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Better linking effects of offshore windfarms on black-legged kittiwakes to populations

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Summary

This report presents a summary of existing evidence, and potential research opportunities, to inform assessment of the linkage of offshore windfarm effects on black-legged kittiwakes to appropriate populations (including Special Protection Areas (SPAs)). This work has been undertaken on behalf of The Offshore Wind Strategic Monitoring Research Forum (OWSMRF) (https://jncc.gov.uk/our-work/owsmrf/). OWSMRF is an industry-led collaborative forum that aims to identify and develop research to fill critical knowledge gaps in our understanding of the impact of offshore wind development on the marine environment.

OWSMRF stakeholders identified cumulative impacts on kittiwakes as the priority need for improving understanding of offshore windfarm environmental impacts. Improving understanding of connectivity between OWF and SPA populations was identified as one of the key knowledge gaps in this area (the other two being: reducing uncertainty around estimates of collision mortality and developing a tool to facilitate cumulative effects assessment). JNCC organised an expert workshop to help understand what research might help to reduce uncertainty in this connectivity. This report provides a summary of existing, relevant, research and evidence, and research opportunities that were discussed during the workshop.

The research opportunities (ROs) suggested as potentially very useful and discussed during the workshop are:

RO2.1: extending a draft apportioning tool that has been developed for Scottish waters (by CEH and RSPB, on behalf of Marine Scotland) into UK waters. This tool uses species distribution predictions based on GPS tracking data presented in Wakefield *et al*. (2017) to provide quantitative apportioning of birds seen within a windfarm footprint to source colonies (for four species including kittiwake). This project would use the code developed for the existing (Scottish waters) tool and the UK-wide work of Wakefield *et al*. (2017) to extend the tool across UK waters.

RO2.2: macro-analysis of existing data to identify spatial and temporal patterns in migration movements. This project uses a collation of currently available data and products from various sources (both at-sea and tracking data types, and distribution map products). These data would be analysed to assess broad latitudinal movements and timings of migration, to indicate the extent at which cumulatively, kittiwakes are interacting with multiple windfarm zones and footprints during different seasons.

RO2.3: strategic (non-GPS) tracking feasibility study. This project would explore the feasibility of, and practicalities around, using smaller lighter and less expensive means of tracking than GPS devices. This would include consideration of VHF radio tracking, Passive Integrated Transponder (PIT) devices and/or colour ringing. If deployed at scale across the UK, this would provide information on linkages between multiple wind farms and colonies (in similar way to existing GPS tagging studies, but over a longer time period, covering many more individuals, at much larger spatial scale, and including the non-breeding season) and on linkages between colonies over time (e.g. do kittiwakes move from one colony to another across years). This RO would also provide synergies with improved understanding of windfarm-induced mortality, and demographic rates for estimating population impacts of windfarm effects.

RO2.4: catching kittiwakes at sea; proof of concept and guidance. This project is a combination of desk-based and at-sea studies which would explore approaches and methods for catching kittiwakes at sea, sampling/device attachment/data collection options, potential biases and other issues to be aware of. It would combine a literature review and

contacting seabird catching experts to learn lessons, and a trial of catching kittiwakes at sea to test lessons and assumptions, and production of guidance for catching of kittiwakes at sea for data collection/device attachment purposes. This would facilitate a more windfarm focussed approach to collection of movement/linkage data, leading to efficiencies and reduced uncertainty in linking windfarm effects to relevant populations.

RO2.5: citizen science to provide age structure information of kittiwakes, both along the coast and at sea. This RO would use citizen science to improve evidence for assessing what proportion of birds seen at a windfarm footprint (and/or potentially affected by a windfarm) are adults. This would allow potential windfarm effects to not only be apportioned to the appropriate population (e.g. colony) but also to the appropriate age-class within each population.

Several of these research opportunities would complement each other, and combined, could lead to real change in the way windfarm effects are apportioned to colonies and populations, and significantly reduce uncertainty in assessments of cumulative impacts on kittiwake from offshore windfarm deployment.

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1 Knowledge gap

Offshore wind farms (OWF) are seen as a key part of efforts to combat climate change (Cook *et al*. 2018; Snyder & Kaiser 2009). However, there are a number of significant concerns about the potential of these wind farms to have a negative impact on wildlife and biodiversity, particularly in relation to birds (Drewitt & Langston 2006; Gibson *et al.* 2017). To inform the planning process of the potential impacts of the effects associated with wind farms, detailed Environmental Impact Assessments (EIAs) and Habitats Regulations Appraisal (HRA) are required. EIAs assess impacts to the wider environment, whilst HRAs assess whether a plan or project will have an adverse effect on a Natura 2000 site protected under either the European Commission's Habitats Directive (Directive 92/43/EEC) or Birds Directive (2009/147/EC))

As the number of wind energy developments increase globally both onshore and offshore, the potential associated environmental impacts are receiving considerable attention, particularly avian impacts. This is of particular concern at the cumulative scale, i.e. considering impacts of windfarms combined rather than of individual developments in isolation.

As the scale of offshore windfarm development expands, the risk of reaching unacceptable levels of cumulative impacts increases. In order to undertake meaningful cumulative impact assessments, there is a need for improved understanding of how birds respond to offshore windfarms and how to quantify the risk to populations of concern. Without such information, decision making is necessarily precautionary, and there is a risk that offshore windfarms may not be deployed at sufficient scale to contribute fully to emission reductions targets and ambitions.

The potential impacts of wind farms on bird populations can be grouped into three main types:

i) collision mortality;
ii) displacement and attraction effects and;
iii) barrier effects (e.g. Cook *et al*. 2018; Vanermen *et al*. 2015).

As part of the impact assessment process, the likely effects (e.g. collision and/or displacement effects) of a proposed windfarm on birds are estimated. Once the magnitude of these effects have been estimated, it is necessary to understand which SPA colonies (if any) these affected birds originate from, in order to then be able to assess the impact of these effects on the SPA population (for HRA assessments) and/or which wider population these affected birds are part of (for EIA assessments). Finally, population modelling is frequently used to evaluate the likely population response to reductions in survival or productivity predicted to occur, once the scale of effect and population linkages have been established (Cook *et al*. 2018).

1.1 OWSMRF background

The Offshore Wind Strategic Monitoring Research Forum (OWSMRF) (https://jncc.gov.uk/our-work/owsmrf/) is an industry-led collaborative forum that aims to identify and develop research to fill critical knowledge gaps in our understanding of the impact of offshore wind development on the marine environment. OWSMRF was initiated by JNCC and six offshore wind developers: EDF-Renewables, Equinor, Innogy, Ørsted, Scottish Power Renewables, and Vattenfall.

The OWSMRF Developer Group agreed to support an initial pilot year during which the focus was on ornithology issues. Key stakeholders were asked to identify which species and knowledge gaps they saw as currently posing the greatest uncertainty in impact assessments for offshore wind development, and most likely to lead to uncertainty in decision making around offshore windfarm consenting in the next few years.

1.2 The OWSMRF process

OWSMRF uses a collaborative process to identify knowledge gaps and research opportunities to fill those gaps. The process involves consulting OWSMRF key stakeholders (RSPB, Natural England (NE), Scottish Natural Heritage (SNH), Natural Resources Wales (NRW), Marine Scotland Science (MSS)) on what species and knowledge gaps currently pose greatest consenting risk to offshore wind development in the near future. Following a review of what is already known about the species and evidence base, academics and other experts are invited to suggest research that would address those knowledge gaps. Finally, the key stakeholders are invited to review the proposed research opportunities, providing feedback on which they see as most beneficial. Offshore wind developers who are funding OWSMRF observe the whole OWSMRF process. This feasibility review describes one of the knowledge gaps identified by OWSMRF stakeholders (reducing uncertainty around linking kittiwakes seen within a windfarm footprint to SPAs and wider populations) and relating to this knowledge gap it provides a review of the current evidence base and a list of research opportunities to fill the knowledge gap.

1.3 OWSMRF Pilot Year

At a meeting on 2 May 2019, OWSMRF key stakeholders agreed that uncertainty around in-combination and cumulative impacts of offshore wind development on black-legged kittiwake (*Rissa tridactyla*) populations currently posed the greatest uncertainty.

Three priority knowledge gaps (KG) to inform cumulative/in-combination assessments were identified:

– KG1: reducing uncertainty around estimates of windfarm collision mortality;

– KG2: improving understanding of connectivity between OWF and SPAs;

– KG3: development of a CEA (cumulative effects assessment) database to facilitate efficient, standardised and transparent cumulative effects assessments.

The CEA effects database was decided by OWSMRF to be better pursued via other avenues, and a new project under KG3 is being developed which will look at improving confidence in modelling population consequences of windfarm effects.

1.4 How effects are attributed to interest features of SPAs

The second knowledge gap (KG2) relates to improved understanding of which SPAs and wider population(s) kittiwakes from a windfarm footprint interact with (and should be attributed to during impact assessment). As offshore wind deployment accelerates, each population may interact with several windfarms and therefore be at risk of in-combination effects across several windfarms. Kittiwakes may interact with other human activities further increasing their risk of cumulative effects, however the work described in this report focuses on improved understanding of offshore windfarm-related effects. Given the wide-ranging nature of seabirds such as kittiwake, it is not always clear how many of the individuals interacting with a particular windfarm are from which population (e.g. SPA). Although there may be tracking data available from large nearby colonies showing whether breeding birds from the colony use the windfarm footprint, this kind of data is not on its own sufficient to allow an assessment of the proportion of birds affected by a particular windfarm that are from a/each relevant colony. Therefore, empirical evidence regarding the provenance of kittiwakes at sea is needed to inform approaches to apportioning effects on individuals observed using a windfarm footprint to appropriate SPAs (and wider populations). This is recognised as a problem for many wide-ranging ocean species, and understanding of connectivity is critical to ensuring management measures are appropriate for the level of risk associated with different degrees of connectivity (Dunn *et al*. 2019).

