uncertainties in the presence of non-breeders leads to potentially inaccurate k-factor values used to convert individuals into breeding pairs, particularly for species that do not have clearly defined nests. Improving the scientific understanding of non-breeders would be beneficial for industries as well as seabird conservation purposes. Therefore, better monitoring and reporting of information on non-breeders is required.

This understanding will be fed into impact assessments within this RO through the generation of updated data on the proportion of non-breeders within populations. This would then feed into both the apportioning and PVA stages of the assessment, by providing more robust, up-to-date estimates of sabbatical rates, as well as empirical data to calculate population structures.

4.4.2. Work required and predicted resources

The first four of the sub-ROs described below are either desk-based or field-based studies. There is merit in both types of studies; indeed, both are recommended for the field-based measurements to validate the results of the desk-based studies. Field-based studies will take longer to obtain results; therefore, it is advisable that these are not postponed until the desk-based studies are complete. The process of generating rates of non-breeding is described in Figure 6.

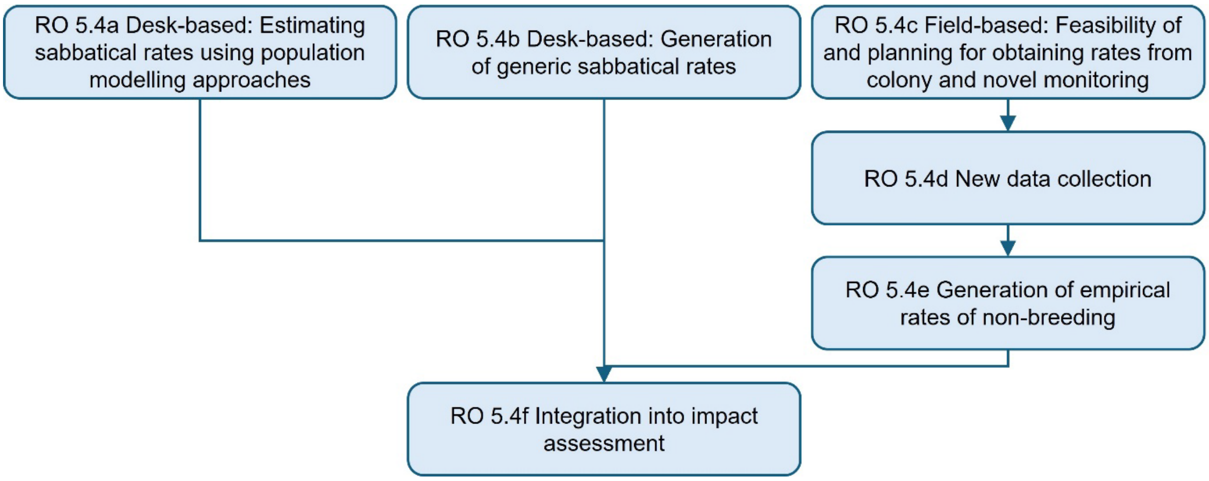

Figure 6. Order of RO 5.4 research.

4.4.2.1. RO 5.4a Desk-based: Estimating sabbatical rates using population modelling approaches

The first part of the RO is a desk-based study using colony count data and population modelling to estimate species-specific sabbatical rates. It would involve making use of, and adapting, existing population modelling frameworks, such as those developed by Glasgow University for kittiwake and gannet. As part of the ORJIP MetaKitti project, a UK-wide kittiwake meta-population model was developed, where “floaters” were estimated as a separate class of individuals (Matthiopoulos *et al.* 2025). In this context, floaters included both unrecruited immatures and adult sabbaticals. Number of floaters associated with individual colonies were inferred based on patterns in kittiwake breeding colony counts, their population trends (and uncertainty) were estimated, as well as their contribution to apparent population growth. For this sub-RO, adaptation of the Matthiopoulos *et al.* (2025a) model would be required to estimate typical non-breeding rates in kittiwake populations for adults separately. This work would then allow exploring spatial (colony) and temporal (yearly) patterns in sabbatical rates as well as potential drivers. A similar exercise may be conducted for gannet, building on the meta-population model developed by Jeglinski *et al.* (2023).

