Marine Scotland

Development of a 'Seabird Sensitivity Mapping Tool for Scotland'

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Final Report

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Offshore Renewables Joint Industry Programme (ORJIP)

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1 Introduction

1.1 Overview

The Scottish Government is committed to increasing the production of electricity from renewable sources, with a target of generating 100% of Scotland's electricity requirements from renewable sources by 2020. The marine environment offers considerable potential with respect to harvesting renewable energy, through wind, wave and tidal stream energy generators. However, the Scottish Government is also committed to protecting the natural environment from adverse impacts in accordance with the requirements of the Marine Strategy Framework Directive (EC/2008/56), the Habitats Directive (EC/92/43) and the Birds Directive (EC/79/409). Central to delivering these is the designation of important areas for species identified in the relevant Directives. For example, under the Birds Directive these are known as Special Protection Areas (SPAs).

Offshore renewable developments (ORDs) have the potential to impact on seabird populations that are protected by the EU Birds Directive due to collisions, displacement from foraging habitat, barrier effects, noise and contamination (Drewitt & Langston 2006; Larsen & Guillemette 2007; Masden et al. 2010; Grecian et al. 2010, Langton et al. 2011, Scottish Government 2011). These potential effects are predicted to be particularly important for breeding seabirds that, as central place foragers, are constrained to obtain food within a certain distance from the breeding colony (Daunt et al. 2002; Enstipp et al 2006).

A critical component of the process to inform sectoral plans, Strategic Environmental Assessments and other impact assessments such as EIAs and HRAs, is to develop a better understanding of the relative sensitivities of offshore areas to licensed activities in relation to protected seabird populations. This project is building upon the existing evidence base, for which step changes in the estimation of seabird at-sea distributions in breeding and non-breeding seasons have recently been made. We have developed a fast, user-friendly tool to estimate the sensitivities of key seabird species to Offshore Renewable Developments in all Scottish waters and produce relative and absolute spatially explicit risk estimates for at-sea locations across a suite of species in both the breeding and non-breeding seasons. The tool will allow users to perform assessment of all Scottish waters or for specified footprints, in relation to multiple seabird species.

1.2 Tool

We have developed a fast, user-friendly tool using R software and Shiny (http://shiny.rstudio.com) to estimate the sensitivities of key seabird species to Offshore Renewable Developments (ORDs) in all Scottish waters. This tool can produce relative and absolute spatially explicit risk estimates for all at-sea locations across a range of species in both the breeding and non-breeding seasons. The tool allows users to perform assessment at both 'global' (all Scottish waters) and 'footprint' (specific to a polygon-defined area of sea) scales, in relation to multiple seabird species. The tool can also output 'apportionment' percentages, allowing users to identify the likely source colony for different at-sea areas across a wide range of species during the breeding season.

The tool includes two main modes, the first of which is of most relevance to spatial planning guidance over all Scottish waters (the 'Map Version'), with the second allowing more focused assessments to be made for specific ORD footprints (the 'Footprint version'):

1.2.1 'Map version': user specifies one species and one or more colonies

The resulting map shows the spatial distribution of the risk score (summed across the specified colonies), covering all Scottish waters. This output of the tool may be fed in to spatial planning, SEA, cumulative/in-combination studies for HRA and EIA and may provide the 'baseline' national and regional context for specific project proposals. It can be applied by policy makers and planners at the strategic stage, by regulators when reviewing assessment studies submitted with applications and by developers when formulating their business plans and specific developments.

1.2.2 'Footprint version': user provides a shapefile, representing the footprint of some proposed development or spatial area

In this mode, the tool will output the total spatial risk score, summed across the footprint supplied by the user. This output of the tool can be applied to a single footprint and fed in to the existing 'baseline' for specific project proposals and hence inform the assessment of specific projects. It can be applied by developers when preparing the assessment studies (EIA and HRA) to be submitted with their application, and by regulators when reviewing such assessment studies.

2 Input data

We consider a set of eleven species: Atlantic puffin, black-legged kittiwake, common guillemot, European storm petrel, great skua, herring gull, lesser black backed gull, northern fulmar, northern gannet, European shag and razorbill.

2.1 Breeding colony size

For each species, we considered the full set of breeding colonies within the British Isles. We derived the size of each breeding colony from Seabird 2000 (http://jncc.defra.gov.uk/page-4460), the most recent complete census of seabird populations within the British Isles, which was conducted between 1998 and 2002. The tool works with Seabird 2000 sub-sites, the finest geographical classification recorded within the census.

2.2 Global utilisation distributions derived from spatial survey data

The study focused upon the exclusive economic zone (EEZ) of Scotland. This area was converted into 2.5 km resolution orthogonal cells. This grid system was used to quantify species presence, species densities (animals per km^2), survey coverage (km^2), and environmental variables in preparation for SDM (Species Distribution Modelling) approaches (Elith and Leathwick, 2009).

Vessel and aerial surveys were collated from across the eastern North Atlantic region (from Norwegian waters to those west of Portugal) between 1985 and 2017. Observers recorded where and when they watched, the platform type (vessel or aircraft), observation position (height above sea level, field of view) and the behaviour of birds (in flight or on the water). The resultant collation of seabird surveys contained survey effort from academic (n=5), commercial (n=1), governmental (n=5) and non-governmental (n=2) organisations across 11 countries, totalling 1.36 million km and 64,244 hr of surveys. There was some spatial and temporal bias in coverage, with the majority of surveys occurring during summer months and post-2000, targeting coastal and shelf-sea regions. To increase statistical power, all surveys were used in the calculation of area effectively covered, commonly known as the effective strip width (*w*). This measure varies among surveys, meaning that animal counts and coverage are not directly comparable. A calculation of the effective strip width standardises counts and coverage, allowing these to be converted into densities (animals per km^2) and area searched (km^2), which enables direct comparisons to be made among surveys. Variations in the effective strip width among surveys were calculated using a half-hazard detection function model. Functions were performed using the package 'mrds' (Thomas et al., 2010) in R Statistics (R Core Team, 2014).

The distance between the observer and animal (m) was the response variable. Transect-design (strip versus line), platform height (m) and sea state (Beaufort scale) were explanatory variables. For each category, all combinations of explanatory variables were modelled, with the combination producing the lowest Akaike's

Information Criteria (AIC) used to estimate variations in *w* for each species among surveys. Whenever possible, the above procedure was followed. However, there were deviations in some categories. These were primarily due to discrepancies for information collected, and low sample sizes for particular combinations of species, platforms and transect design (see report for a full description). Calculations of the area searched (km^2) per transect were then made using the formula:

$$Area\ Searched\ = w * l * \ s$$

where *l* is the transect length (km), and *s* indicates whether observers searched on 1 or 2 sides of the platform.

Environmental variables included in the model were sea surface temperature, sea depth, mean current speed and stratification. Seabirds are central place foragers during the summer months, with distributions of species often centred upon large colonies (Gaston, 2004). A colony index was therefore calculated for each cell to quantify spatial and temporal variations in their influence, based on Seabird 2000 (http://jncc.defra.gov.uk/page-4460). A cumulative colony index (CI) was then calculated for each cell. A separate index was calculated for each species. Densities (animals per km^2), area covered (km^2), and environmental variables were calculated for every combination of survey, day and cell. All processing was performed using the 'raster' package (Hijmans, 2013) in R statistics (R Core Team, 2014).

A hurdle approach was used to quantify relationships between the density of animals and environmental variables. This approach comprises two elements: a presence-absence model relating to the probability of encountering animals, and a count model which relates to the density of animals when encountered (Zuur et al., 2009b). The presence-absence model was used to predict biogeographical range, whilst the count model was used to identify aggregations within those ranges. This division allowed explanatory variables to be included at appropriate scales. Generalized Linear Models (GLM) in combination with General Estimating Equations (GEE) were used throughout analysis (Koper and Manseau, 2009), performed using the 'geepack' package (Højsgaard et al., 2006) in R Statistics (R Core Team, 2014). Throughout the analysis, forwards-model selection based on AIC was used to select the optimal model (Zuur et al., 2009a).

The output from the models are the predicted density of birds (per km^2) for each cell k on a regular 2.5 x 2.5km grid that covers the Scottish part of the UK EEZ, for each species i, for either "flying" or "non-flying", for each month of the year. We then averaged over months to find the mean monthly predicted density of birds for the breeding and non-breeding seasons, for both flying birds (d_{Fk}) and non-flying birds (d_{Nk}). Based on advice from the project steering group, we included two alternative definitions of the breeding season. In the first definition, 'MERP_breeding_season', we choose the set of months defining the breeding season based on expert knowledge (Table 1a). In the second definition, 'SNH_breeding_season', we used months provided by SNH (https://www.nature.scot/sites/default/files/2017-07/A2332152%20-%20Suggested%20seasonal%20definitions%20for%20birds%20in%20the%20Scottish%20Marine%20Environment%20-%203rd%20February%202017.pdf) for the 'breeding period (strongly associated with colony)' (Table 1b).