This feasibility review aims to identify a set of potential research projects that could be undertaken in the very near future to reduce uncertainty in apportioning of effects seen at a windfarm to relevant populations in both the breeding and non-breeding seasons. It follows on from previous work looking to identify research priorities for improved understanding of ornithological issues relating to the expansion of the UK offshore wind industry, such as the Strategic Ornithological Support Services group (SOSS, https://www.bto.org/our-science/wetland-and-marine/soss) and Collaborative Offshore Wind Research into the Environment (COWRIE), and more recently, commissioned summaries of research needs e.g. (Furness 2016) and the Scottish Marine Energy Research (ScotMER) evidence maps (https://www2.gov.scot/Topics/marine/marineenergy/mre/research). This review is informed by discussions with ecological consultants, SNCBs and academic/kittiwake/seabird research experts.

In August 2019, JNCC organised an expert workshop to help understand what research might be most useful to help improve understanding of linkages between kittiwake populations and windfarm footprints. This workshop, in Glasgow, was attended by: Bob Furness (MacArthur Green), Francis Daunt (Centre for Ecology and Hydrology), Ewan Wakefield (University of Glasgow), Saskia Wischnewski (RSPB), Aly McCluskie (RSPB), Verena Peschko (Kiel University), Tom Evans (Marine Scotland), Alex Robbins (Scottish Natural Heritage), Martin Kerby (Natural England), Mark Trinder (MacArthur Green) as well as several OWSMRF stakeholders and members of the OWSMRF developer group.

During the workshop, several stakeholders presented summaries of existing relevant evidence and ongoing research and needs in terms of providing statutory advice to decision makers on environmental impacts of windfarms, specifically relating to this knowledge gap. Experts were then invited to summarise the knowledge gaps and produce a list of possible research ideas that could help to address these gaps. After discussion, a selection of these ideas was then discussed further in order to provide additional detail regarding what a research project might involve, risks and limitations *etc*. JNCC then used the outputs of this workshop, in combination with further discussion as required to fully understand each research opportunity, to inform this report.

2 Existing evidence and understanding

As stated above, this report looks at evidence requirements for establishing (and if possible, quantifying) a linkage between predicted seabird effects from individual windfarms and populations of origin (i.e. are birds observed at a footprint coming from an SPA or other population of interest, and if so in what proportion). This section summarises the existing evidence base on black-legged kittiwake movement ecology relevant to this question, as well as the approaches and tools available to attribute kittiwakes seen at a windfarm footprint to appropriate SPAs or wider populations. This covers both colony-focused approaches (e.g. GPS or geolocator tagging of breeding individuals from the colony) as well as (if appropriate) windfarm-focused approaches (establishing provenance of birds captured or observed within a windfarm footprint).

There may be effects of a windfarm on kittiwakes at all times of year, and on juvenile as well as adult birds. During the assessment process emphasis is placed on effects which may impact on an SPA population, and hence there is a heavy focus on linkage of windfarm effects to SPAs (most kittiwake SPAs in the UK are colony focussed) and on breeding adults. However, there is increasing recognition that effects which might impact on the wider population are of concern, especially within the context of cumulative effects, and that effects to juveniles, non-breeders and to breeding adults outside of the breeding season, can have knock-on consequences for SPA populations. Thus, we are also interested in evidence which provides this linkage across the population and seasons.

2.1 Summary of existing evidence base

2.1.1 Foraging distribution of black-legged kittiwakes during the breeding season

At-sea distribution of seabirds is commonly assessed using two approaches: 1) transect-based surveys, which provides a reasonable understanding of the distribution of all birds observed in the survey area but no information on their origin, and 2) tracking movements of a sample of birds tagged at colonies, which gives detailed at-sea usage information of birds from those colonies, but not the wider seabird population. The value of combining these two complementary sources of information is well recognised.

Kittiwakes are a pelagic species, with a patchy distribution further offshore (Wakefield *et al*. 2017). In the UK, they primarily forage within 100km of the coast (Wakefield *et al*. 2017), with a mean max (i.e. the maximum range reported in each study averaged across studies) foraging distance from colony currently estimated as 60.0km (+/- 23.3 SD) (Thaxter *et al.* 2012). Such estimates of generic foraging ranges are being updated as part of an ongoing refresh of foraging ranges based on more recent evidence, being undertaken by NiRAS and BTO on behalf of The Crown Estate.

With the FAME and STAR tracking projects, the RSPB has collected a substantial amount of GPS tracking data on UK breeding adult kittiwakes. Predicted at-sea distribution maps of breeding adults have been produced for UK waters based on habitat modelling approaches applied to GPS tracking data (Wakefield *et al*. 2017) (Figure 1). These are distributions across UK colonies, derived from kittiwake colony-specific foraging distributions across the UK (n = 20 colonies), which were then combined to provide UK maps of foraging distribution.

These showed:

- Scotland: importance of areas along the entire east coast of Scotland + areas around the coast of Shetland and the Hebrides
- England: importance of areas off the coast of Yorkshire (southeast of Flamborough Head) and the northern Norfolk Banks
- Ireland: importance of central Irish Sea and Galway Bay (west of Ireland)

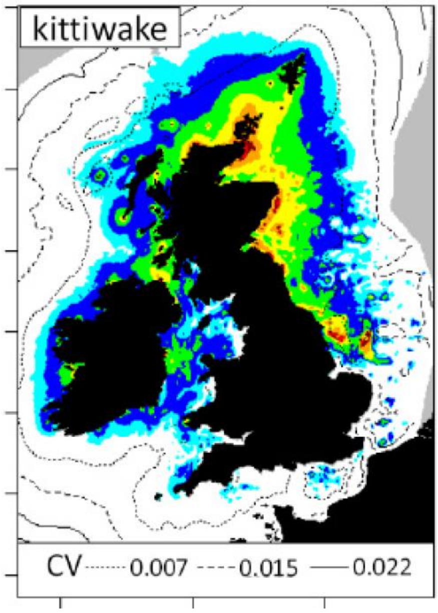

Figure 1. Predicted foraging distribution of adult breeding kittiwakes in UK waters based on RSPB tracking data (Wakefield *et al*. 2017).

Based on these GPS tracking data, Wakefield *et al*. (2017) identified density-dependent competition close to colonies and predicted that, during the breeding season, immature birds most likely avoid these areas due to competition with (more experienced) breeding adult birds (Wakefield *et al*. 2017).

The RSPB have also produced UK and SPA-level hotspot maps using the FAME and STAR project tracking data (Cleasby *et al*. 2018). UK-level hotspot maps were conducted for each SPA independently in which a given species – e.g. black-legged kittiwake – was listed as a feature, and then individual SPA outputs were merged to create a single, combined SPA hotspot map across the UK (Figure 2). These hotspot maps are based upon established techniques for deriving hotspots from density data for the purposes of delineating potential Marine Protected Areas (e.g. Kober *et al.* 2012).

These predicted distribution maps apply only to breeding adults from UK colonies; therefore, a large part of the UK population and populations from further afield are excluded. This is important to consider when using these maps to apportion effects to the wider population, particularly at times of year or locations when/where immatures, failed breeders or breeding sabbaticals (i.e. adults birds skipping a breeding year) are likely to make up a large part of the birds observed at a development site. With this in mind, it is recognised that gaining a better understanding of the behaviour and distribution of non-breeders is crucial.

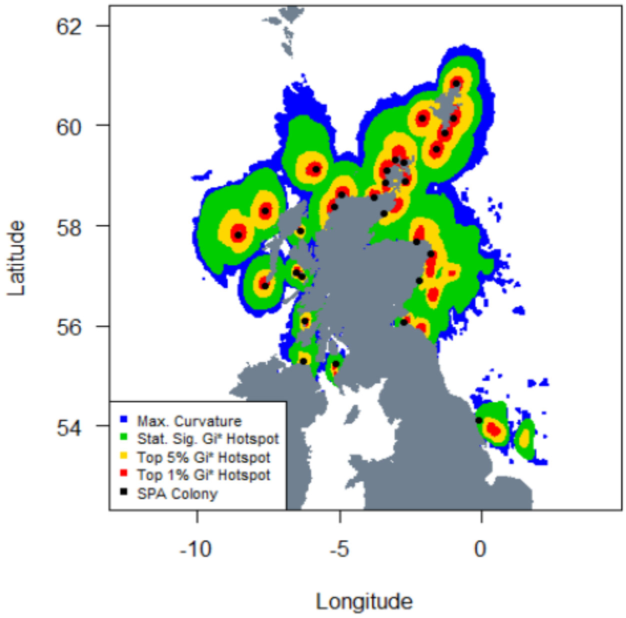

Figure 2. Predicted hotspots of all kittiwake SPA colonies in the UK based on RSPB tracking data (Cleasby *et al*. 2018).