For other species, sabbatical rates might be inferred from modelling too; however, feasibility would need to be assessed first, based on availability and quality of colony monitoring data (e.g. counts, demographic rates, including long-term trends). New population models may need to be developed for those species. Ideally, these models would allow both immatures and adult sabbaticals to contribute to population growth. To tease out various sources of uncertainty, induced for example by how models are specified and parameterised, this work will test out a range of scenarios, for example different model structures and ranges of demographic rate values, to estimate a range of plausible sabbatical rates. Auks and Manx shearwater may be good candidate species, with likely best data to enable their modelling due to long-term colony monitoring. A population model developed by Glasgow University for Manx shearwaters on the Isle of Rum (Matthiopoulos *et al.* 2025b) may be used for this exercise. Crucially, feasibility of this exercise for a range of species would need to be undertaken through close engagement with population modelling and seabird ecology experts to identify key potential limiting factors (e.g. uncertainty in colony monitoring data, modelling assumptions, resources required).

This is therefore an indirect way to estimate sabbatical rates but is a starting point without the need for additional data collection. The output of this sub-RO is therefore modelled sabbatical rates (with associated uncertainty) for a range of species with sufficient data to enable robust parameter estimation. It will also provide details of species where there are insufficient or uncertain parameters to undertake this exercise. Species-specific sabbatical rate estimates inferred from this approach could then be compared with estimates generated from both life-history correlations (RO 5.4b) and field-based studies (RO 5.4c, d), providing some additional means of validating estimates from various sources.

Resource requirements will be variable depending on the scope the work. Familiarity with data of various types and format is required and experience of extracting, manipulating and combining data from disparate sources and in various formats is required. Experience of population modelling is essential.

Therefore, predicted resources for this sub-RO are moderate and can be variable, depending on the number of colonies and species considered and the extent to which existing modelling framework could be utilised (between £100,000 and £250,000).

4.4.2.2. RO 5.4b Desk-based: Generation of generic sabbatical rates

This RO would investigate life history characteristics of different species to make an expert judgement, potentially through expert elicitation, as to whether known sabbatical rates can be applied to other relevant species. This would be an indirect method of generating sabbatical rates (with associated uncertainty) without the need for additional data collection. If correlations between life history traits can be identified, it may be possible to generate generic sabbatical rates across similar species. Consideration should also be given to region-specific rates, and reasons for these, when generalising from other locations, as well to variation over time, due to, for example, effects of environmental conditions or acute mortality events. In this way, the environmental drivers of non-breeding would be investigated to gain better understanding of the variability in rates of non-breeding. This would be primarily focused on environmental variables and would not necessarily include factors such as loss of mates, loss of nest space and individual fitness. Furthermore, experts will be consulted to help formulate agreed standards around terminology, approaches and metrics when estimating sabbatical rates, to facilitate integration of information. Due to the current lack of evidence around sabbatical rates, this work would benefit from being reviewed and updated in the future, as new evidence is generated. This may also include the development of a framework for critically assessing and incorporating new evidence as it becomes available, as currently being explored for ornithology through the Offshore Wind Evidence and Knowledge Hub (OWEKH). Validation against empirically derived sabbatical rates will also be undertaken as part of update cycles.

As this is desk based, the resource requirements will be restricted in terms of time and cost. Ecological knowledge is required to compare across species.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.4.2.3. RO 5.4c Field-based: Feasibility of and planning for improving colony monitoring and use of novel technology to understand rates of non-breeding

This RO will focus on the improvements that could be made to existing colony monitoring to obtain better estimates of non-breeding rates (including for both immatures and sabbaticals), as well as other parameters such as non-breeder survival rates. This RO will explore improvements in colony monitoring techniques to gather better data on non-breeders, how much additional effort this would require and the feasibility of collating extra data. Recommendations will also be given as to updating monitoring guidance, such as the Seabird Monitoring Handbook (Walsh *et al.* 1995), to enable practitioners to implement such changes. One key element of this is the conversion factor used to take colony counts of individuals to breeding pairs, and how uncertainties in non-breeding numbers can be better estimated to get more accurate breeding pair counts.