Table 1a. Months used to define breeding season under the 'MERP_breeding_season' definition for each species, based on the months during which strong association with the focal breeding colony tends to start and end.

Species	start of association with colony	end of association with colony
Northern Gannet	April	September
Common guillemot	April	July
Northern Fulmar	April	August
Lesser black-backed gull	April	July
European Shag	March	August
Black-legged Kittiwake	April	August
Razorbill	April	July
Great skua	April	July
Atlantic puffin	April	September
Herring gull	April	August
European storm petrel	May	October

Table 1b. Months used to define breeding season under the 'SNH_breeding_season' definition for each species (based on SNH guidance).

Species	start of association with colony	end of association with colony
Northern Gannet	March	September
Common guillemot	April	August
Northern Fulmar	April	September
Lesser black-backed gull	March	August
European Shag	March	September
Black-legged Kittiwake	April	August
Razorbill	April	August
Great skua	April	September
Atlantic puffin	April	August
Herring gull	April	August
European storm petrel	May	October

For each season (breeding and non-breeding) these can be converted into overall estimates of the "global" utilisation distribution for flying:

$$g_k = \frac{d_{Fk}}{\sum_k d_{Fk}}$$

for all behaviours combined:

$$g_k = \frac{d_{Fk} + d_{Nk}}{\sum_k (d_{Fk} + d_{Nk})}$$

And for the proportion of time that birds spend flying within each grid cell:

$$f_k = \frac{d_{Fk}}{d_{Fk} + d_{Nk}}$$

2.2.1 Assessment of survey effort and uncertainty in maps estimated from at-sea survey data

Survey effort from data used to develop bird density maps from at-sea survey data varied spatially, and over time. For a full discussion of survey effort and uncertainties in bird density estimation see Waggitt et al. (*in review*).

Here, we provide summary maps for the survey effort per month (see figure below). Please see Tables 1a and 1b for the 'MERP' definitions and the 'SNH' definitions of breeding and non-breeding seasons. Effort was generally highest in summer months (May to September). In particular, large areas of the North Sea were covered during July. Outside of July, the majority of effort was concentrated around ports and along ferry/shipping routes, reflecting the use of 'vessels of opportunity' for surveys. Intense patches of effort were also seen along the eastern North Sea during June, which likely represent focussed surveys around wind-farms or oceanographic features of interest. The choice of modelling approaches were driven by the spatiotemporal heterogeneity in effort; conventional density-surface modelling approaches using kriging interpolation or coordinates as explanatory variables are unsuitable for these data.

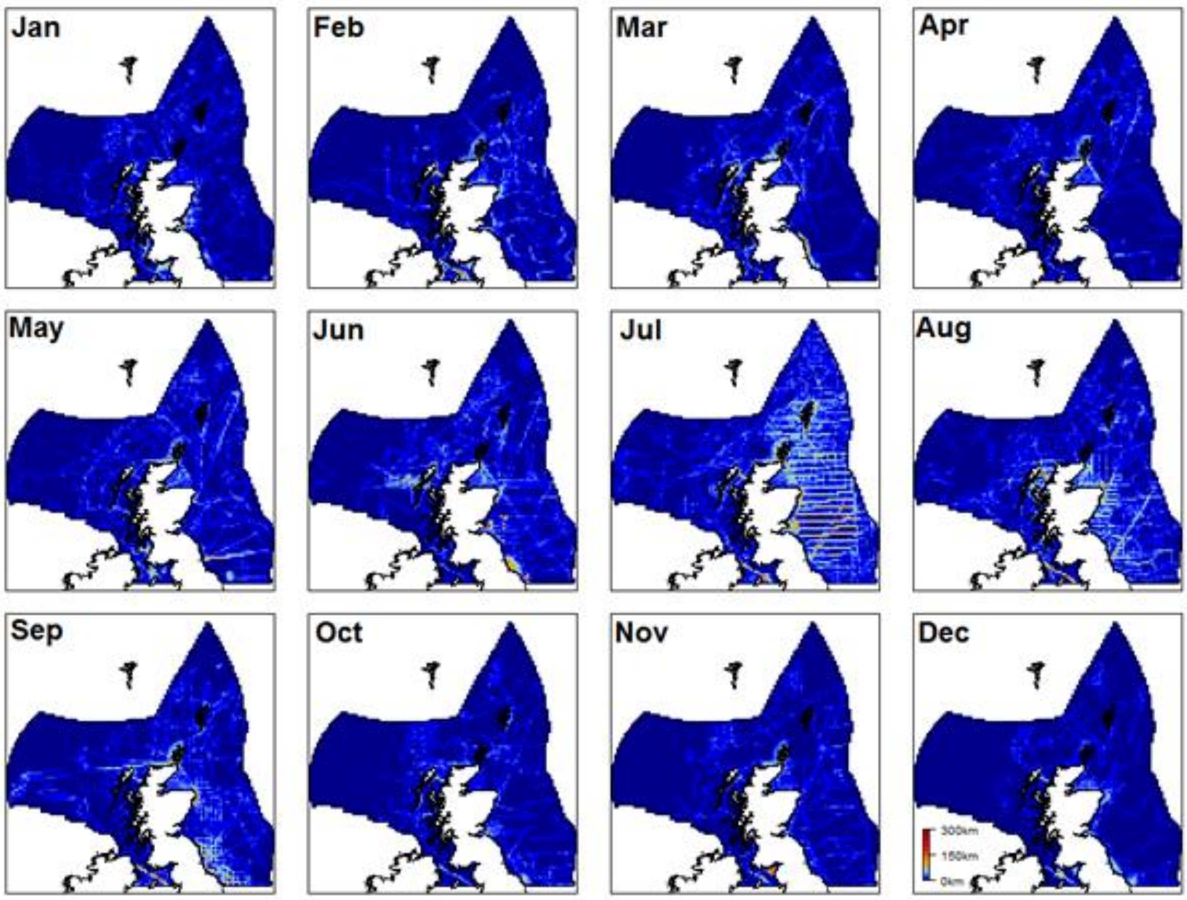


Figure 1. Monthly survey effort (km) for at-sea survey data used in generating bird utilisation distributions.

2.3 Local and global utilisation distributions derived from GPS tracking data

Wakefield *et al*. (2017) fit spatial point process models to GPS tracking data from multiple breeding colonies in order to derive the "local" (i.e. colony-specific) predictive utilisation distributions (UDs) associated with each breeding colony j within the British Isles for each of four species: kittiwake, guillemot, razorbill and European shag. They use a regular 2x2km grid that covers the waters of the UK and Republic of Ireland EEZs (or a regular 0.5x0.5km grid for European shag), and calculate the utilisation distribution u_{jk} to be the proportion of time that a bird of a particular species from colony j spends within grid cell k. The UD is a probability distribution, so it follows that the UD values must sum to one when summed across all grid cells. The UD is assumed to be zero for grid cells that lie beyond the foraging range.

Wakefield *et al.* (2017) also calculate the "global" utilisation distribution, describing the overall distribution of birds (regardless of breeding colony). This can be derived as a weighted sum of the "local" UDs associated with each colony, where the weights are given by the size n_j of the colonies. More specifically, the global UD is equal to

$$g_{Gk} = \frac{n_j u_{jk}}{\sum_k n_j u_{jk}}$$

2.3.1 Note on resolution for spatial data derived from GPS tracking

We aggregated the estimated distributions for European shag up to the same spatial resolution as the other species (i.e. upscale from a 0.5x0.5km grid to a 2x2km grid), using the "aggregate" function within the R package "raster". This was to ensure comparability between species and to prevent the sizes of the input data files within the tool from becoming prohibitively large.

2.4 Apportionment to colonies

Two methods have been proposed for calculating the "apportionment proportion" p_{jk}: the estimated probability that a bird of a particular species observed at sea within grid cell k originates from breeding colony j.

2.4.1 The SNH Apportionment Tool

The SNH tool assumes that the apportioning proportions have a very simple parametric form. Specifically, the current version (SNH, 2018; https://www.nature.scot/sites/default/files/2018-11/Guidance%20-%20Apportioning%20impacts%20from%20marine%20renewable%20developments%20to%20breeding%20seabird%20populations%20in%20SPAs_0.pdf) assumes that they are proportional to

$$p_{jk} \propto \frac{n_j}{a_j d_{jk}^2}$$

where d_{jk} denotes the distance by sea from colony j to the midpoint of grid cell k, and where a_j denotes the proportion of sea within the foraging range of colony j. The apportioning proportions are rescaled so that for each grid cell k they sum to one when summed across colonies.