The RSPB have also collected extensive tracking data from the Flamborough and Filey Coast SPA, which can provide useful information relevant to windfarms in the southern North Sea. For example, these data show that there is an increase in kittiwake foraging ranges over the course of the breeding season (from hatching to chick-rearing), which can be useful when considering likely effects across the breeding season and in understanding when the greatest risk period is.

The Marine Ecosystem Research Programme (MERP) has produced predicted monthly distribution maps of 11 seabird species, including kittiwakes, based on long-term time series of at-sea survey data in the North Sea (Waggitt *et al.* 2019). Distribution maps of cetaceans and seabirds at basin and monthly scales are needed for conservation and marine management. These are usually created from standardised and systematic aerial and vessel surveys, with recorded animal densities interpolated across study areas. However, distribution maps at basin and monthly scales have previously not been possible because individual surveys have restricted spatial and temporal coverage. This study develops an alternative approach consisting of:

1) collating diverse survey data to maximise spatial and temporal coverage;
2) using detection functions to estimate variation in the surface area covered (km^2) among these surveys, standardising measurements of effort and animal densities; and
3) developing species distribution models (SDM) that overcome issues with heterogeneous and uneven coverage. 2.68 million km of survey data in the North-East Atlantic between 1980 and 2018 were collated and standardised.

SDM using Generalized Linear Models and General Estimating Equations in a hurdle approach were developed. Distribution maps were then created for 12 cetacean and 12 seabird species at 10km and monthly resolution. Qualitative and quantitative assessment indicated good model performance. Synthesis and applications. This study provides the largest ever collation and standardisation of diverse survey data for cetaceans and seabirds, and the most comprehensive distribution maps of these taxa in the North-East Atlantic. These distribution maps have numerous applications including the identification of important areas needing protection, and the quantification of overlap between vulnerable species and anthropogenic activities. This study demonstrates how the analysis of existing and diverse survey data can meet conservation and marine management needs (Waggitt *et al.* 2019). In contrast to maps derived from tracking data, these predicted distributions will include non-breeding individuals such as immatures and adults taking a sabbatical. However, the origin of birds observed at sea cannot be inferred from these at-sea survey data.

Overall, most of the existing data on at-sea distributions of kittiwakes in recent years has been collected using GPS devices attached to breeding adults, and with a bias towards the late-incubation and chick-rearing periods. Some information on foraging distribution and/or ranges of breeding adults during incubation and hatching exists, but there is very little information on pre-laying, post-fledging, failed breeders, sabbatical breeders and non-breeders (including immatures). In contrast, there is a wealth of older, at-sea survey data from the European Seabirds at Sea (ESAS) database (e.g. Kober *et al.* 2012) that include all birds regardless of breeding status, across months and seasons (note that there have been only few recent additions to the database maps since the publication of the Kober *et al*. 2012 report). To date the ESAS database contains data from over 750 cruises, representing transects of approximately 525,000km in length (over 13 times around the world at the equator) with a total count of roughly 3.5 million seabirds and cetaceans. It is the largest offshore seabird database in the world. This kind of data can provide distribution patterns during the breeding season (and other seasons) that includes all kittiwakes including immatures, failed breeders or breeding sabbaticals. A comparison of this kind of at-sea data with data which is exclusively collected from breeding adults (such as the GPS data described above), can indicate the extent to which immatures, failed breeders or breeding sabbaticals have a similar, or different, distribution, from breeding adults (Carroll *et al.* 2019; Sansom *et al.* 2018).

2.1.2 Distribution of kittiwakes during the non-breeding season

Kittiwakes range widely across the North Sea and the Atlantic outside the breeding season (Bogdanova *et al*. 2017, 2011; Frederiksen *et al*. 2012; see also SEATRACK online database http://www.seapop.no/en/seatrack/). Two main wintering areas have been identified for adult kittiwakes breeding in the UK: east Atlantic/North Sea and west Atlantic (Bogdanova *et al*. 2017, 2011; Frederiksen *et al*. 2012). Tracking of breeding adults with light geolocators across the North Atlantic indicate that most birds that winter in the North Sea are either of local origin (i.e. three colonies tracked in the North Sea: Fair Isle, Bulbjerg and the Isle of May) or the Barents Sea (i.e. Bear Island, Cape Krutik, Hornøya, Hjelmsøya), with a relatively small proportion of birds also coming from the Norwegian Sea and the Celtic-Biscay Shelf (Frederiksen *et al.* 2012). Moreover, most tracked birds observed wintering in the Celtic-Biscay Shelf were of local origin (i.e. two colonies tracked in the Celtic-Biscay Shelf area: Rathlin and Skomer) (Frederiksen *et al*. 2012).

This means that offshore wind development that affects kittiwakes during the wintering season in the North Sea could be affecting UK colonies, and the nature of this may change throughout the season. Further information is therefore required on the nature of these linkages (e.g. location, distance to development footprints, timing of migration).

Some high-level information on distribution of immature kittiwakes during the non-breeding season can be inferred from kittiwake ring recoveries (mainly from places where hunting takes place). Ring recoveries from Greenland, Newfoundland and the Bay of Biscay indicate that immature kittiwakes from Britain move progressively south (and west) within the Atlantic during the autumn and winter months (Coulson 2008).

2.1.3 Influence of environmental conditions

Kittiwakes can modulate their foraging behaviour during the breeding season in response to changes in prey abundance (Chivers *et al*. 2012); when food is scarce, kittiwakes extend their foraging range to increase the probability of encountering more profitable prey patches. Greater intraspecific competition may occur as environmental heterogeneity concentrates resources into relatively more profitable patches (Trevail *et al*. 2019). A study conducted across kittiwakes' British and Irish range showed that in areas with greater resource patchiness, kittiwakes undertook longer foraging trips, spent proportionally more time foraging while away from the colony, overlapped more with other individuals and had reduced breeding success (Trevail *et al*. 2019). While individuals can learn to exploit predictable food patches, any associated fitness gains may be countered by increased levels of competition. These have implications for the potential additive or synergetic effect (with climate change) of offshore windfarms on prey distribution and kittiwake breeding populations.

2.1.4 Sensitivity to windfarms and apportioning methods

Various methods currently exist to assess connectivity between birds observed at sea during the breeding season and their colonies of origin (SNH 2018). These include both model-based and data-led empirical approaches and can be used to apportion potential effects from marine activities to breeding seabird populations in protected sites.
Model-based approaches are straightforward to apply but tend to be overly simplistic by relying on three main assumptions:

1) birds are evenly distributed at sea;
2) seabird colonies are independent of one another;
3) seabirds breeding at large colonies have larger foraging ranges than smaller colonies.

These models are however useful when site-specific foraging ranges are not available. Empirical approaches, on the other hand, make use of colony-specific tracking data; they are more powerful, especially when integrated in complex models combining information on density-dependent and environmental processes.

Marine Scotland have been developing an apportioning tool for use during the breeding season that addresses some of the limitations of model-based approaches. It is based on RSPB GPS tracking data and accounts for between-colony segregation as well as environmental heterogeneity (Butler *et al*. 2019). Recently, the ORJIP sensitivity mapping project (Butler *et al.* 2019) combined this method with the predicted seabird utilisation distribution maps developed by MERP and RSPB (see above section) to estimate seabird sensitivity and vulnerability to windfarms of all at-sea locations within Scottish waters. The toolkit has two built-in options:

1) the map version identifies and maps high sensitivity areas for Scottish waters and is useful for spatial planning;
2) the footprint version estimates the overall sensitivity of a particular development footprint.

Different footprints' sensitivity scores can then be compared. The toolkit produces outputs for collision and displacement effects, which are relevant to kittiwakes. Users can select a kittiwake colony, see where birds go or select a footprint and see which SPAs are affected and the proportion of birds in the footprint that are from each SPA.

In addition, Natural England has developed a method to apportion potential non-breeding season impacts to relevant populations in UK waters (spatially distinct Biologically Defined Minimum Population Scales, BDMPS) (Furness 2015). This method makes use of data on e.g. demography, movements, migration timing and at-sea distribution.

2.1.5. Inferring kittiwake marine distribution from transect-based surveys

Kittiwakes at-sea distribution can be mapped based on observations made from boat or flight surveys. Since kittiwakes associate with boats (Skov & Durinck 2001) - much as fulmars, other gull species, gannets and great skuas do - the presence of boats can create biases in the observed species proportions from boat-based surveys.

It is possible to identify a very high proportion (typically over 99%) of small gulls (which includes kittiwakes) to species from digital video aerial surveys (A. Webb, pers. comm.); therefore, these methods represent a fairly good way to map kittiwake marine distribution.

It is also relevant to note that it is not possible to distinguish adult breeding individuals from adult non-breeders from digital video surveys, but it may be possible to distinguish some sub-adults from adults based on plumage (A. Webb, pers. comm.). This is reasonably easy to determine systematically if birds are flying, but less easy if they are sitting on the sea surface. This is the same issue for all survey methods, not just digital aerial survey methods.

2.1.6. Tagging of kittiwake

Significant effort has already been put into tagging adult breeding kittiwakes around the UK to study their foraging distribution:

- *during the breeding season*:
RSPB FAME and STAR tracking projects (2010-2015): GPS loggers; 20 sites, 583 individuals, up to 5 years of data at a given site;

RSPB / Orsted Flamborough and Filey Coast SPA (Seabirds and Windfarm, SaW) tracking project (2017-present): GPS (n = 32; 2 years), altimeters (n = 13; 1 year) and accelerometers (n = 18; 2 years);

Ongoing GPS tagging projects from CEH on the Isle of May. Total of six years of tracking data (2010, 2012, 2013, 2014, 2018, 2019; sample sizes 36, 17, 22, 11, 16, 25, total 127 individual birds tracked). Funding was provided by the Forth and Tay Offshore Wind Developers Group (2010), CEH/RSPB (2012-14) and EDF (2018, 2019). The latter two years have been part of EDF's post-consent monitoring.