This work is likely to require novel technologies, therefore will include a review of new colony monitoring techniques. For example, remote monitoring such as time lapse photography or video, and AI detection of species, which should be less intensive than, but complementary to, typical observer-based monitoring. Monitoring may be at the colony or at sea surrounding the colony for species that are known to aggregate at club sites and perhaps not return to land. The methods should explore the potential of the technology to identify breeding and non-breeding individuals (immatures, sabbaticals), and the biases associated with monitoring at or close to the colony, such as missing sabbaticals or immatures that do not return to the colony. The work should also include potential locations for where this may be feasible, how representative of other locations the data may be, the amount of effort required to develop the technology at the colony but also at scale, and the species to be covered. This work will also explore what alterations to databases would be required to enable data collected on non-breeders to be widely shared and made available, along with guidelines as to how the data has been collected and should be processed and interpreted. Additional recommendations on future database requirements would be needed. Candidate species likely include auks, kittiwake, fulmar, large gulls and gannet due to existing long-term monitoring of these species.

As this is desk based, the resource requirements will be restricted in terms of time and cost. Knowledge of existing and new technologies for monitoring seabirds at colonies is required.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.4.2.4. RO 5.4d Field-based: Deployment of improved colony monitoring and novel technology to understand rates of non-breeding

This work would deploy suitable novel technologies to obtain new or better estimates of non-breeding (immature and sabbatical) rates for several priority species, for which this is deemed feasible. The type of technology would be deployed on the species of relevance and monitored based on the outputs of RO 5.4c. A pilot phase may be required prior to wide scale roll out. On-going reviews of data collection and management processes, and how data is being used to inform conservation management in practice, would be required to ensure the database used to collate these data and accompanied guidance are fit for purpose and future-proof.

Resources required will be better understood based on the outcomes of RO 5.4c

The predicted resources for this sub-RO are high (several years and over £500,000), best achieved through collaborative approach.

4.4.2.5. RO 5.4e Field-based: Generation of rates of non-breeding, including variation in rates

Once improved colony monitoring, which may include novel technology, has been carried out, this work will synthesise the data to generate new empirically evidenced sabbatical and immature rates. Linking to RO 5.4b, experts will be consulted to help formulate agreed standards around terminology, approaches and metrics when calculating sabbatical rates, to facilitate integration of information. The work would include an investigation into the potential drivers of non-breeding to gain better understanding of the variability in rates. Important factors are likely to include environmental variables and effects of periodic mass mortality events and would not necessarily include factors such as loss of mates, loss of nest space, and individual fitness.

As this is desk based, the resource requirements will be restricted in terms of time and cost. Ecological knowledge required to compare across species.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.4.2.6. RO 5.4f Integration of rates of non-breeding into population viability analyses

This work is to synthesise the work of RO 5.4a to 5.4e on the rates of non-breeding (including both immatures and sabbaticals) to ensure the outputs can be utilised within impact assessments. This would generate up-to-date sabbatical rate estimates (with uncertainty) across a range of species, leading to updated recommended rates for use in assessments.

As this is desk based, the resource requirements will be restricted in terms of time and cost. Expertise in population modelling is required.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.4.3. Benefits and outcomes

The key outcomes of this RO are more accurate estimates of the rates of non-breeding across a range of species, and the variability in these rates. From understanding the numbers of non-breeders each year at risk from offshore wind, to understanding their role in population resilience, to modelling population-level impact of anthropogenic activities, an estimate of non-breeding rate is crucial to multiple stages of an impact assessment. Outcomes will include regular updates to proportions of non-breeders as well as other demographic parameters, for direct use in PVAs. Improved estimates may come from different methods across the sub-ROs; modelling, tagging, and colony monitoring, generating results across a range of timescales. RO 5.4a-b will generate relatively quick outputs. Empirical measures of non-breeding demographics from field studies will also be obtained through this RO, therefore whilst it may take more resources, time and money to undertake, the results will be a substantial improvement to our understanding of non-breeders.

4.4.4. Existing work, synergies, and risks

Some modelling frameworks are already available, which would enable the inference of sabbatical rates for some species, decreasing the burden of generating new modelling. There are population modelling tools such as the NE/JNCC PVA tool, and meta-population models generated for kittiwake and gannet by the University of Glasgow. Few long-term colony monitoring studies on immatures and sabbaticals exist. This work would aim to improve existing colony monitoring programmes and be complementary to them, rather than designing a new separate programme. Similarly, improvements in existing methods of disseminating data on seabird demographics and monitoring campaigns are to be explored, enhancing current tools rather than inventing new systems.