The proportion of sea a_j within the foraging range, R, can be calculated to be the ratio of the number of cells that are at sea and for which the distance by sea to the colony is less than R to the number of grid cells for which this would potentially be true. This is therefore equal to

$$a_j = \frac{\mathrm{I}(d_{jk} < R)}{(\pi R^2)/C}$$

where I denotes the "indicator function" (which is one if an event occurs, and zero otherwise) and C denotes the size of a grid cell (in km^2).

The SNH apportioning tool involves no unknown parameters. The density of birds is assumed to decay in inverse proportion to the square of the distance (by sea) from the colony. Note that the spatial distribution associated with the SNH tool is not normalized to sum to one, across grid cells, and so does not necessarily represent a probability distribution.

The SNH Apportionment Tool is not linked to any particular spatial grid, or grid resolution. Within this project we generate SNH apportionment percentages for both the 2.5x2.5km regular grid associated with the maps derived from at sea survey data and the 2x2km regular grid associated with the maps derived from GPS data.

2.4.2 The MSS Apportionment Tool

Searle et al. (2017) produced, under a project funded by Marine Scotland Science, a tool that used the colony-specific utilisation distributions u_{jk} generated by Wakefield *et al*. (2017) as the basis for calculating apportionment proportions. The apportioning proportions, which we hence refer to as "MSS" apportioning proportions, are calculated to be:

$$p_{jk} = \frac{n_j u_{jk}}{\sum_j n_j u_{jk}}$$

These values were generated, on a regular 2x2km grid, for three of the species considered by Wakefield *et al*. (2017); for the current project we also generate these proportions, on the same grid, for the remaining species (European shag).

We used the "resample" function within the "raster" R package to reproject the MSS apportionment proportions onto the 2.5x2.5km grid, to allow the tool to have the option to use the at-sea utilisation distributions in conjunction with the MSS apportionment proportions.

If the MSS apportioning tool is used – i.e. if apportioning of birds to breeding colonies is based upon maps derived from GPS data - then the foraging ranges are fixed to be equal to the values used in creating the underlying statistical models of GPS data (Wakefield et al., 2017). If the SNH apportioning tool is used then the user enters the foraging range.

3 Risk Scoring

Certain et al. (2015) developed a framework that has been applied to assessing the relative risk associated with ORDs and seabirds in UK waters. Their framework applies a factor-mediated vulnerability assessment that combines (i) information on species ecological traits and conservation status organised in a matrix of "vulnerability factors", (ii) a conceptual model of how these factors affect species vulnerability, and (iii) data on the spatial distribution and abundance of each species.

The tool implements this framework for each of the 11 species using the specific equations developed by Certain et al. (2015). However, we updated the individual scores for each of the species using information from Furness et al. (2013) and Wade et al. (2016) to better reflect the UK context, and to update some scores based on new knowledge or assessments. More specifically, all score range from 1 (low) to 5 (high), and we applied the following changes:

- For 'habitat flexibility' the Furness et al. (2013) scores were used – these scores are also the same as those in Wade et al. (2016)
- For 'nocturnal activity' the Furness et al. (2013) scores were used – these scores are also the same as those in Wade et al. (2016); with the exception of:
    - Northern gannet – changed from a score of 2 to 1
    - Herring gull - changed from a score of 3 to 2
    - Kittiwake - change from a score of 3 to 2
- The percent height at blade height for northern gannets was scored at a value of 4 in line with Furness et al. (2013); note that Wade et al. (2016) used a score of 3
- The disturbance vulnerability for each species was calculated using the 'displacement to structures' scores from Wade et al. (2016) rather than the 'displacement to vessels' scores used in Certain et al. (2015)

These calculations provide three quantities for each species (Table 2):

- Species-level vulnerability to ORD collision impacts;
- Species-level vulnerability to ORD displacement impacts;
- The sensitivity of the species to change (conservation score).

Certain *et al*. (2015) calculated overall scores for the risk associated with collision risk and displacement risk for each species, by multiplying the sensitivity score by the relevant vulnerability score.

Table 2. Species level vulnerability scores to collision and disturbance, and sensitivity scores for conservation status.

	Species level vulnerability scores		
	Collision	**Disturbance**	**Conservation**
Atlantic puffin	0.17	0.79	0.64
Black-legged kittiwake	0.53	0.60	0.56
Common guillemot	0.23	0.90	0.64
European shag	0.35	0.32	0.68
European storm petrel	0.25	0.48	0.6
Great skua	0.44	0.41	0.64
Herring gull	0.60	0.52	0.64
Lesser black-backed gull	0.60	0.52	0.64
Northern fulmar	0.35	0.32	0.64
Northern gannet	0.67	0.85	0.68
Razorbill	0.20	0.90	0.64

3.1 Exposure

For each species, i, footprint-specific calculations relating to exposure require a range of values of relevance to other tools, such as the Stochastic Band model used to calculate collision mortality, or the displacement matrix for estimating mortality arising from displacement effects. The tool outputs these values for specific footprints, and assumes that the user will then use these outputs within alternative frameworks (using the Band Model and the Matrix approach) to determine the final absolute risk in terms of the number of birds predicted to suffer mortality as a result of the ORD:

- Proportion of time in grid cell that is spent flying
- Utilisation distribution just for flying = proportion of flying time spent in footprint
- Proportion time all behaviours
- Density per km2 for flying birds
- Density per km2 for all birds

4 Internal Calculations

The essential function of the tool is to use the available input data (spatial distribution of birds, behaviour, estimated source colony and risk scores) to generate maps of predicted risk or exposure (footprint mode only) in relation to impacts from ORDs.

This involves addressing three key questions:

1. **Where are the birds at sea?** (spatial maps of estimated density of birds)
2. **What are the birds doing at sea?** (spatial maps of estimated density of birds performing different behaviours – flying, on sea, all behaviours)
3. **Where have the birds originated?** (spatial maps for apportioning birds observed at sea to source colonies in the breeding season only)

The tool allows users to select from the alternative sets of input data for each species (at-sea surveys versus tracking, different behavioural categories, breeding versus non-breeding), to select the method for apportioning birds to colonies (MSS or SNH), and to specify the type of pressure to use in estimating risk (collision, displacement or both). Some of the options are constrained by higher level user specified decisions; for instance, only four species have the option to use bird density maps derived from GPS tracking data; and if users wish to produce maps for the non-breeding season only bird density maps estimated from at-sea survey data may be used. This is because of the limitations of currently available data used to underpin the tool (Fig. 2).

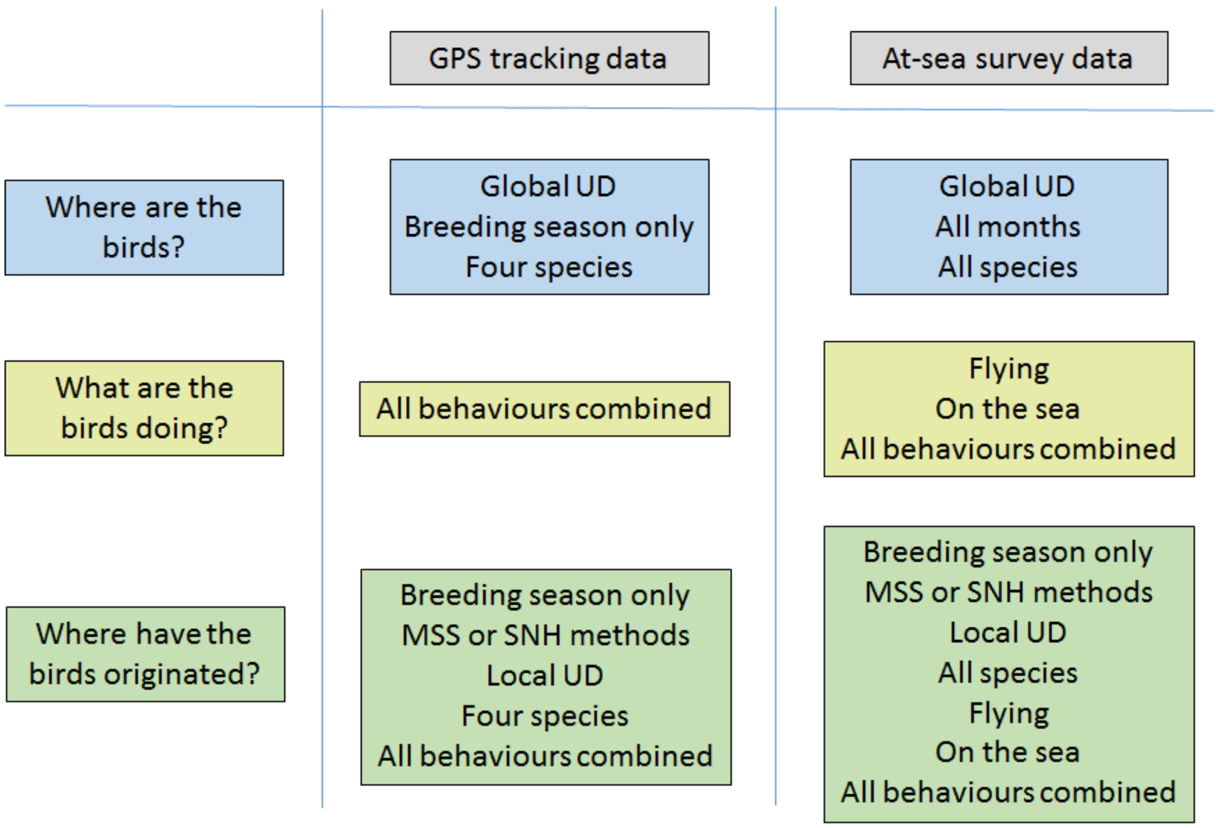


Figure 2. Summary of available data and methods for addressing the three key questions necessary for producing spatial risk maps in the tool.