- *during the non-breeding season*:
CEH ongoing tagging project on the Isle of May using GLS loggers (7 years) (which is part of SEATRACK).

GPS tracking uses the global positioning system of satellites to determine the precise location of the animal. GPS tags record fine scale location information. A GPS tag can be attached to the tail or back of a kittiwake. Attachments to the back may increase aerodynamic drag (Vandenabeele *et al*. 2012), but there have been some concerns that placement on the tail might affect balance (S. Christensen-Dalsgaard pers. comm.). While older types of tags needed to be retrieved within two to five days to download the data (before tags become detached from feathers), latest approaches (attaching to tail feathers or glued to trimmed back feathers) are now giving longer deployments, up to 30 days (Ponchon *et al*. 2017; S. Wischnewski, pers. comm.). Moreover, newer tags have increased battery life (using solar panels) and allow data to be downloaded remotely from base stations close to colonies. These types of devices have been deployed on kittiwakes in Norway (Ponchon *et al*. 2017) and by the RSPB / Orsted (Flamborough and Filey SPA tracking project), and therefore offer interesting prospects for assessing temporal variation in kittiwake foraging distribution, and hence in the level of interactions with marine renewables developments, throughout the breeding season. However, longer-term (e.g. several months) attachment of GPS tags with harnesses is not an option for kittiwakes at present due to potential welfare and licensing issues.

An alternative to satellite-telemetry for at-sea usage and connectivity with relevant colonies is Global Location Sensing (GLS). GLS loggers record ambient light, from which sunset and sunrise times are estimated from thresholds in light curves; latitude is derived from day length, and longitude from the time of local midday with respect to Greenwich Mean Time and Julian day. Compared to GPS, GLS loggers have a much lower resolution and can only infer an animal's putative location with ~185km accuracy (Phillips *et al*. 2004). GLS loggers, as well as other loggers such as Time Depth Recorders (TDR), are usually attached to plastic rings on kittiwake legs and can therefore be deployed for protracted periods of time with relatively small effects on the individual, compared with back or tail-mounted tags. Studies deploying geolocators over a year or two reported tag recovery rates lower than the species annual survival rate (56.7% in studies across the North Atlantic) (Frederiksen *et al.* 2012), although this is probably (at least partially) due to the difficulty of re-catching tagged individuals to retrieve tags.

Tag effects are now being shown by several published studies, especially where tag weight exceeds 3% of body mass (Bogdanova *et al*. 2017; Heggøy *et al*. 2015). Devices weighing 3% of bird body mass have been found to increase energy cost of flight by 4.7%-5.7% depending on the anatomy of the species (Vandenabeele *et al*. 2012). This increase in flight cost may reduce the flight speed of birds equipped with loggers and alter their foraging flight behaviour. There is also evidence indicating that the unequipped partner increases work rate to compensate for impact on one adult so that chick growth and breeding success may not change despite tag effects. Recent work has suggested that tag effect is a function of the tags influence on dynamic forces in addition to its weight (Kay *et al.* 2019) and so effective tag design can minimise the effects for a given weight. Analysis of the FAME/STAR and the Flamborough and Filey Coast SaW data has been inconclusive in demonstrating tag effects, because of too many confounding variables. There may therefore be long-term consequences on ability to survive and reproduce for both tagged adults and their partners, which might be difficult to measure and therefore it is difficult to know the extent of any effects and their significance. In addition to welfare concerns, any tag effects may bias the data that is collected using these methods and this needs to be borne in mind when using such data in impact assessments.

2.1.7. Stable isotope analyses

In addition to fitting loggers on birds, some other tools such as Stable Isotope Analyses (SIA) are available to assess the linkages between at-sea usage areas and relevant breeding colonies.

Carbon and nitrogen isotopes naturally occur in the environment and in living organisms. In the marine environment, the isotopic composition of carbon and nitrogen in phytoplankton varies spatially. These differences are reflected in higher trophic level organisms and can be used to infer habitat use by animals and movement patterns across marine isotopic gradients. In the context of feather moulting in seabirds, the isotopic composition of a regrown feather provides a chemical record of the area from which resources used in feather growth are derived. In breeding kittiwakes, moulting of primary feathers occurs sequentially from late spring to early winter; therefore, in theory it is possible to infer moulting/foraging areas during the breeding season, staging and wintering, albeit with relatively low precision.

Norwegian studies indicate that breeding kittiwakes' innermost primaries P1 and P2 are moulted from late May to mid-July, while P3 to P4 are moulted from late July to mid-August (González-Solís *et al.* 2011). There is also detailed kittiwake moulting data in studies by John Coulson at North Shields (UK colonies) – he considers that higher latitude colonies start moult later than the UK colonies. Therefore, SIA of P1 to P4 could potentially be used to infer the foraging distribution of adult kittiwakes caught at sea or at the colony during the breeding season, although there is limited data available from other colonies. Different situations may apply for immature birds due to variation in timing of moult between age classes. Moreover, juveniles have feathers that relate to where adults were foraging around their colony.

Carbon and nitrogen isoscapes have recently been produced for the North Sea (Trueman *et al.* 2017). These can be used to assign seabirds to likely foraging/moulting areas but with relatively low accuracy (similar to GLS ~200-300km) (González-Solís *et al.* 2011). Combining both GLS tagging and SIA of feathers can help reduce uncertainty in foraging area during the non-breeding season (e.g. moulting) (St. John Glew *et al.* 2018). Environmental data (e.g. Sea Surface Temperatures) can also be combined with GLS analyses to increase location accuracy (Merkel *et al.* 2016).

2.1.8. Morphological and genetic structure among kittiwake populations

Regional differences in animal species morphometrics and genetics can help identify different geographic ranges between regional populations (not colonies).

In the North Atlantic, there is some evidence for a clinal variation in black-legged kittiwake size with latitude. Wing length is about 12mm longer, on average, in Norway compared to the UK, and is 5mm longer in Shetland than in North Shields (B. Furness, pers. comm.), which suggests that wing length (accounting for age and sex) may allow a fairly good assessment of likely populations present in the non-breeding season if birds were sampled at sea (however inter-observer measurement error effects would need to be accounted for). There are also some differences in primary tip patterns between Arctic and British Isles populations (Chardine 2002).

There is also evidence for kittiwake genetic structuring between Pacific populations and those in the North Atlantic (McCoy *et al.* 2005). However, there is no evidence for genetic structuring (microsatellite markers) of kittiwake populations within the North Atlantic, which may be due to large distance dispersal (ringing and GLS data suggest large scale movements >500km) (McCoy *et al.* 2005). In addition, appreciable gene flow is expected between colonies since numbers of new immigrants often exceed numbers of philopatric recruits (Coulson & Coulson 2008). Prospecting movements of failed breeders have been recorded up to 40-50km away from their colony of origin (Ponchon *et al.* 2017). A higher structure in the mitochondrial genome has been observed with the distinction of five genetic groups (northeast Atlantic: British Isles and France / Barents / Svalbard / Newfoundland / Arctic Canada) (Patirana 2000). However, the reason why microsatellite and mitochondrial DNA markers give different genetic structuring patterns is not clear, and at the moment using genetic markers to assign kittiwakes to their region - even less their colony - of origin is not recommended.

3 Gaps in understanding

Most of the available evidence allowing linkages to be made between effects seen at windfarms and populations of interest is based on data that is acquired from tagging of individual kittiwakes. Such tagging studies are usually based at colonies and target breeding individuals due to the requirements to be able to safely capture and recapture individuals. This means that for any given colony for which sufficient representative data has been collected, we can establish whether breeding adults use a particular windfarm footprint during a part of the breeding season (using GPS tags). In some cases we can establish whether adults tagged at a colony use a wider area of sea outside of the breeding season (using GLS tags which provide spatial information at a much coarser resolution than GPS tags). This allows at least an establishment of a link between a population and a windfarm(s) but does not provide information which helps us understand what proportion of the birds using a particular windfarm footprint come from a particular colony or population versus another (or indeed are younger birds who may not be showing affinity with a specific colony).

Therefore, the obvious gap is evidence of where birds seen in a windfarm footprint have originated, and which population(s) they are linked to. For example, some of the individual kittiwakes within a windfarm footprint during the breeding season may be active breeders and therefore originating from a specific breeding colony. Others may be inactive breeders but with established links to specific colony (e.g. adults taking a sabbatical, younger birds which are linked to a specific colony but have not started actively breeding). Outside of the breeding season, birds seen within a windfarm footprint could be juvenile, sub-adult or adult, from various colonies within and out-with the UK.

This gap can be addressed by collecting data from all populations (i.e. breeding colonies) including data from juveniles and non-breeding individuals which have affinity with the colony in question. This data collectively can help build a map of linkages at sea. Alternatively, it can be addressed by collecting data from the windfarm footprint allowing linkages to be established only for the areas at-sea for which we are interested. The research opportunities described below cover both of these angles.

4 Potential research opportunities to improve understanding

4.1 Possible research ideas/opportunities

This is a list of research ideas and/or opportunities (RO) which workshop attendees, in small groups, suggested as potentially providing useful information for improving our understanding of linking kittiwake effects at windfarms to populations.