The outputs of this work will be complementary to the Scottish Government’s Marine Directorate’s funded project (in progress) “Identifying technologies for remote, long-term seabird population and demographic monitoring”, delivered by BTO, in collaboration with the National Trust for Scotland and the University of Gloucestershire. In addition, there are plans for analysing Manx shearwater sabbatical rates and the drivers of these rates by the University of Gloucester, which may feed into, and be complementary to, the work of this RO. There is a dependency between this RO and multiple others; sabbatical rates will aid planning tagging studies on sabbaticals (RO 5.2) and behaviour (RO 5.3 and RO 5.6) studies, as well as informing sensitivity analyses as part of RO 5.5. There is also the potential for corroborating estimates from various sources (RO 5.4a, b, e) to help validation.

A key risk to acquiring data on non-breeders from field-based studies is that an unknown proportion of immatures and adult individuals taking sabbaticals may not return to the colony (or surrounding sea area), therefore these will be missed from at-colony monitoring (i.e. some sabbatical albatrosses effectively remain permanently at sea during their sabbatical year (Weimerskirch *et al.* 2015)).

4.5. RO 5.5 Role of non-breeders in population persistence and their treatment in population viability analysis

4.5.1. Rationale

A key area of uncertainty is whether to include, and if so how to treat, sabbatical birds in PVA within impact assessments. This relates to the question of how important the pool of non-breeding adults is in determining the resilience of populations, for example in the context of external shifts (e.g. environmental change) and shocks (e.g. HPAI). The review of evidence in this report indicated that sabbaticals could provide a buffer to populations, and can very quickly fill gaps left by breeders, hence maintaining populations. Within the current NE/JNCC PVA tool, sabbaticals are not included as a separate class of individuals, hence their buffering effects against external pressures is not considered, and their mortality from OWFs cannot be modelled within PVA. The R package of the tool allows applying a sabbatical rate (which accounts for a proportion of adult birds that skip breeding within the population in a year), but this functionality is not available within the commonly used user-friendly PVA interface. There is also limited evidence to estimate robust sabbatical rates across species, which creates uncertainty in assessments.

Another area of uncertainty relates to assigning levels of impacts to different age classes within PVA. The application of stable age structures in population modelling is typically used to apportion OWF impacts to age classes proportionally to their relative representation in populations. This approach is based on theoretical population modelling assumptions that may not necessarily reflect site-specific age class compositions. In addition, the NE/JNCC PVA tool does not allow assigning differential mortality rates to individual immature age classes (a single mortality rate can only be applied across all immature age classes). It remains unclear how deviations from these approaches can influence population modelling outcomes.

The outcome of this RO is to generate guidance on how to treat non-breeders within PVA. Crucially, it will provide the evidence base to assess the relative importance of sabbaticals to population persistence and resilience. It will also provide recommendations on how to best account for OWF mortalities of different age classes and breeding status, and how to set up the population structure accounting for non-breeders. This will underpin the level of emphasis placed on assessing the mortality of non-breeders alongside breeders.

4.5.2. Work required and predicted resources

4.5.2.1. RO 5.5a Simulation of the role of sabbaticals in seabird populations

The first step within the RO is a simulation exercise to identify circumstances where sabbaticals are likely to have a more or less important role in population persistence. Here an age-structured demographic model would be created, which includes sabbaticals as a separate class of individuals contributing to breeding population sizes at various time steps. Then it is envisaged that the specific role of sabbaticals in population resilience in different contexts would be tested; for example, how do chronic vs. acute pressures on breeding birds affect overall population persistence when certain proportions of sabbaticals are included in the population. Identifying for example whether sabbatical rates need to be very high to have any noticeable impacts on the population trajectory in various contexts of pressures would be useful. Following this, the effect of these pressures on sabbaticals, and how this changes population responses, would be tested. The extent of the buffering effect in different contexts could also be investigated, as well as testing different starting population sizes and population trends.

As this is desk based, the resource requirements will be restricted in terms of time and cost. Population modelling experience is essential.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.5.2.2. RO 5.5b Sensitivity analyses

The next step within this RO is to run a series of sensitivity analyses to identify key demographic parameters that would need to be understood to be able to create a robust, ecologically realistic demographic model that includes non-breeders. A series of age-structured demographic models would be run by explicitly accounting for immatures and non-breeding adults as separate classes of individuals. As part of a first series of runs, proportions and demographic rates of sabbaticals would be varied sequentially, to determine at which point the value of these parameters makes a significant difference to predicted population size and help identify important parameters that have most influence. For example, how does the misspecification of sabbatical rates influence the outcomes of PVA? Sabbatical rates from the literature as well as those obtained under RO 5.4 would be used to inform the range of rates to be explored.