There are many potential combinations of input data that can be used to produce different types of outputs within the tool, resulting in considerable complexity (Tables 3 & 4). Combining the different available types of input data also leads to some assumptions that should be considered when interpreting the final map output:

- Selecting to use MSS apportioning methods results in apportioning proportions based on estimates from the GPS tracking data for birds engaged in all types of behaviour (e.g., flying is not separated from on sea activity). Therefore, even though 'collision risk' maps may be produced using at-sea survey global UDs and the MSS apportioning method, they are produced by multiplying the collision risk score by the estimated density of birds from particular colonies resulting from apportioning derived from birds engaged in all behaviours, not those only engaged in flying.

- It is possible to apportion four species of birds using the MSS apportioning method, even when bird densities are estimated from at-sea survey data. Therefore, in this instance, the apportioning of birds to source colonies assumes the spatial pattern of apportionment proportions for at-sea survey derived bird densities is the same as that for GPS tracking derived densities.

Table 3. Summary of available input options. Mode specifies if the tool is to be run in 'map' or 'footprint' mode. Output type specifies is the tool is to be used to estimate apportionment proportions ('apportioning'), risk score (e.g., for collision, displacement or both), or absolute exposure (footprint mode only). Global method specifies the type of data to be used in estimating the global utilisation distribution of birds; 'ASU' are UDs derived from at-sea survey data (Waggitt et al. in review), 'GPS' are UDs derived from GPS tracking data (Wakefield et al. 2017). Note that for mapping apportioning proportions, no global UD need be specified ('none'). Apportioning method specifies if birds seen at sea are to be attributed to source colonies using either the 'SNH' or 'MSS' methods. Data refers to the underlying input dataset used in the relevant calculation. Rows highlighted in grey are only available for the four species modelled by Wakefield et al. (2017) (black-legged kittiwake, common guillemot, razorbill and European shag); where "data" is listed as A1 or A2 this means that A2 is used for these four species and A1 for all other species.. Details of 'Data' underlying methods are in Table 4 below.

Mode	Output type	Season	Pressure	Global method	Apportioning method	Data
Map	Apportioning	Breeding	Not relevant		SNH	A1 or A2
					MSS	A4
	Risk score	Breeding	Collision	ASU	SNH	G4, A1
			Displacement	ASU	SNH	G1, A1
					MSS	G1, A3
				GPS	SNH	G2, A2
					MSS	G2, A4
			Both	ASU	SNH	G1,G4,A1
		Non-breeding	Collision	ASU	Not relevant	G5
			Displacement	ASU	Not relevant	G3
			Both	ASU	Not relevant	G3,G5
Footprint	Apportioning	Breeding	Not relevant		SNH	A1 or A2
					MSS	A4
	Risk score	Breeding	Collision	ASU	SNH	G4, A1
			Displacement	ASU	SNH	G1, A1
					MSS	G1, A3
				GPS	SNH	G2, A2
					MSS	G2, A4

			Both	ASU	SNH	G1,G4,A1
		Non-breeding	Collision	ASU	None	G5
			Displacement	ASU	None	G3
			Both	ASU	None	G3,G5
	Absolute exposure	Breeding	Collision	ASU	SNH	G1,G6,A1
				ASU	MSS	G1, A3
				GPS	SNH	G2, A2
			Displacement	GPS	MSS	G2, A4
			Both	ASU	SNH	G1,G6,A1
		Non-breeding	Not relevant	ASU	None	G3,G7

Table 4. Summary of the spatial input data files used in tool calculations. Each row represents a spatial dataset that is used by the tool, with "Dataset ID" providing a label for each dataset. For example, Dataset ID 'G1' is created using the global utilisation distribution for all behaviours from at-sea survey data (ASU) during the breeding season on the spatial grid used in modelling at-sea survey data (ASU). Datasets highlighted in grey are only available for black-legged kittiwake, common guillemot, razorbill and European shag.

Type	Season	Method	Grid	Dataset ID
Global UD, all behaviours	Breeding	ASU	ASU	G1
	Breeding	GPS	GPS	G2
	Non-breeding	ASU	ASU	G3
Global UD, flight only	Breeding	ASU	ASU	G4
	Non-breeding	ASU	ASU	G5
Global proportion of time flying	Breeding	ASU	ASU	G6
	Non-breeding	ASU	ASU	G7
Apportionment proportions	Breeding	SNH	ASU	A1
		SNH	GPS	A2
		MSS	ASU	A3
		MSS	GPS	A4

4.1 Calculating exposure

A key input for risk-related calculations is "exposure" – in effect, the proportion of time that birds (from a single colony, or multiple colonies, or all colonies), with a particular behaviour (either flying only, or all behaviours combined) spend within the area of interest. The tool begins by calculating exposure for each cell of the regular grid.

For each grid cell k the input data provide us with:

1. the "global" (overall) relative spatial distribution of birds, g_k, for each behaviour (flying, all behaviours), for each data source (at-sea data, and, where available, GPS data), for each season (breeding, and, where available, non-breeding season)
2. the apportioning proportions p_{jk} for each colony j for this grid cell, derived using either the SNH or (where available) MSS method
3. the proportion of time spent flying, f_k

4.1.1 Overall exposure

The overall exposure for a grid cell – i.e., the exposure averaged across all colonies – will be equal to the global utilisation distribution g_k for this grid cell. The tool allows the global UDs to be derived either from at-sea data (Waggitt et al. *in review*), or, for only four species, from GPS tracking data (Wakefield et al. 2017).

In the non-breeding season, this is the only type of exposure that can be calculated, because colony-specific exposure values require birds to be apportioned to breeding colonies, which is not currently possible in the non-breeding season. It is therefore impossible for users to select specific colonies if the non-breeding season is selected within the tool.

In the breeding season, within map mode, the tool will calculate overall exposure, if users select colonies to be "all", but users are also able to use colony-specific exposure values.

4.1.2 Colony-specific exposure

Within the tool colony-specific exposure values can potentially be derived using either of the two methods for calculating global spatial distributions (GPS or at sea), in combination with either the SNH or MSS apportionment tools. There are, therefore, potentially up to four methods available for calculating colony-specific exposure. However, these four methods are only available for the four species analysed by Wakefield *et al*. (2017) (black-legged kittiwake, common guillemot, razorbill and European shag) and are restricted to the breeding season for birds engaged in all behaviours combined.

1. Global UD (at-sea) * MSS apportionment
2. Global UD (at-sea) * SNH apportionment
3. Global UD (GPS tracking) * MSS apportionment
4. Global UD (GPS tracking) * SNH apportionment

For all remaining species, only one method is available for calculating colony-specific exposure, using global UDs derived from at-sea data and the SNH apportionment tool.

For each combination of input data type (at sea, GPS) and apportioning method (SNH, MSS) we can estimate the exposure associated with each colony j at each grid cell k to be

$$E_{jk} = \frac{g_k p_{jk}}{\sum_k g_k p_{jk}}$$

i.e., the relative overall density of birds in this grid cell, multiplied by the apportioning proportion for this colony, and renormalized so that the exposure values sum to one. The exposure represents an estimate for the proportion of time (either time spent in all behaviours, or flying only time) that birds from colony j spend within this grid cell.

If "global UDs derived from GPS tracking data" are used in combination with "MSS apportionment tool" then the resulting exposure values will simply be the local utilisation distributions (local UDs) produced by Wakefield *et al*. (2017). For the other combinations of methods the resulting exposure values effectively represent a new product.

4.1.3 Exposure for multiple colonies

In the breeding season, in "map" mode, users may also request multiple colonies to be considered. In this case, the tool will sum the apportioning proportions for these colonies together before calculating the exposure.

4.2 Footprint mode

If the tool is run in "footprint" mode, the user must specify a polygon associated with a footprint F, and the first step of the calculations involves deriving the proportion of each grid cell k lying within the footprint.