4.1.1 RO2.1 Extend Scottish-waters draft apportioning tool across UK

Evidence need/rationale for doing this RO
Latest empirical evidence and understanding of kittiwake foraging behaviour has been incorporated into a user-friendly apportioning tool. However, the tool currently only includes Scottish waters. The tool essentially reverses the models presented in Wakefield *et al*. (2017) for four species including kittiwake, to allow quantitative apportioning of birds observed within a windfarm footprint back to source colonies around the UK. The tool is based on breeding season distributions obtained from extensive tracking data from colonies around the UK, and incorporates colony size and distance, environmental/habitat covariates, and colony segregation.

Work required
This RO would extend the tool mentioned in section 2.1.4, which is being developed by CEH and RSPB on behalf of Marine Scotland, to the whole UK.

In addition to being extended across all UK waters, this work could also update the colony information with latest monitoring data such as that collected as part of the current UK breeding seabird census (Seabirds Count http://archive.jncc.gov.uk/default.aspx?page=7413). Ideally it would also include a facility to directly allow apportioning for SPAs rather than colonies more generally, but this may not always be possible given the mismatch between monitoring sections and SPA boundaries.

Benefits/key outcomes
This project would provide a generic tool to identify, for any given windfarm footprint around the UK, linked kittiwake colonies and estimated proportions of birds from within the footprint that are from each of the linked kittiwake colonies. The tool would also allow users to derive useful information for impact assessments, such as the percentage of time kittiwakes spend flying or foraging within a particular footprint at any given time of year, and therefore are vulnerable to collision or displacement, respectively.

For developments planned in marine areas outside of Scotland, this tool could provide a quick, efficient and standardised approach to apportioning predicted wind farm effects to SPA interest features. It could improve assessments both in terms of identifying which colonies are likely to be affected by a planned development and delivering better quantification of effects to SPA populations.

This would be based on breeding kittiwake data (from GPS tracking) but by inclusion of distributions based on at-sea survey, which would include non-breeders, the impact this has on apportioning outcomes can be assessed.

Risks/inter-dependencies
This RO has no significant risks or interdependencies; all data required to extend the apportioning tool are currently available and methods for undertaking this work have already been used to develop the tool in Scotland.

It should be noted however that this tool does not allow for apportioning outside of the breeding season, nor of immatures and non-breeding adults (unless we can assume that the distribution of non-breeding individuals is similar to that of breeding individuals, of which there is some evidence especially closer to colonies, see Sansom *et al*. 2018).

Predicted resources required to deliver this RO
As this is a desk-based study in the first instance, it is likely to be of restricted duration and cost. Detailed understanding of the existing tool as developed for and applied to Scottish waters, and ability to produce user-friendly tools for complex analysis with clear and un-ambiguous guidance to users are required.

LOW resource requirements (less than one year and less than £100,000).

4.1.2 RO2.2 Macro-analysis of existing data to identify spatial and temporal patterns in migration movements

Evidence need/rationale for doing this RO
As with most species, passage or migration is a time of year for which information on distributions and movements of kittiwakes is poorly understood and for which there is currently a paucity of data. Yet passage could be a time when many kittiwakes are exposed

to cumulative risk of collision if they migrate through multiple areas of offshore wind development. Furthermore, a lack of data regarding timings and distribution of migratory kittiwake means that it is difficult to carry out robust apportioning at times when both migratory birds and also breeding birds from closer colonies could be present. Consequently, a better understanding of the timing and location of peak migration movements of kittiwakes is needed to know the origin of kittiwakes occurring in an offshore windfarm and the amount of time they may spend interacting with these windfarms.

This RO would look across existing data on at-sea distributions of kittiwakes throughout the year for patterns in density peaks as kittiwakes move and migrate through marine areas of interest.

Work required
Undertaking this RO would require access to at-sea survey data and other products including maps of distribution from sources such as:

- Survey data from Round 3 windfarm zones, monthly surveys 2009 – 2012, some of which may be available on The Crown Estates Marine Data Exchange (http://marinedataexchange.co.uk/). Possibly other developer data available from similar timeframe e.g. in Scottish waters.
- European Seabirds at Sea data, which is a collation of data from vessels of opportunity, going back to 1979. Distribution maps have been produced in Kober *et al*. 2010, and as part of various sensitivity tools such as Webb *et al*. (2016) and Bradbury *et al*. (2017).
- Monthly distribution maps across UK waters are expected to be available soon from the Marine Ecosystems Research Programme (MERP) (https://www.marine-ecosystems.org.uk/Research_outcomes/Top_predators) which is based on at-sea survey and environmental covariates. Note that these include ESAS data and other available data, potentially including data from Round 3 windfarm zones
- Geolocator data provides broad indications of distributions by season and is available for the northern North Sea, Barents Sea and Norwegian Sea, through the SEAbird POPulation programme (http://www.seapop.no/en/seatrack/). Non-breeding season maps and population of origin maps can be accessed via the SEATRACK web portal.
- Ongoing data collection from offshore windfarms, either as part of baseline survey work or from post-construction monitoring
- Trektellen is a public database to share migration counts and ringing results (https://www.trektellen.nl/). It contains data from across the UK and Europe and includes coastal observations from regularly-watched sea-watching stations such as Flamborough Head and Whitburn.

Combining these data together could provide snapshots of kittiwake at-sea distribution at different temporal and spatial scales.

Benefits/key outcomes
Analysing these data could show broad latitudinal north or south movements in certain months, the extent to which birds from UK colonies stay within UK waters versus elsewhere outside of the breeding season and finer resolution on timings of movements for parts of the UK which have intensive sea watching/coastal survey effort. It may be possible to separate out movements of breeding individuals (moving away from colonies) from movements of non-breeding individuals, e.g. if age classes can be separated on some of the observation data, and/or if geolocator data (of adults) shows different movement patterns from other data types (which could include all age classes).

At cumulative scale such an analysis can indicate the extent to which kittiwakes are moving across/between different windfarm zones and footprints and interacting with multiple windfarms. At individual windfarm scale, this information could help to establish more precisely whether birds using windfarms at beginning/end of breeding periods are in fact birds from elsewhere migrating through or could be birds from linked colonies. In reality, it may often be a mix of both, but this analysis could provide some useful information to inform the extent to which kittiwakes during certain months are likely to be passing through rather than 'local' birds.

Risks/inter-dependencies
Some sources of at-sea distribution data are relatively old and potentially dated, e.g. ESAS. Seasonal patterns of movement could have changed with substantial changes to the marine environment, e.g. due to climate change. Others are only available at fairly crude scales e.g. monthly surveys, which may therefore not accurately capture movements.

Some sources of data may not be readily available, e.g. not all Round 3 windfarm zone data is available through the Marine Data Exchange (although project-specific data should be available). A review of the feasibility of undertaking a meta-analysis for red-throated diver found data accessibility to be a potential problem with undertaking this type of work (Coppack *et al.* 2017).

Data from SEAPOP is currently constrained to describing movement patterns of adult birds which had been breeding in the previous season. Note that SEATRACK has recently deployed GLS devices on immatures from some colonies, but it may be several years before this data can be retrieved. Non-breeders and immature birds may well undertake seasonal movements earlier or later than breeding birds due to not having the locational constraints and physiological demands of breeding.

Data on Trektellen is collected by volunteers with a principal interest in unusual sightings, e.g. rarer seabirds, and at times of large seabird movements commoner species such as kittiwake may not be counted. In addition, sea-watching locations may be close to kittiwake breeding colonies, the day-to-day movements of local birds potentially obscuring patterns of migratory birds.

Predicted resources required to deliver this RO
As this is a desk-based study in the first instance, it is likely to be of restricted duration and cost. 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. This data gathering is likely to lead to the identification of gaps in our understanding that could be addressed by further work e.g. geolocator studies in additional locations, which could form part of an extension to the RO.

LOW resource requirements (less than one year and less than £100,000).

4.1.3 RO2.3 Strategic (non-GPS) tracking. Feasibility study

Evidence need/rationale for doing this RO
GPS devices provide detailed and accurate information on animal movements but have several disadvantages: they are expensive which means that only small sample sizes are usually possible, and they can be bulky which for small animals such as kittiwakes, means that they should not be deployed for long periods due to potential effects on animal behaviour and welfare.

Other types of devices are available which are much smaller, lighter and less expensive. These could potentially be deployed on much larger scale; many more animals can be followed and for much longer periods. Such devices generally provide lower resolution of data than GPS devices however and rely on a means of ‘re-sighting’ such as by observers or receivers which record each time a device passes within signal-range. This project would explore the opportunities, limitations and requirements for such a large-scale study-design in order to provide useful data for improving understanding of connectivity between breeding adults (or other population of interest if device attachment were not limited to breeding individuals caught at the colony) and windfarms. It could then be deployed at scale if appropriate.

Work required
This project would explore the feasibility of using VHF radio or Passive Integrated Transponder (PIT) tags, potentially combined with expansion of colour ringing to derive movement information across UK waters. These types of device are small, inexpensive and easily attached to legs using small rings. Radio and PIT devices can be read by a receiver, which would need to be placed strategically around the UK seas in order to collect data on when a tagged bird passes (within signal receiving range of) the receivers. This would provide information on which birds (of known provenance) were passing through (or spending time in) which areas of seas.