A separate series of sensitivity analyses would help determine whether different age class proportions and differential levels of mortality across age classes have an influence on population persistence. Different scenarios of age class distribution within populations could be investigated, using for example theoretical assumptions from the stable age structure (as currently done in impact assessments) and at-sea usage data from either DAS or tracking (building in the outcomes of RO 5.1). In addition, a range of impacts could be tested to further explore the sensitivity of mis-specifying impact levels across immature age classes on the population trajectory. Gannet may be a useful case study for this exercise as at-sea distribution data of immatures is more likely available (e.g. through tracking and DAS).

As this is desk based, the resource requirements will be restricted in terms of time and cost. Population modelling experience is essential.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.5.2.3. RO 5.5c Targeted collection of demographic data for population viability analyses

Should it be determined that there is insufficient or unsuitable data on the most important parameters for PVA, then this RO would explore the collection of this data. An exercise would first be carried out to assess the feasibility of collating new data, followed by targeted data collection, and eventually fed into PVA. It is crucial that population modellers and those undertaking the data collection work together to ensure usability of the data, and correct interpretation of the data.

The resource requirement for this RO is dependent on need. Should RO 5.5a and initial work within RO 5.5b conclude that existing demographic rates of non-breeders provide reasonable estimates to use as input parameters to population models, then there would be no requirement for this RO. However, should that prove not to be the case, which is likely for some species, then there may be a need for multiple years of data collation at multiple locations.

Therefore, predicted resources for this sub-RO are high (several years and over £500,000), best achieved through collaborative approach.

4.5.2.4. RO 5.5d Integration of non-breeders into population viability analysis

This work is to synthesise the work of RO 5.5a to 5.5c on the role of non-breeders in population persistence, to ensure the outputs can be utilised within impact assessments. This RO will investigate the need for either modification of existing PVA tools or developing a new model. Mortality of non-breeders may be included within new PVAs, particularly if it is the case that non-breeders are at a different risk compared to breeders due to offshore wind. A workshop with modelling experts may be required to understand currently available modelling frameworks, assess data availability and model requirements. A road map for implementation may be useful to prioritise steps to take.

As this is desk based, the resource requirements will be restricted in terms of time and cost. Expertise in population modelling is essential.

Therefore, predicted resources for this sub-RO are low (less than one year and less than £100,000).

4.5.3. Benefits and outcomes

This RO would provide information on the relative importance of different proportions of sabbaticals to population resilience. This will allow better understanding of the role of sabbaticals in different species, which will be useful for impact assessments but also wider understanding of population ecology and conservation efforts. Population modelling including sabbaticals would be a key output of this RO, enabling impact assessments to model population-level effects more accurately than is currently possible. Again, this will have wider benefits to analysing the impact of mortalities from other sources, and management of protected areas. New data collection covering demographic rates of sabbaticals will be undertaken for the first time, adding to our understanding of population dynamics.

This RO would also allow testing common assumptions around age class specific levels of impact and provide a quantitative assessment of how sensitive seabird population modelling outcomes are to misspecification of immature proportions within seabird populations as well as their mortality rates. This will help inform appropriate levels of precaution required when interpreting outputs from stable age structures and generate best practice guidance for how to treat immature mortality within PVA.

Investigating this on gannet using at-sea distribution data (see RO 5.1) would yield results that could be applied in future apportioning and population model processes within an impact assessment for that species.

4.5.4. Existing work, synergies, and risks

Some modelling frameworks are already available, which would enable the modelling of sabbaticals, decreasing the burden of generating new modelling. This includes for example work in the Netherlands undertaking cumulative assessment PVAs at regional scales, and the ORJIP MetaKitti meta-population tool which considers “floaters”.

Expert elicitation (RO 5.4b) conducted alongside the RO 5.5 modelling exercise would provide a cost-effective way to generate new, up-to-date estimates of sabbatical rates for a range of species, therefore refining the range of parameter values to be modelled as part of this simulation work.

4.6. Appendix: RO 5.6 Seabirds’ behavioural response to artificial light

An RO on seabirds’ behavioural response to artificial light is provided as an Appendix to this report.