The exposure associated with the footprint is then calculated to be the sum, across all grid cells k, of

(Proportion of grid cell k lying within footprint F * Exposure for grid cell k)

This formula can be applied to overall exposure values, colony-specific exposure values, or exposure values associated with a selection of multiple colonies.

The apportioning proportion associated with the footprint can be calculated by dividing the footprint-level exposure for the colony of interest by the sum of footprint-level exposure values across all colonies.

5 Outputs from the tool

The tool is able to produce three possible types of output: risk scores, absolute exposure, or apportioning proportions.

5.1.1 Risk scores

For any particular grid cell (in map mode) or footprint (in footprint mode) and colony, or set of colonies, three possible risk scores can be calculated, based on the pressure being considered.

The risk scores are calculated to be:

(1) Location-specific risk score for displacement = Overall species-level risk score for displacement risk * Location-specific exposure (all behaviours)

(2) Location-specific risk score for collision = Overall species-level risk score for collision risk * Location-specific exposure (flying only)

(3) Location-specific risk score for both pressures combined = Location-specific risk score for displacement + Location-specific risk score for collision

Note that the calculation of combined risk for *both* collision and displacement results from summing the individual risks for collision and displacement. No weighting is given to the different types of risk.

5.1.2 Absolute Exposure

The tool can be used to produce a range of footprint-specific values relating to exposure that can be used within other tools, such as the Stochastic Band model used to calculate collision mortality, or the displacement matrix for estimating mortality arising from displacement effects. The tool outputs these values for specific footprints, and assumes that the user will then use these outputs within these additional tools (such as the Band Model and the Matrix approach) to determine the final absolute risk in terms of the number of birds predicted to suffer mortality as a result of the ORD.

If “absolute exposure” is specified (which is only possible in “footprint” mode), then the following outputs are produced for each colony, for the selected species and user-specified footprint:

1. exposure (all behaviours)
2. exposure (flying only)
3. mean proportion of time in grid cell that is spent flying
4. density per km^2 (all behaviours)
5. density per km^2 (flying only)

Note that the density of birds per km^2 within the footprint is simply calculated to be:

$$\text{Density of birds} = \text{Colony size} * \text{Exposure} / (\text{Area of footprint in km}^2)$$

This calculation can be performed either for all behaviours, or for flying only; the difference lies in the exposure value used.

5.1.3 Apportioning birds to colonies

Within the breeding season, the tool also allows the option of mapping the apportionment proportions themselves (i.e., p_{jk}); note that this is only possible (and only meaningful) within the breeding season when birds are associated with breeding colonies.

6 Caveats and Limitations

6.1 General

- Outputs are dependent upon the quality of the underlying input data. For a full discussion of the limitations and uncertainties associated with the bird density estimates, see Wakefield et al. (2017) and Waggitt et al. (i*n review*).

- Some of the combinations of input data necessarily imply certain assumptions, and outputs should be interpreted accordingly. For instance:

    - Selecting to use MSS apportioning methods results in apportioning proportions based on estimates from the GPS tracking data for birds engaged in all types of behaviour (e.g., flying is not separated from on sea activity). Therefore, even though 'collision risk' maps may be produced using at-sea survey global UDs and the MSS apportioning method, they are produced by multiplying the collision risk score by the estimated density of birds from particular colonies resulting from apportioning derived from birds engaged in all behaviours, not those only engaged in flying.

    - It is possible to apportion four species of birds using the MSS apportioning method, even when bird densities are estimated from at-sea survey data. Therefore, in this instance, the apportioning of birds to source colonies assumes the spatial pattern of apportionment proportions for at-sea survey derived bird densities is the same as that for GPS tracking data derived densities.

    - Producing estimates of risk for *all colonies* during the breeding season using the at-sea bird utilisation distributions will result in maps with non-zero densities of birds beyond the foraging range of colonies. This is likely because the global utilisation densities include observations of breeding and non-breeding birds.

- The use of the SNH apportioning method requires the user to set a maximum foraging range to use in the calculation of apportionment proportions. Results of the SNH apportioning method are, therefore, strongly dependent upon this user-specified value. The SNH apportioning method makes very strong assumptions about the spatial distribution of birds. It ignores the effects of competition and environmental heterogeneity, and assumes that the density of birds is always proportional to the inverse square of distance from colony, regardless of species. The method also introduces a discontinuity (step change) at a distance equal to the observed foraging range – the predicted density of birds will be non-zero at this distance, but is fixed to be zero for all distances greater than the foraging range.

- The tool allows user to map *both* collision and displacement risk combined, using the 'Pressure' equals 'both' option in the user interface. This implies that the two kinds of vulnerability, collision and displacement, are equally important and interact additively. However, collision and displacement are two distinct types of mutually exclusive pressure (if a bird is displaced it cannot suffer collision), with different causes and consequences that might lead to different management measures (Drewitt and Langston, 2006; Fox et al., 2006, Certain et al. 2015). As such, it is recommended that when users select to combine both pressures in tool outputs, they also consider the outputs when pressures are estimated separately, as advocated by Furness et al. (2013) and Certain et al. (2015).

- Overall risk is calculated by multiplying the predicted bird density at each at-sea location with the species risk score. The risk framework is designed to be able to compare species with one another (Certain et al. 2015). However, the risk scores don't have a meaningful quantitative scale, and are instead just scored along an ordinal gradient from 1 to 5. Therefore, it is not clear if a species with a risk score at a location that is twice that of another species is in fact at twice the risk of the second species.

- The tool has limitations in the potential combinations of input data and in the biology underpinning assessments of sensitivity. Within the tool there are a series of rules determining which combinations of datasets and options within the tool are permissible:

  - The first set of these limitations relates to the internal logic or structure of the tool, and the biological constraints used in sensitivity calculations:
    - **Rule 1a**. if risk is set to 'absolute exposure' or to 'apportioning' then the pressure cannot be specified. This is because, by request, absolute exposure outputs cover five different tool outputs of relevance to both collision and displacement pressures; and because when apportioning proportions are selected as the form of output the specification of pressure type is irrelevant.
    - **Rule 1b.** if 'risk' is selected, pressure may not be left as empty; this is because the calculation of risk requires the use of either collision, displacement, or both sets of sensitivity scores.
    - **Rule 2a**. if apportioning is selected for the form of outputs, the spatial product for estimating bird densities must be set to empty. This is because the apportioning proportions are derived from apportioning maps calculated using either the MSS or SNH methods, and do not require underlying global maps for bird utilisation distributions.
    - **Rule 2b**. conversely, if 'risk' or 'absolute exposure' are selected, users must also specify the global spatial product to be used. This is because both calculations require an underlying bird utilisation distribution.
    - **Rule 3a**. If the season is selected as non-breeding, the users may only select to display results for 'all colonies'. This is

because apportioning to source colonies is not possible in the non-breeding season.
  - **Rule 3b**. Similarly, if the season is set to non-breeding, then apportioning must be set to empty.
  - **Rule 3c**. If the apportioning method is set to empty, then users may only select ‘all colonies’.
  - **Rule 3d**. if the season is set to breeding season, then the apportioning method must be set to either of the two options (MSS or SNH) and may not be empty.
  - **Rule 4**. if map mode is selected then risk cannot be set to absolute exposure (this is only available in footprint mode because it is only logical to estimate the five components of absolute exposure in relation to a relatively small, defined area e.g., a footprint)
  - **Rule 5**. If footprint mode is selected, then ‘colony type’ may only be set to ‘all colonies’. This is because in footprint mode the tool automatically outputs results for all colonies for the selected species.

- The second set of limitations relates to the data underlying the tool:
  - **Rule 6**. if season is set to non-breeding, then only bird utilisation distributions derived from at-sea survey data may be used. This is because the GPS-derived utilisation distributions used in the tool only relate to the breeding season months when tracking data were collected.
  - **Rule 7**. if ‘pressure’ is set to ‘collision’ or to ‘both’ then the product to use for the global spatial distribution may only be set to at-sea. This is because only the at-sea data used in the tool provide utilisation distributions for birds in flight, the GPS derived utilisation distributions are for all behaviours combined.
  - **Rule 8a**. If the species selected is not European shag, black-legged kittiwake, razorbill or common guillemot, then GPS derived utilisation distributions may not be used, because they are not currently available for any other species.
  - **Rule 8b**. If the species selected is not European shag, black-legged kittiwake, razorbill or common guillemot, then the MSS apportioning method may not be used.

6.2 Technical limitations of tool

6.2.1 Edge effects

The tool either covers the waters of the UK EEZ (if “GPS tracking” data is used to calculate the global UD) or Scottish waters (if “At sea” data is used to calculate the global UD). If the distance between the chosen footprint and the edge of the spatial domain is less than the foraging range (in footprint mode), or the selected colony lies within the foraging range of the edge of the spatial domain, then edge effects are liable to lead to bias in the results. In particular, the importance of colonies that lie close to, or beyond, the edge of the spatial domain is likely to be systematically over-estimated, because the part of the UD that lies outside the foraging range will be omitted from the calculations.