Radio and PIT devices are smaller, cheaper, last the life-time of the animal (no or very low power requirements for the tag) and are easier to attach than GPS or GLS tags and hence can be deployed at a much larger scale. Colour ringing is a standard method deployed across the full range of seabird species. Coloured rings are attached to a bird’s leg and can either have numbers and/or letters (which need to be read in order to ID an individual) or are simply a unique combination of different colours on each individual. Volunteers and surveyors can then report when and where a specific individual has been re-sighted. RSPB have recently set up a kittiwake colour-ringing project at the Flamborough and Filey Coast SPA (with 51 birds’ colour ringed in 2018 and a significant number of re-sightings in 2019) which could feed into and inform this RO.

RO2.3a. This RO would need to start with a desk-based feasibility study but could lead to recommendations for RO2.3b.

The study would need to consider:

- literature review of relevant existing projects/studies using these types of devices
- comparison of device types and associated receivers; This would need to consider signal range (theoretical and in-practice), read-rate, tag size, costs.
- attachment method(s) and implications; can this be deployed on chicks at the nest, juveniles/adults caught at sea, implications for life-time of bird, *etc*.
- potential for colour ringing instead of tagging devices; observer effort instead of receivers.
- how many tags would need to be attached across the North Sea and the UK to provide useful information? (scale of deployment; power analysis)
- what logistics would be involved in achieving the required scale of deployment (e.g. who would attach devices, costs, collating and storage of data, *etc*).
- how many receivers would there need to be to gain a reasonable quantity of data, where should they be placed, and what are the practicalities around this (for example can they be attached to existing infrastructure, how is data retrieved, what are power/battery requirements, maintenance requirements, *etc*). Or for colour ringing, how much observer effort would be required and logistics of this in practice.
- future-proofing the system so additional receiver stations can be added if desired/funding available to increase sample sizes, rates of re-sighting/recording of tagged individuals and statistical power.

- how would data be stored and managed?
- how would the data be analysed, and what other information might it be combined with?
- would this work best as a colony-focused exercise or would it be useful (or required) to catch birds at sea (e.g. within existing or planned windfarm footprints)?
- experimental design (how to get the information that is required to improve estimates of apportioning).

RO2.3b. Pilot deployment to check assumptions and conclusions around logistics, costs, scale of deployment required, infrastructure requirements, data retrieval, *etc*. If this is to include colour ringing, then it would also assess feasibility of getting sufficient re-sightings and effort required.

If found to be feasible under RO2.3a and RO2.3b, a UK-wide deployment (RO2.3c) could be undertaken.

***RO2.3c*.** Appropriately placed receivers and extensive deployment of device attachment, and if appropriate extensive colour-ring re-sighting effort across the UK, leading to extensive data on movements of individuals from colonies across the UK, at precise spatial scale. It is unlikely that many data-points would be collected per tagged individual, but many individuals can be tagged/ringed leading to a large sample of data across the UK population (potentially restricted to breeding individuals but depends on where and how birds are caught) and across months/seasons. It may be that a combination of radio or PIT tags and colour ringing would bring the greatest power, with strategically placed receivers ensuring data coverage of key locations (e.g. wind farms/colonies) and opportunistic sightings providing some coverage beyond these locations. Decisions around which device(s) to incorporate would be informed by work under RO2.3a and RO2.3b.

As a minimum, if deployment of receivers and/or colour-ring re-sighting effort were focussed within colonies and existing or planned windfarm footprints, this would provide information on linkages between wind farms and colonies. This could be similar to data currently acquired from GPS tagging studies, but over a longer time period, covering many more individuals. If devices/rings were to be attached at-sea within a wind farm footprint in sufficient numbers, it would provide a direct estimate or relative proportions of birds at wind farms from each linked colony where receivers were erected (this is dependent on outcomes of RO2.44.1.4).

In addition to the spatial/movement data that would be collected, deploying unique marks on individuals is a form of mark-recapture study (recapture when a bird makes contact with a receiver or is re-sighted). Wide-scale deployment could therefore provide spatially-explicit data on kittiwake survival. If a sufficient number of individuals were marked and recaptured frequently enough, it may be possible to obtain survival information for birds interacting with windfarms versus those not interacting with windfarms (informing estimates of windfarm-induced mortality, as discussed in Black *et al*. 2019). It would also provide extremely valuable information on survival for use in population modelling to assess cumulative impacts of large-scale offshore windfarm deployment on kittiwake populations. If deployed across a large enough spatial scale, this would provide data on actual survival which would incorporate meta-population movements between colonies, as opposed to apparent survival for which emigration and death cannot be differentiated. If enough data were to be collected, it may be possible to establish spatial variation in survival related to e.g. foraging strategies and areas, wintering areas, migration strategies.

Small, rechargeable (solar powered) and remotely-downloadable GPS tags may be suitable for consideration under this broad umbrella, but it is unlikely that these are (yet) of sufficiently low cost and are therefore unlikely to be deployed at a large scale. SEATRACK are currently working with PATHTRACK to develop small GPS-loggers that can be fastened to a leg ring and would provide data throughout the year. Although still under development, and may be too costly for large-scale deployment, it may be beneficial to include these within a feasibility study (RO2.3a), especially given that it would provide location data for when the bird had not been within transmitting distance of a base station (transmission to receiving signal is required to download the data, but the data could have been collected continuously by means of GPS). This could therefore provide much more data per individual.

Benefits/key outcomes

Existing collaborative research using radio telemetry for small flying birds has markedly improved understanding of movements of species/populations included within the project (https://motus.org/about/). For example, Howell *et al*. (2019) demonstrate the predictability of migration timings for radio-tagged sanderlings (*Calidris alba*) and potential for mitigation to considerably reduce the risk of windfarms to this species. (Howell *et al.* 2019)

Colour ringing is used extensively for many species. For example, Grist *et al*. (2014) used colour ringing of European shag (*Phalacrocorax aristotelis*) to demonstrate high among-individual variation and within-individual repeatability, both within and among winters, in movements and migration strategy (Grist *et al.* 2014).

Kittiwakes are much more pelagic than shags, making re-sighting of colour-ringed birds less likely. Strategic placement of receivers for radio or PIT devices could replace observer re-sighting and lead to substantial improvements in understanding of breeding and non-breeding season movements of individuals. If receivers were placed in key locations, data would be acquired on movements of kittiwakes between SPA colonies and offshore wind farms in both the breeding and non-breeding seasons. This information would reduce uncertainty about the origin of individuals occurring in a wind farm, and depending on study design and deployment location, could considerably improve estimates of the number and location of SPA birds affected by a development, at different times of year.

Another substantial benefit of this RO is the synergistic opportunities to address KG1 and KG3 evidence needs, through obtaining improved estimates of kittiwake survival. With a sufficiently large marked kittiwake population and frequent enough recoveries (re-sightings or detection by a receiver), it may be possible to obtain information on inter-colony movements, more accurate estimates of survival and differential survival rates for individuals associating with wind farms vs those not using wind farm areas. This evidence would be of direct benefit for validating model-based estimates of offshore wind farm mortality (KG1) and improving confidence in population models used to assess consequences of wind farm mortality (KG3). All of this will reduce uncertainty in the assessment process for kittiwakes as well as provide empirical evidence of cumulative impacts for kittiwakes across existing windfarms.

Risks/inter-dependencies

If taken as far as RO2.3c, the scale of deployment would need to be large with substantial initial investment. In order to make this feasible and practicable, a substantial number of partners would need to be involved for both cost-sharing and access to a sufficient number of offshore structures, and deployment of a sufficient number of devices/colour rings.

There may be some logistical issues around installing receivers on offshore structures.

There is a risk that after working through RO2.3a and/or RO2.3b, it is concluded that it is not feasible to deploy any of these devices at a suitable scale to acquire the information that would be required. It is unknown how likely this is; similar approaches have been successfully undertaken for other species, but usually either terrestrial or less wide-ranging species, so it is difficult to judge the likelihood of success for wide-ranging seabird species such as kittiwake. However, note that the RSPB colour-ringing project at Flamborough and Filey Coast SPA has resulted in re-sighting of 45 of the 51 colour-ringed birds at the colony the following year (which provides information on survival, although this alone does not provide any information on the movements of these birds between successive breeding seasons). This risk will be much better understood after completion of RO 2.3a and RO 2.3b.

Predicted resources required to deliver this RO
RO 2.3a is a desk-based study and is likely to be of restricted duration and cost. Experience with radio and PIT tagging devices and understanding of best practice and issues around catching, handling and attaching devices to kittiwakes would be required. Expertise in processing and interpreting tracking data would be desirable in order to be able to estimate data requirements to provide a representative picture across the study area. General understanding of marine industries and infrastructure is required to assess infrastructure needs and opportunities for receivers and potential risks/limitations to mass deployment.

LOW resource requirements (less than one year and less than £100,000).

RO 2.3b requires localised deployment of devices and strategic placement of a small number of receivers (and/or observer re-sighting effort), and data processing and analysis. This is likely to be best undertaken over 1-2 years with a small collaboration e.g. between a specific SNCB and windfarm developer and expertise in handling kittiwakes and attaching devices.

Difficult to estimate resources, as it is not known what the cost of hosting/deploying a receiver is. Excluding receiver placement and hosting, resources are likely to be **MEDIUM** resource requirements (1-2 years and less than £500,000)

RO2.3c requires collaboration across a wide spatial scale, among many stakeholders including many developers (for deploying receivers at wind farms) as well as SNCBs and NGOs (for tagging SPA birds and deploying receivers at colonies). A research project of this type and scale could only be delivered through a collaborative initiative such as OWSMRF (and other initiatives, e.g. ORJIP).