The topic of seabirds’ behavioural responses to artificial light was discussed by academics, technical experts and Key Stakeholders at the non-breeding bird workshop in September 2025. Light attraction, disorientation and avoidance are well-recognised issues for several seabird species, particularly nocturnal burrow nesting seabirds such as Procellariiformes (Deakin *et al.* 2022). Whilst juvenile birds appear to be highly susceptible to light-induced behavioural change, several critical knowledge gaps are pertinent to all age classes. Moreover, it remains unclear to what extent lighting effects differ between immature and adult birds (Deakin *et al.* 2022). This is therefore an important knowledge gap for both breeding and non-breeding seabirds, and there are efficiencies to be made by addressing this issue across age groups.

RO 5.6 is presented as an appendix to the main KG5 report in acknowledgement of the fact that this knowledge gap does not solely apply to non-breeding birds. The outputs of this RO will however help improve understanding of non-breeder (i.e. immatures) sensitivity to artificial lighting, as well as possible lethal and sub-lethal consequences from collision, displacement and barrier effect. Novel evidence will then be used to inform how non-breeder mortalities should be treated within the Population Viability Analysis stage of impact assessments.

5. Synergies and overarching notes

The present report outlines a list of six Research Opportunities (ROs) which, either alone or in combination with other project ideas, will improve our understanding of the at-sea distribution of non-breeders, their behaviour in relation to offshore wind farms, the proportion of the whole population that they make up, and their role in seabird populations.

Due to current levels of uncertainty around how to treat non-breeders in offshore wind impact assessments, especially within HRAs, an important place to start would be to develop an understanding of the importance of both immatures and sabbaticals in population responses to OWF impacts. This would explore for example what influence mis-specifying sabbatical rates and immature mortality impacts has on population outcomes, as described under RO 5.5. This approach would therefore provide a framework for inclusion of non-breeders in impact assessments, for example through developing or adapting appropriate tools to accommodate the specification of different age classes and breeding status.

Acquiring better evidence on sabbatical rates across species, and how they may vary over time, is another priority area as this would reduce uncertainty in both the apportioning and population modelling stages of the impact assessment process. To do so, desk-based studies and expert consultations (RO 5.4a, b) have the potential to yield new evidence in a reasonable timeframe. While developing and implementing colony monitoring programmes at scale (RO 5.4c, d) will take longer to deliver, empirical evidence from field studies would help validating estimates of non-breeding rates acquired through other means for a range of species. Exploring the feasibility of such large-scale monitoring programme (RO5.4c) would seem important in the first instance.

In the medium term, improving our understanding of at-sea distribution of immatures and sabbaticals (RO 5.1, RO 5.2) would seem valuable, followed by better understanding at-sea behaviour and how this may influence risk of collision and displacement (RO 5.3, RO 5.6). All four of these ROs (RO 5.1–5.3, RO 5.6) are highly reliant on obtaining access to existing tracking data or deploying new tracking studies; therefore, feasibility assessments should be undertaken first (RO5.1a-b, RO5.2a, RO5.3a and RO5.6a), while maximising synergies between ROs (e.g. datasets could be searched for immatures, sabbaticals, distribution and behaviour all at a time). Developing and implementing new tracking programmes, if required, is a longer-term aspiration and would need to be undertaken strategically; opportunities for collecting data to inform several components of RO 5.1, RO 5.2, RO 5.3 and RO 5.6 would need to be sought.

These recommendations are presented in Figure 7 below.