In extreme cases – e.g. where we consider a colony that lies completely outside the spatial extent – the resulting outputs are likely to be visibly strange; in less extreme situations, the results will look plausible, but are still likely to include systematic bias.

6.2.2 Inconsistencies between spatial distributions and apportioning proportions

The apportioning percentages and "local UDs" used in calculating risk scores will not, in general, be consistent with each other. In other words, the "apportioning percentages" that are calculated using these local UDs will not exactly match the apportioning percentages produced using the SNH or MSS methods. This is not a mistake, but a fundamental limitation of combining global UDs derived under one set of assumptions with apportionment proportions that have been derived under a different set of assumptions: in this context, it is impossible to ensure that the apportionment proportions sum to one, the local UDs sum to one and the global UDs sum to one.

6.2.3 Re-projection

If the “At sea” method is used in calculating the global UD and “MSS” is used as the method for apportionment then the apportionment proportions will be reprojected from a 2x2km grid (used in the MSS tool) to a 2.5x2.5km grid (used in calculating the global UDs), prior to any calculations being performed. Re-projection always risks introducing error or bias into the calculations, although as the two grids involved have similar resolutions the magnitude of any such error or bias will hopefully be small in this case.

6.2.4 Density of birds

The calculations involved in calculating “density of birds” (per km^2) only focus on the behaviours recorded in at-sea surveys - flying, foraging and resting on the water – and ignore time spent at the colony. They are, therefore, likely to systematically overestimate the true density of birds, because they ignore the fact that birds will not spend all of their time at sea.

7 Updating the tool

7.1 Contents of the tool

The tool internally consists of six distinct elements:

Block 1. a set of files that contain the code needed to construct the Shiny user interface;

Block 2. a file (currently orjip-riskmapping-v1.6-functions.R) which contains the R functions used by the Shiny interface;

Block 3. a CSV file, species_meta.csv, which contains the species-level risk scores relating to collision and displacement;

Block 4. a set of .RData input files that are called by the R functions, and which contain pre-processed versions of the input data;

Block 5. the R file used to create the .RData input files from the underlying raw data (orjip-generate-inputs-22march2019-run.R); and

Block 6. an R file containing the functions that are used in constructing these .RData input files.

The first four elements are involved in running the tool, whereas the final two are only involved in updating the tool if new or revised versions of the raw input data become available.

The files within Block 3 should never be altered directly – if changes to these files are required they should be re-generated using the .R file in Block 5. Changes to Blocks 1, 2 and 6 are likely to required considerable technical knowledge, may alter the structure of the calculations performed by the tool, may potentially introduce errors, and should only be taken with great care.

The tool is set up so that two types of change can be made as easily as possible:

a) changes to the species-level risk scores; and
b) changes to the other underlying raw data.

7.2 Risk Scores

The species specific risk scores may be updated or altered by changing the values in the **species_meta.csv** file in the Tool-input-files folder. This file contains the species-specific risk scores for the 11 species currently in the tool:

- CEAc: collision vulnerability score
- CEAd: disturbance vulnerability score
- CEAs: conservation score
- RRCO: collision risk score (collision vulnerability multiplied by conservation score)
- RRDB: displacement risk score (displacement vulnerability multiplied by conservation score)

SpeciesCode	EnglishName	LatinName	BangorName	geotype	CEAc	CEAd	CEAs	RRCO	RRDB
ATPU	Atlantic puffin	Fratercula.arctica	AtlanticPuffin	Bangor only	0.17	0.79	0.64	0.11	0.51
BLKI	Black-legged kittiwake	Rissa.tridactyla	BlackLeggedKittiwake	Both	0.53	0.60	0.56	0.30	0.34
COGU	Common guillemot	Uria.aalge	CommonGuillemot	Both	0.23	0.90	0.64	0.15	0.58
EUSH	European shag	Phalacrocorax.aristotelis	EuropeanShag	Both	0.35	0.32	0.68	0.24	0.22
EUSP	European storm petrel	Hydrobates.pelagicus	EuropeanStormPetrel	Bangor only	0.25	0.48	0.60	0.15	0.29
GRSK	Great skua	Stercorarius.skua	GreatSkua	Bangor only	0.44	0.41	0.64	0.28	0.26
HEGU	Herring gull	Larus.argentatus	HerringGull	Bangor only	0.60	0.52	0.64	0.38	0.33
LBBG	Lesser black-backed gull	Larus.fuscus	LesserBlackBackedGull	Bangor only	0.60	0.52	0.64	0.38	0.33
NOFU	Northern fulmar	Fulmarus.glacialis	NorthernFulmar	Bangor only	0.35	0.32	0.64	0.22	0.20
NOGA	Northern gannet	Morus.bassanus	NorthernGannet	Bangor only	0.67	0.85	0.68	0.45	0.58
RAZO	Razorbill	Alca.torda	Razorbill	Both	0.20	0.90	0.64	0.13	0.58

New species may be added as a new row in this file, however the appropriate maps for bird utilisation distributions would need to be processed and added to the tool (see above).

7.3 Changes to other input data

Changes to any of the other input datasets involve:

1. deleting the relevant .RData input files from the directory containing the tool;
2. modifying the R code in Block 3 so that it uses the revised raw input data; and
3. running the revised R code.

The updated versions of the .RData files should then be generated automatically. Note that this can be computer intensive – updating all input data is liable to take between 24-48 hours of run time on a typical modern laptop.

Generation of the input .RData files involves 11 steps (Table 7.3.1), which involve a range of different sources of raw data (Table 7.3.2). Not all changes to the underlying raw data require all stages of the input data generation to be re-run. The steps that need to be re-run are outlined in Table 7.3.3, depending on the changes that have occurred to the underlying raw data.

Table 7.3.1. Steps involved in creating the .RData input files used by the tool.

Stage	Description
1	Set up files relating to the regular spatial grid
2	Generate colony meta-data files, containing colony sizes and locations
3	Calculate distance to colony by sea from each point on the regular grid
4	Calculate proportion of sea within foraging range for each colony
5	Calculate normalisation constant for SNH apportioning
6	Extract global UDs based on GPS data
7	Extract MSS apportioning proportions
8	Calculate normalization constants for calculating exposure (using GPS data)

9	Extract global UDs based on At Sea data
10	Calculate normalization constants for calculating exposure (using at-sea survey data)
11	Check the validity of the resulting set of .RData input files

Table 7.3.2. A description of the raw data files used in creating the .RData input data files for the tool.

Data source	Description	Required for stages
Grid templates	Raster files that contain the land-sea mask for each grid used in the modelling of GPS and at-sea data	1-11
Colony meta-data	A CSV file containing the locations and sizes of each colony for each species	2-11
Set of potential foraging ranges to consider	A list (vector) of numeric values – this is not a file, it is specified directly within the R code	4-11
GPS-based UDs (global)	A series of raster files – one per species	6-8 and 10-11
GPS-based UDs (colony-specific)	A series of raster files – one for every “node” (a sub-division of Seabird 2000 sub-site, created by Wakefield et al., 2017)	7-8 and 10-11
Colony key file for GPS analysis	A CSV file which specifies the Seabird 2000 sub-site that each “node” belongs to	7-8 and 10-11
Spatial distributions from at-sea data	A series of raster (.asc) files: one for each combination of species, behaviour and season	9-11
Seasonal definitions associated with at-sea data		9-11

Table 7.3.3. Guidance on the stages of the input data generation that need to be re-run, depending on the changes that have occurred to the underlying raw data.

How have the raw data changed?	How do the tool input files need to be updated?
1. The modelled spatial maps derived from at-sea data have changed, but the spatial grid	Re-run stages 9-11 within "generate-orjip-tool-inputs.R", after ensuring the first part of that R file has been modified to refer to the correct raw data files

	(extent, resolution and projections) are unchanged	
	2. The modelled spatial maps derived from at-sea data have changed, and the spatial grid (extent, resolution or projections) has changed	Re-run stages 1-5, and then stages 9-11, within "generate-orjip-tool-inputs.R", after ensuring the first part of that R file has been modified to refer to the correct raw data files
	3. The modelled spatial maps derived from GPS data have changed, and/or the colony size/location data have changed	All stages of the R code (1-11) will need to be re-run, but in this case it is also likely that further changes (e.g. to the underlying functions) may also be needed, so in this case detailed quality control is important

8 Tool validation

8.1 Empirical data

The only wind farm in Scotland that has been operational for a while, and for which there are some monitoring data for pre-, during and post-construction is Robin Rigg (in the Solway Firth).