HIGH resource requirements (several years and potentially over £500,000), best achieved through collaborative approach.

4.1.4 RO2.4 Catching kittiwakes at sea; proof of concept

Evidence need/rationale for doing this RO
The main evidence gap is knowledge of where birds seen in a windfarm footprint have originated, and which population(s) they are linked to. Therefore, a means of assessing this directly (rather than indirectly by means of following individual kittiwakes from potentially linked colonies and populations) can lead to both improved efficiencies in evidence collection (by focussing only on birds that are actually interacting with a windfarm) and reduced uncertainty. A means of following the movements of kittiwakes observed within a windfarm footprint is therefore required. Some of the ROs described above could be applied to kittiwakes observed within a windfarm footprint if a means of deployment at sea were to be developed/tested. Catching seabirds at sea has already been shown to work for other species, particularly those which can be attracted to boats for food (which kittiwakes are known to do) (Bugoni *et al.* 2008; Ronconi *et al.* 2010).

Work required
This is a combination of desk-based study (RO2.4a) and an exploratory at-sea study (RO2.4b).

RO2.4a Desk-based to review the feasibility of catching kittiwakes at sea

This part would explore different technologies and sampling options to establish what kind of data could usefully/should be collected from kittiwakes caught at sea, sample size requirements, and appropriate technology. It would also review different catching methods used previously for other species, potential biases to consider, *etc*.

Options for technologies and data to acquire from caught birds could include:

- Attaching devices (GPS, GLS, radio or PIT tags, colour rings, see 4.1.3). This should consider re-capture requirements (and associated welfare issues), data retrieval, device life/battery requirements, likely resolution of resulting data (alone and in combination with other data types).
- Feather collection for Stable Isotope Analysis (SIA); which feathers should be sampled at different times of year, processing/analysis requirements for samples, likely resolution of resulting data (alone and in combination with other data types).
- Age inferences (either direct observation or via photography)
- Morphometric measurements; what additional information might be achieved, cost-benefit analysis of additional handling time *etc*.

Options for capture methods could include:

- Cast nets
- Hoop nets
- Butterfly nets
- Lamping
- Noose pole
- Cannon nets

For each method, this project would need to consider suitability for kittiwakes, requirements, likely levels of stress caused, risk of injury, safety aspects for handlers, biases, *etc*.

Assessing methods of capture is likely to involve going beyond published literature, e.g. contacting people who may have undertaken catching of birds at sea and asking about their experiences, including what did not work. This could involve using ringing forums, seabird message boards and face-to-face opportunities such as seabird conferences.

RO2.4b Exploratory catching

This part would be informed by RO2.4a and would trial catching kittiwakes at sea. It would trial capture methods identified in RO2.4a as potentially suitable for kittiwakes, assess the level of effort required to achieve specified sample sizes, consider limitations, e.g. weather conditions, distance offshore, size of vessel required, health and safety considerations, check assumptions around welfare and stress implications, establish processing time and considerations for different data/sampling/device attachments. This would need to be undertaken across a range of sites, weather conditions and distances from shore. It should provide a set of recommendations for how to undertake catching of kittiwakes at sea, issues to be aware of if this were to be applied at larger scale and potential resource requirements needed to achieve desired sample sizes.

This project ties in with several of the other suggested projects. For example, attaching of devices as described under RO2.3 (radio, PIT, colour rings) could be done either at the colony or at sea. Being able to catch kittiwakes at sea and apply unique marks to individuals would greatly broaden the empirical evidence that could be gathered under RO2.3, compared with only marking birds at colonies. A means of collecting data from, or attaching devices to, birds within a windfarm footprint would enable collection of data which directly informs the provenance of kittiwakes seen at a wind farm footprint, rather than as with tagging data obtained to date, simply telling us whether birds from a particular colony use a particular wind farm footprint or not (but nothing about which other birds might also be using the footprint, e.g. from other colonies or non-breeders).

Benefits/key outcomes
This project in itself does not provide outcomes which directly feed into impact assessments or improved understanding of linkages of kittiwakes using windfarms to colonies/wider populations. However, this RO assesses the opportunity for collection of data from kittiwakes observed using windfarm footprints which combined with other ROs (e.g. RO2.3) could lead to considerable increases in precision of apportioning of effects seen at windfarms to appropriate populations (e.g. colonies).

Improved understanding of if, and how, to mark or sample from kittiwakes observed within a windfarm footprint (either proposed or constructed) can lead to considerable efficiencies in terms of the amount of evidence required to assess population linkages of kittiwake effects from individual offshore windfarms and combined effects across windfarms. It would mean that, in theory, all colonies (including SPAs) and wider populations that have linkage with the windfarm footprint, could be identified without the need for extensive tagging projects at each potentially linked colony (as is currently the case). In addition to simply identifying which colonies are linked to the windfarm footprint, with sufficient effort it may be possible to understand what proportion of kittiwakes using a windfarm footprint are from each of those linked colonies.

Risks/inter-dependencies
There may be some health and safety concerns for personnel, and welfare concerns for kittiwakes, but the intention is that RO2.4a would identify and provide suggestions for solving these concerns whilst RO2.4b would test proposed solutions and produce detailed recommendations and guidelines for catching of kittiwakes at sea to avoid such risks.

There is a risk that after working through this project, it is concluded that it is not appropriate to catch kittiwakes at sea for device deployment and sampling (of e.g. feathers for SIA). It is unknown how likely this is but given that this has been successfully undertaken for other (often much larger) seabird species, it seems small.

Predicted resources required to deliver this RO
This project has two parts which are best undertaken sequentially. This project would require expertise in kittiwake behaviour and experience of catching birds at sea, as well as appropriate vessels and vessel skipper/personnel.

RO2.4a is a desk-based study and is likely to be of limited duration and cost. It would require expertise in kittiwake behaviour and some understanding of the different data types and devices that the project would consider. It would require knowledge of different seabird groups and for a and ability to reach out to relevant experts.

LOW resource requirements (less than one year and less than £100,000).

RO2.4b requires chartering of suitable craft and skipper(s), and needs to cover different locations, weather conditions and times of year to fully understand limitations and requirements. It may be possible to capitalise on existing vessel traffic such as that linked to windfarm developments or operators, which may have relevant expertise, vessels and knowledge of the areas to be sampled. It requires experience of catching birds at sea and attaching devices and taking samples (such as feathers).

LOW – MEDIUM resource requirements (likely could be done within 1 year but could require up to 2 years, and less than £500,000)

4.1.5 RO2.5 Citizen science to provide age structure information

Evidence need/rationale for doing this RO
The above ROs would lead to improved evidence for assessing what proportion of birds seen at a windfarm footprint (and/or potentially affected by a windfarm) are from each of the potentially linked colonies and wider populations, in order to fully link into the next step of impact assessment (assessing the impact of the predicted effects on the linked population(s)), it is necessary to understand the age structure of the affected individuals. For example, if a windfarm area is used primarily by breeding adults, then once colony of origin has been identified for these adults, it is necessary to understand how individual level effects on these adults might impact the overall size and productivity of those linked colonies. If on the other hand the windfarm footprint is used primarily by juvenile and sub-adult birds, it is only future recruitment to breeding populations that could be impacted and this would be treated differently in population stages of the impact assessment.

Work required
This is a citizen science project which would use existing kittiwake photographs, and or/volunteer photographers and/or volunteer seabird surveyors, to assess age structure of regional populations and spatial variation in age structure across UK waters. During summer months it is possible to distinguish three age-classes for kittiwakes: juvenile, 2nd calendar year and adult (refers to plumage only not breeding status). With some training, it is thought that most experienced seabird surveyors (including volunteer surveyors) would be able to make such distinctions. At other times of year it is possible to at least distinguish juveniles from older individuals, and at certain times adult plumage from 2nd calendar year individuals.

There could be several elements to this project:
RO2.5a Programmed trawl of online photograph libraries (e.g. flickr) to pick out photographs of kittiwake that could be assessed. There is software available which can be trained to recognise specific images and filter these from large online libraries. These could then be assessed, and age confirmed for those which contain kittiwake images of sufficient quality.

RO2.5b Active ‘upload’ system where volunteers can upload photographs they have taken of kittiwakes from coast and vessels of opportunity (ferries and/or wildlife watching boat trips). These could then be assessed for age of kittiwake.

RO2.5c Pushing kittiwake aging as part of the survey agenda for volunteer surveyors taking part in JNCC’s Volunteer Surveyors At Sea programme. This currently operates on routes off western Scotland with plans to extend to eastern Scotland and beyond.

These would all prove potentially informative because of the way kittiwakes change plumage as they progress from juvenile to full-adult plumage.

Both RO2.5a and RO2.5b would rely on a minimum quality of photograph as well as time and location information.

Barring RO2.5c, there is a high likelihood that such a process would be heavily biased towards photographs taken on land rather than at sea unless sufficient volunteers were successfully recruited to take photographs of kittiwakes from vessels of opportunity (e.g ferries or wildlife watching boat trips). There is also likely to be further bias towards popular areas such as nature reserves or more accessible sections of coast. It may be that dedicated automated photography e.g. at a windfarm footprint, would provide the best solution to providing information on ages of kittiwakes occurring at a specific location (beyond the scope of this RO).