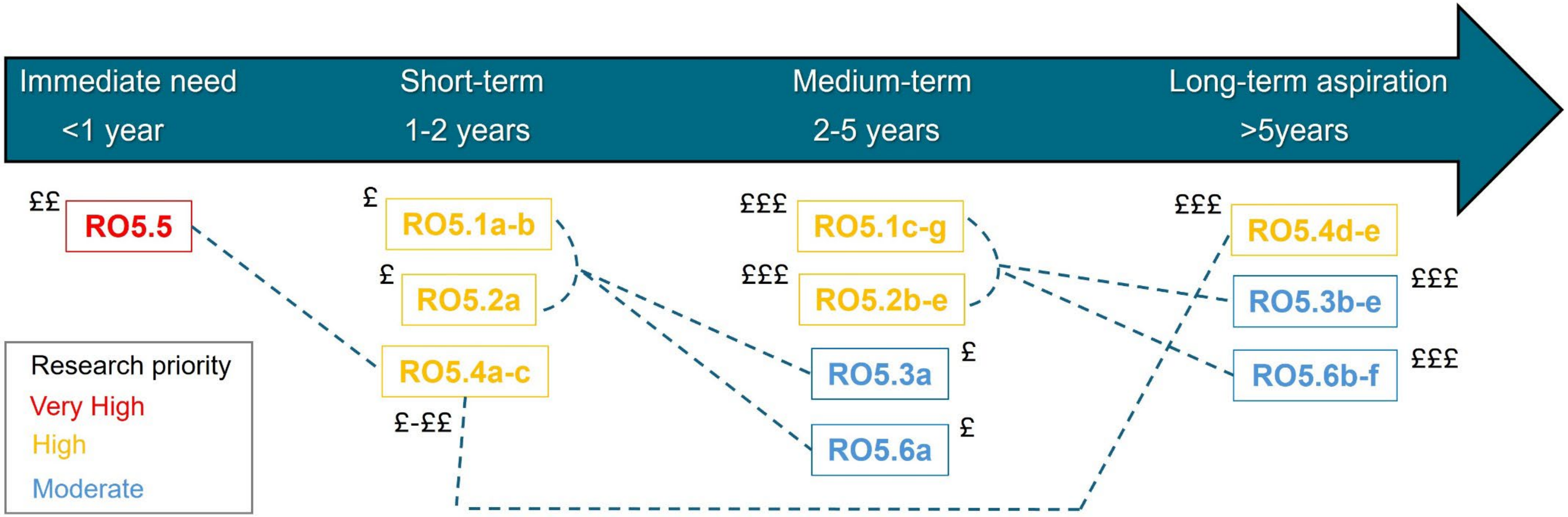

Figure 7. Synthetic diagram presenting each of the six Research Opportunities (ROs) in terms of their level of priority (very high, high, moderate), timescale (immediate, short-term, medium-term, longer-term) and indicative budget (low < £150,000, medium £150,000–300,000, high > £300,000). The integration of new evidence into impact assessments (not captured here) is a final and vital step across all ROs, and will become possible as/when new evidence is delivered. Dotted lines indicate where synergies between ROs may lie, leading to reductions in overall project costs.

6. Conclusion

A review of the literature of non-breeders suggests that they can play a role in the maintenance of seabird populations, yet detailed information about their distribution, behaviour, and even their abundance is lacking, particularly for species found within the UK. To understand and estimate the potential impact of offshore wind farms on non-breeders, and hence the wider population, better data collection is required on several topics.

The distribution of non-breeders has been studied for species largely occurring outside the UK, such as albatrosses and skuas, but that of UK non-breeders is largely unknown. Similarly, the behaviour of non-breeders, and how this may influence their risk of collision or displacement requires further data collation. Without these key pieces of information, estimates of the mortality of non-breeders due to OWFs will remain unknown, or at least assumed to be the same as successful breeders. Research on a few UK seabird species, with sufficient sample sizes, addressing several behavioural and distributional traits is required.

Incorporating non-breeders into population models has been done on occasion throughout the literature (Aebischer & Wanless 1992; Penteriani *et al.* 2005, 2008; Potiek *et al.* 2022). However, vast assumptions are often made, and current data is lacking to carry out a robust population model on UK species. Better data on UK species covering a range of vital rates, and even the proportion of a population that is non-breeding is essential to progress the generation of population models. An understanding of how important these parameters are to modelling, and where data collection is best targeted is also required to ensure efficient and effective research.

This report sets out a series of six potential Research Opportunities, which were suggested and discussed amongst a consortium of experts on seabird ecologists. These projects are seen as part of a dynamic process to improve understanding, either working synergistically or undertaken in sequence to contribute to subsequent ROs. Although these ROs work together and inform each other, they could in theory be approached as separate pieces of work, but some could not be delivered without the outputs of previous ROs. By and large, however, each of the ROs presented in this report represent a single coherent piece of work of varying resource requirements. Many are entirely desk-based (e.g. analysis of existing of data), but there are several which involve further data collection. This represents an appropriate balance between making the most of any data that are collected or already available, and where required, collecting additional data to answer the questions that are unable to be fully addressed with existing data.

The intention is that this report represents a reference resource, laying out current understanding of non-breeders in seabird populations and key evidence gaps in the context of offshore wind impact assessments. It also provides a signpost towards research that can contribute to reducing uncertainty around apportioning of offshore wind impacts and modelling population outcomes. Altogether this research will contribute to overall reduced uncertainty in offshore windfarm impact assessments for seabirds. Improving understanding of non-breeders in seabird populations is becoming more important in the context of offshore windfarm expansion further offshore and the impacts of extrinsic pressures such as climate change and periodic mass mortality events. Incremental reductions in uncertainty through research will facilitate meaningful and precise cumulative impact assessments, therefore maximising the potential for sustainable marine development within the limits set by environmental protection and regulation.