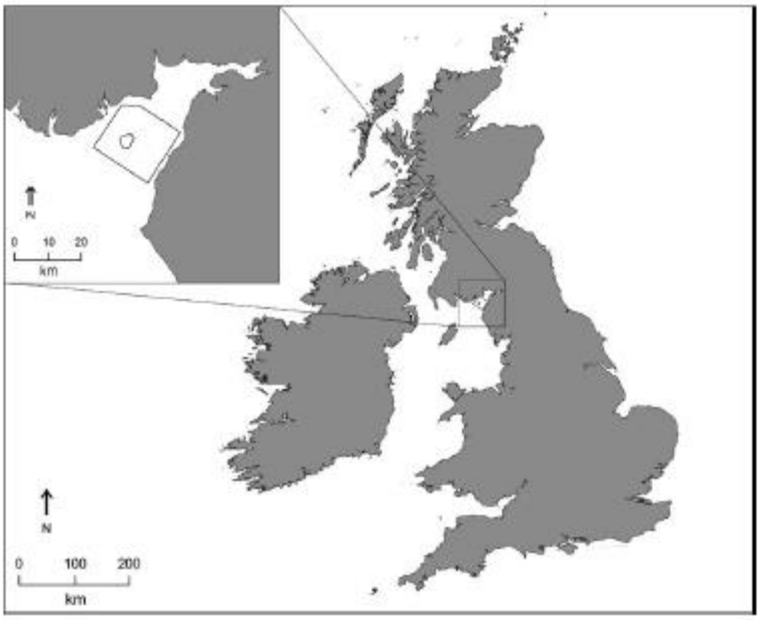


FIGURE 1 Location of the Robin Rigg offshore wind farm in the context of the UK and the Solway Firth (inset). Small polygon shows the offshore wind farm footprint. Larger polygon shows the study area

Figure 3. Location of the only wind farm in Scottish waters that has been operational for a while, and for which there are available pre-, during, and post-construction monitoring data for changes in the distribution of seabirds (Robin Rigg). Figure taken from Vallejo et al. (2017).

The report on the marine ecology monitoring for this windfarm (Canning et al. 2013) includes density estimates (mean number of individuals per unit effort in a 600m x 600m sampling block from all months combined) for five species, in each of the three phases of construction:

Table 5. Estimates for mean number of individuals per unit effort in the three construction phases of the Robin Rigg wind farm in the Solway Firth. From Canning et al. (2013).

EnglishName	pre-construction	construction	post-construction
Black-legged kittiwake	0.16	0.15	0.16
Common guillemot	0.71	0.48	0.60
Herring gull	0.22	0.14	0.13
Northern gannet	0.08	0.07	0.06
Razorbill	0.38	0.24	0.30

We first compared the species ranking of the bird density estimates for 'pre-construction estimates' to the species ranking of density estimates from the tool across a range of combinations of data definitions and apportioning methods (where appropriate). We only used bird utilisation distributions from at-sea survey data, because those derived from GPS tracking data were only available for three of the five species with data in the Canning et al. (2013) report:

	Pre-construction ranking from report (density all months)	Tool BS (MERP) MSS at-sea all behaviours density ranking	Tool BS (MERP) SNH at-sea all behaviours density ranking	Tool NB (MERP) at-sea all behaviours density ranking	Tool NB (MERP) at-sea flying density ranking
Common guillemot	**1**	1 (4.91)	2 (2.91)	2 (0.00044)	3 (0.000045)
Razorbill	**2**	2 (1.45)	3 (1.01)	4 (0.00017)	4 (0.000011)
Herring gull	**3**	NA	1 (4.02)	5 (0.00001)	5 (0.000004)
Black-legged kittiwake	**4**	3 (0.41)	4 (0.49)	3 (0.00041)	2 (0.00016)
Northern gannet	**5**	NA	5 (0.42)	1 (0.0012)	1 (0.00073)

Density rankings were similar between those reported in the Robin Rigg assessment report (Canning et al. 2013), and those estimated by the different methods in the tool. The breeding season density rankings from the tool (columns 2 and 3 in the table above) are consistent with the density rankings from the report, particularly when the MSS apportioning method was used. When the SNH apportioning method was used the rankings were similar, with the exception of herring gull being predicted to have the highest density of all 5 species in the tool.

Density rankings in the non-breeding season were more different when comparing the tool estimates to those in the report (Canning et al. 2013). In the tool, northern gannets were predicted to be in the greatest density of all five species (columns 4 & 5 in the table above), and herring gulls were estimated as the species with the lowest density.

Collision assessments in the Robin Rigg report (Canning et al. 2013) were not split by species, so we do not attempt to compare to tool output here:

Table 5.2: Summary of collision risks from the Robin Rigg offshore wind farm as predicted in the Environmental Statement.

Species	Sensitivity of local population	Magnitude of effect	Significance	Significant impact?
Common scoter	High	Negligible	Very low	No
Red-throated diver	High	Low	Low	No
Migrant waterfowl	Very high	Negligible	Low	No
Other seabirds	Medium	Low/negligible	Low/very low	No
Migrant land birds	Low	Negligible	Very low	No

However, the report did split disturbance assessments by species, so we also used the tool's estimate for displacement risk to rank the five species in the report and compare the report's assessment of disturbance impacts.

Table 5.3: Summary of disturbance assessment from the Robin Rigg development, as predicted in the Environmental Statement. The magnitude of impact is that which would arise if birds were displaced from an area 1 km around the wind farm and what disturbance zone would be needed to result in a significant impact.

Species	Sensitivity of local population	Buffer width (for national importance)	Magnitude of effect	Significance	Significant impact?
Common scoter	High	3 km	Low	Low	No
Red-throated diver	High	>5 km	Low	Low	No
Manx shearwater	Medium		Negligible	Very low	No
Storm petrel	Medium		Negligible	Very low	No
Gannet	Medium		Negligible	Very low	No
Cormorant	Medium		Low	Low	No
Scaup	Medium		Low	Low	No
Kittiwake	Medium		Low	Low	No
Guillemot	Medium		Low	Low	No
Razorbill	Medium		Low	Low	No
Other seabirds	Low		Low	Very low	No

The rankings for displacement risk (breeding season) based on estimates from the tool were consistent with the categories reported in the Robin Rigg assessment report (Canning et al. 2013). In the report, three species (Common guillemot, razorbill and black-legged kittiwake) were reported as having 'Low' disturbance significance, whilst two (storm petrel and northern gannet) were reported as having 'Very low' disturbance significance (Canning et al. 2013). The tool was able to estimate disturbance risk associated with the Robin Rigg footprint for all five species when using the SNH apportioning method, and reported the lowest estimates for storm petrel (zero risk, ranked fifth) and northern gannet (0.0005 risk, ranked fourth). The other three species had higher risk from disturbance (razorbill 0.078, ranked first; common guillemot 0.028, ranked second; and black-legged kittiwake 0.0047, ranked third). We also provide the estimated risk rankings from the tool when using the MSS apportioning method, for comparison over the three species for which this method could be applied.

	Disturbance sensitivity from report ('Significance')	Tool BS (MERP) MSS at-sea disturbance risk	Tool BS (MERP) SNH at-sea disturbance risk
Common guillemot	**Low**	2 (0.028)	2 (0.023)
Razorbill	**Low**	1 (0.078)	1 (0.044)
Black-legged kittiwake	**Low**	3 (0.005)	3 (0.007)
Storm petrel	**Very Low**	NA	5 (zero)
Northern gannet	**Very Low**	NA	4 (0.0005)