JNCC's Volunteer Surveyors At Sea programme relies on experienced surveyors to train volunteer mentors who can support less experienced volunteer surveyors in order to undertake seabird and cetacean surveys on ferries. This scheme currently operates on routes off western Scotland with plans to extend to eastern Scotland and beyond. Given that the scheme is already running successfully, with 227 kittiwake records within just three months of surveys on west coast routes for example, this is likely to be the area where the most gains could be made. The only additional material that would be required is specific guidance on aging of kittiwakes and some effort to ensure that all mentors and surveyors are aware of the need to undertake this step as part of the survey (which they should already be doing but may need a push to ensure it happens consistently). This data would only be collected from established survey routes, but the guidance could be provided to volunteers to collect information on age of kittiwakes seen opportunistically outside of these ferry routes (essentially combining RO2.5b and c, above). In other words, with appropriate guidance available, there may be no need for photographs which would facilitate easier and less costly collection of information.

Benefits/key outcomes
If successful, this project would lead to improved understanding of variation in kittiwake age structure in both space and time. This could partially inform the extent to which kittiwakes using a windfarm colony could be breeding individuals from linked colonies (although this information does not distinguish breeding adults from non-breeding adults or older sub-adults, see below).

Risks/inter-dependencies
As this is dependent upon volunteer effort, it is difficult to predict the up-take and the amount of data that might be collected by these means. RO2.5c is perhaps more predictable given that the scheme is already established and there is plans for further roll-out. RO2.5a and 2.5b are likely to provide data that is largely biased towards coastal locations and summer months during good weather. The RSPB's Project Puffin (https://www.rspb.org.uk/reserves-and-events/events-dates-and-inspiration/puffarazzi/) which invites members of the public to submit photographs of puffins with food in their bills, to help understanding of how the food that puffins carry has changed over time, has been successful with submissions of more than 3000 useable photographs from across the UK since 2017. Kittiwakes may not be such a popular subject as puffins and there is no guarantee of similar levels of uptake.

It should be borne in mind that sub-adult kittiwakes can only be identified to 2nd year whilst the first breeding attempts of kittiwakes are typically year 4-5 (with a recorded range of year 3-8). In addition to this, some adult kittiwakes take breeding sabbaticals in some years. This RO will not be able to distinguish non-breeding adults or older (year 3+) sub-adults from breeding adults. It therefore can provide an indication of the proportion of a population that is made of kittiwakes up to their 2nd year, but this proportion does not incorporate all non-breeding kittiwakes.

Predicted resources required to deliver this RO
All three elements would entail initial high-intensity effort followed by lower intensity effort to maintain, but with element RO2.5c requiring less set-up than ROs 2.5a and 2.5b given that the scheme is already in place.

RO2.5a would involve initial set-up costs to train the recognition software to recognise photographs of kittiwakes, and to undertake an initial trawl of existing online libraries and images. Experienced coding/software personnel would be required to train, test and implement the software, with input from experienced kittiwake ecologists who can advise on how to age kittiwakes from the acquired images. Image processing and analysis is also required. Follow-up costs would be smaller; periodic image trawl for additional images, and updated analysis.

MEDIUM *resource requirements (1-2 years and less than £500,000). Unknown follow-on costs for periodic refresh.*

RO2.5b would involve initial set-up costs of communications materials and recruitment campaign, with smaller ongoing costs to liaise with volunteers and manage and process images.

LOW resource requirements (less than one year and less than £100,000). Unknown follow-on costs for ongoing volunteer liaison and image management, processing and analysis.

RO2.5c would involve low set-up costs to train mentors in aging of kittiwakes and establish guidance material for volunteer surveyors. There would then be low ongoing costs for volunteer coordination and data management.

LOW resource requirements (less than one year and less than £100,000). Unknown follow-on costs for ongoing volunteer liaison and data processing and analysis.

An optional add-on which would take this beyond citizen science is to explore use of commercially-collected digital aerial survey images. This may not provide sufficient image quality to be able to assess age (or as a minimum adult versus non-adult) for a sufficient number of kittiwake observations but this has not been established and could be explored. This would raise the costs of this project opportunity considerably and may be most effectively undertaken in conjunction with digital aerial survey providers. If successful and images were of sufficient quality to provide the information required, this could be applied to project-specific pre-consent surveys in order to understand location-specific kittiwake age structures.

4.1.6 Non-Breeding kittiwakes

A consistent theme that came through the workshop was how to consider non-breeding kittiwakes which might be using a windfarm during the breeding season. No distinct project idea was suggested. Rather, there is various information that is required and which would emerge from the projects listed above, to start to piece together a picture of the distributions of, and movement patterns of, immature kittiwakes and adult kittiwakes during sabbatical years.

For example, RO2.5 could provide information on the contribution of younger birds to the populations observed using windfarm footprints. RO2.3 and RO2.4 combined, could lead to deployment of projects which could increase understanding of linkage of young and non-breeding kittiwakes to colonies and year-round movements. If successful, retrieval of GLS data from immature birds currently part of SEATRACK would provide useful information.

4.2 Synergies/overarching notes

Several of the research opportunities described in section 4.1 would complement each other. For example catching of kittiwakes at sea (4.1.4) could facilitate attachment of radio tags, PIT tags or colour rings (4.1.3 to birds caught within a windfarm footprint (which could subsequently be used to test modelling apportionment ratios as in RO2.1). Improved understanding of age-structure distributions at sea (4.1.5) could further inform representativeness of modelled apportionment ratios (RO2.1) (which is based on data for breeding adults) to the wider population.

A means of effectively and efficiently ascribing population of origin to kittiwakes interacting with proposed, consented or operational windfarms could transform offshore windfarm impact assessments in terms of reduced uncertainty. No single project described above can do this alone, but a combination of projects could. For example, if the apportioning tool described in RO2.1 were to be extended to cover all UK waters, then this could be used as a hypothesised apportioning map which would require validating/testing.

Note one of the limitations of the apportioning tool as described in RO2.1 is that it applies only to breeding adults, during the breeding season only. Even if considering apportioning during the breeding season as distinct from apportioning during the non-breeding season, further work would need to be included in order to ascertain the extent to which such apportioning could be assumed to apply similarly to non-breeding adults and sub-adults, during the breeding season. During development of the apportioning tool in Scottish waters, CEH and RSPB explored using the discrepancy between the spatial distribution of birds that is estimated from spatial at-sea survey data (e.g. boat or aerial-based transect surveys) and the distribution of birds that is estimated based on GPS data to predict how many of the birds seen at a site/footprint might be non-breeding. Outputs from RO2.5 could inform the ratio of breeding to non-breeding birds expected in different regions/areas at sea, to help parameterise such a model, and catching kittiwakes at-sea (RO2.4) in strategic areas could be used to test the predictions of such a model for breeding as well as non-breeding kittiwakes. This could then help inform the confidence in an apportioning tool that could include non-breeders and highlight areas or situations with lower confidence where proposed windfarms may require additional survey effort to ascertain accurate apportioning ratios.

Apportioning during the non-breeding season is generally seen as lower priority than apportioning during the breeding season. However, if the windfarm industry were to make the most use of available data to reduce uncertainty in impact assessments, then depending on the outcomes of RO2.2 and RO2.3, an update of the BDMPS tool (Furness 2015) may reduce uncertainty in non-breeding season apportioning.

Data collected from a sample of sites using e.g. attachment of either radio tag, PIT tag or colour rings as described in RO2.3, attached to a sample of kittiwakes from each of the sample sites based on recommendations from the project described in RO2.4, could then be used to assess if, and in what regions/contexts, the modelled apportioning ratios are accurate. Combined with an estimate of age structures of sampled kittiwakes and kittiwakes across the UK (or from specific regions) (RO2.5), an indication of the extent to which the modelled apportioning ratios might represent the wider population can be achieved.

Several of the project ideas involve handling of kittiwakes and attachment of devices, in most cases devices which would remain attached to the animals for several years/lifetime. Geen *et al.* (2019) has shown that across studies which looked for or reported an effect of devices on birds, the effect of device mass is particularly important for long-duration studies (more than three months) on seabirds. The devices considered in the projects described are largely small and light in relation to the bird's body mass, but given the length of time the device will stay attached to the animal, it is important that steps are taken to estimate the extent of any influence of device attachment on both the individuals welfare/survival, and the representativeness of data, and that steps are taken to minimise any such effects.

5 Conclusions

This report has set out a series of five potential research opportunities (ROs) which were suggested and discussed at a workshop of experts in kittiwake movements. Most of the projects described consist of more than one stand-alone piece of work, for example RO2.4 includes a desk-based study and a field element. Although they have been brought together into coherent ‘projects’, an element of ‘pick and mix’ is possible, for example if limited budgets do not allow for each full project idea to be pursued as a whole. Equally, some of these projects represent exploratory or feasibility assessments, and depending on the outcomes of these, could pave the way for much larger data-collection projects, and this has been pointed out and described briefly where appropriate.

The intention is that this report provides a signpost towards research which can contribute to reducing uncertainty around the linkage of effects on kittiwakes seen at a windfarm to populations, and thus contribute to overall reduced uncertainty in offshore windfarm environmental impact assessments. Incremental reductions in uncertainty will become more important as the wind sector is expanded, in order to facilitate meaningful and precise cumulative impact assessments, therefore maximising the potential for sustainable marine development within the limits set by environmental protection and regulation.

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