7. Acknowledgements

Thanks to the OWSMRF III Developer Group for funding work under KG5, including the workshop and production of this report: EDF power solutions UK and Ireland, Equinor, Ørsted, Scottish Power Renewables, SSE Renewables and TotalEnergies.

Thanks to all those who attended the workshop and/or have provided helpful comments on earlier versions of this report: Emma Ahart (Ørsted), Magali Colin (Total Energies), Emily Nelson (SSER), Christopher Robinson (SPR), Polly Tarrant (EDF power solutions UK and Ireland), Reinier Zountenbier (Equinor), Sophy Allen (Natural England, NE), Orea Anderson (JNCC), Saskia Bloor (Natural Resources Wales, NRW), Jenny Coomes (Scottish Government's Marine Directorate, MD), Francis Daunt (UKCEH), Alice Edney (National Trust for Scotland, NTS), Tom Evans (RSPB), Kirsty Franklin (RSPB), Andrew Harwood (NE), Mark Jessopp (University College Cork), Anna Lowden (MD), Liz Morgan (NTS), Astrid Potiek (Waardenburg Ecology), Alex Robins (NatureScot), Helen Rowell (NRW), Aurore Ponchon (IRD), Bethany Smith (NatureScot), Paul Thompson (University of Aberdeen) and Matt Wood (University of Gloucestershire). Thanks to others who have provided support and input along the way: Sophie Bennett (BTO), Katherine Booth-Jones (MD), Liz Humphreys (BTO), Aly McCluskie (RSPB), Nina O'Hanlon (BTO) and Julie Miller (MD).

Thanks also to Bryony Baker (JNCC) for facilitating discussions at the workshop and reviewing a draft version of the report, Olivia Martin (JNCC) and Mairi Hilton (JNCC) for taking copious notes at the workshop, Jackie Kelly (JNCC) for taking notes and managing OWSMRF contracts, Mary Anna Fowler (JNCC) for her help in OWSMRF III development, and Helen Baker (JNCC) for her continuous support.

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9. Glossary and list of abbreviations

Table 4. Glossary of terms.

Term	**Definition**
Age class	A group of individuals from the same species that are of similar age.
Breeder	An adult bird of breeding age that attempts to breed in a given year.
Non-breeder	A bird, either sexually mature or not, that does not breed in a given year, as opposed to birds during the non-breeding season.
Immature	A bird that is not yet physiologically mature and has not reached breeding age. This category encompasses both early years immatures (or juveniles) and older immatures (or sub-adults or pre-breeders)
Sabbatical bird	An adult bird that does not attempt to breed in a particular year but may attempt to breed in subsequent years.
Failed breeder	An adult bird that did attempt to breed but failed to produce offsprings.

Table 5. List of abbreviations.

Term	**Definition**
AON	Apparently Occupied Nest
AOS	Apparently Occupied Site
CRM	Collision Risk Model
DAS	Digital Aerial Survey
DG	Developer Group
EIA	Environmental Impact Assessment
GW	Gigawatts
HRA	Habitats Regulations Assessment/Appraisal
InTAS	Integration of tracking and at-sea survey data
INTOG	Innovation and Targeted Oil & Gas
JNCC	Joint Nature Conservation Committee
KG	Knowledge Gap
MD	Marine Directorate
NE	Natural England
NRW	Natural Resources Wales

Term	Definition
NS	NatureScot
NTS	National Trust for Scotland
ORJIP	Offshore Renewables Joint Industry Programme
OWEC	Offshore Wind Evidence and Change
OWEER	Offshore Wind Environmental Evidence Register
OWEKH	Offshore Wind Evidence and Knowledge Hub
OW	Offshore Wind
OWF	Offshore Wind Farm
OWSMRF	Offshore Wind Strategic Monitoring and Research Forum
ProcBe	Procellariiform Behaviour and Demographics
PVA	Population Viability Analysis
RO	Research Opportunity
RSPB	Royal Society for the Protection of Birds
SNCB	Statutory Nature Conservation Body
SPA	Special Protection Area