8.2 Internal comparison – overall maps

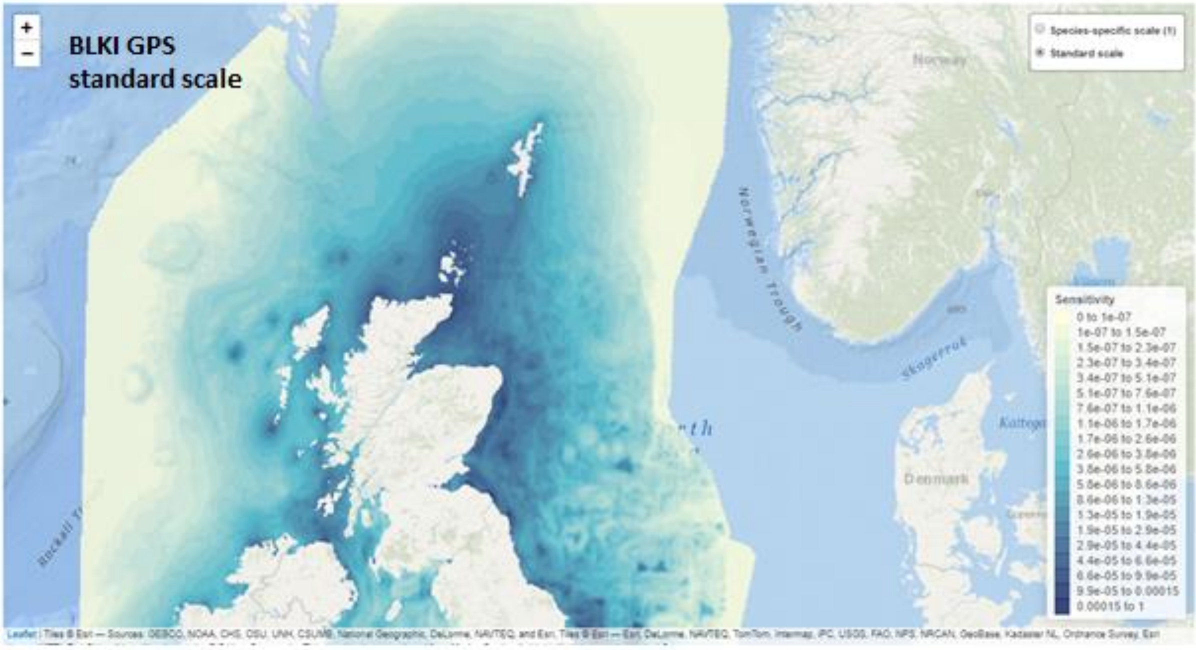
In general, we would expect bird utilisation distributions estimated from GPS tracking data (Wakefield et al. 2017) and from at-sea survey data (Waggitt et al. *in review*) to differ from one another for a number of reasons. Biological reasons include differences between the breeding status of individuals in the different datasets; at-sea surveys contain counts of all birds (breeding and non-breeding), whilst GPS tracking is restricted to breeding adults in most cases. The distribution of all birds may at some locations differ markedly from those of breeding birds. In particular, the less marked decline with distance from colonies and higher densities at some locations further offshore in the at-sea survey maps that are not apparent in the GPS maps may occur if non-breeding birds are less strongly associated with colonies and accessing concentrations of resources that are too distant from colonies to be profitable to breeding birds. Differences in distribution from the two methods may also arise because the habitat utilisation models underlying the two types of data use different environmental covariates. Data collection methods may also explain differences between the two distributions. At-sea survey data typically encompass a much longer time period (set of years) than GPS tracking data, thereby potentially capturing more year to year variation in bird densities. However, at-sea survey data are subject to weather and diurnal bias, with data typically only collected under good weather conditions and in daylight, compared to GPS tracking data which are collected in a broader range of weather conditions and across all hours of day.

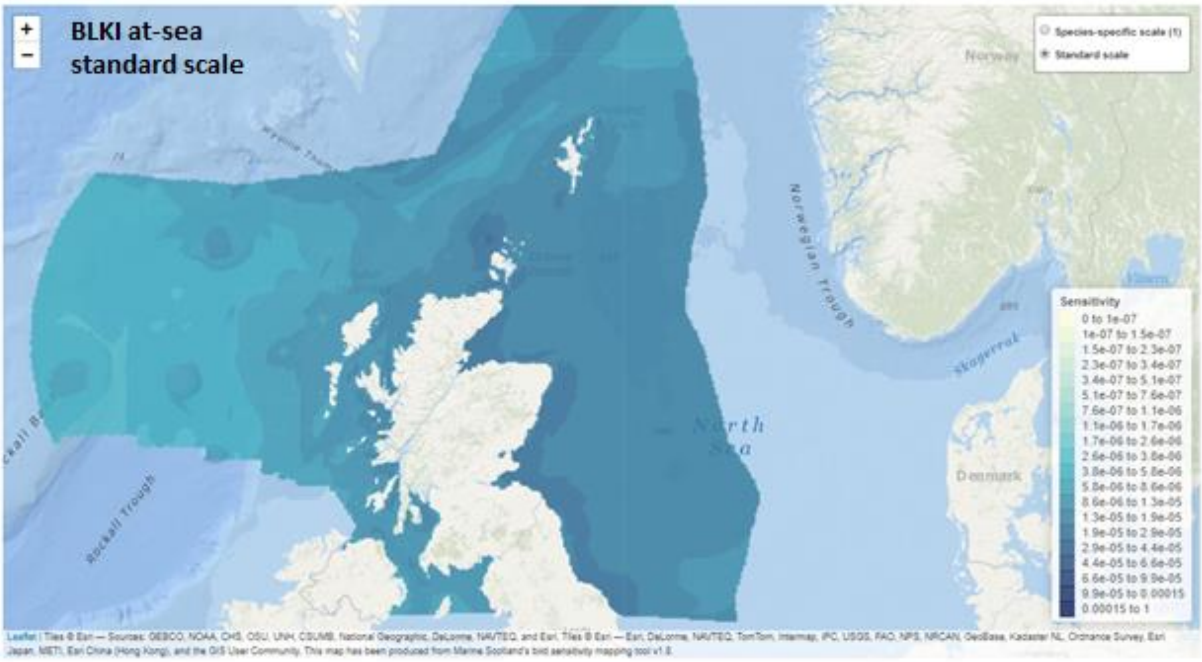
For the four species for which Utilisation Distributions are available from GPS tracking data (black-legged kittiwakes, common guillemots, razorbills and European shags), a comparison can be made with summer distributions obtained from at-sea survey data. Below are maps for each species derived from the two data collection methods. We have visualised these maps in two different ways to allow for a comparison of both the absolute differences in UDs ('standard' scale maps) and of the relative differences in spatial patterning of UDs ('method-specific' scale maps). The 'standard' maps for each species have the same scale and legend, and hence can be used to compare absolute predicted UDs for a species, when using either GPS tracking data or at-sea survey data to derive the UD. The 'method-specific' maps for each species have scales and legends for visualisation that are bespoke to each method (GPS or at-sea), and are used to highlight the spatial patterning in the UDs for each method, rather than for comparing absolute predicted UDs across the two methods.

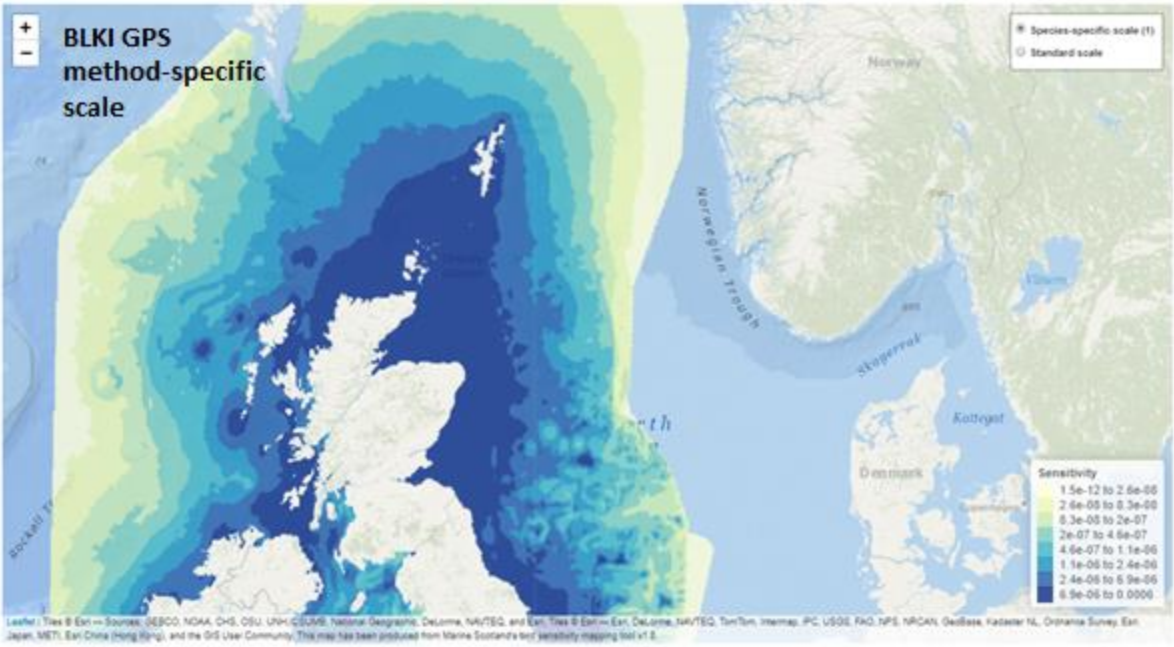
When considering the 'method-specific' maps that highlight the spatial patterning in the UDs derived from each method, it is immediately apparent that there is broad similarity in distribution from the two methods. In all species, higher densities occur close to the coast. This is because breeding birds are acting as central place foragers, repeatedly commuting to and from the nesting site to foraging grounds, resulting in a decay in density with distance to colony. GPS data are based on breeding adults, so the coastal distribution is as expected. That it is also apparent in the at-sea surveys will likely be for two main reasons. First, a significant proportion of birds seen on at-sea surveys are breeding adults. Second, a proportion of non-breeding birds – both immature birds that have not recruited to the breeding population and adults that have failed in their breeding attempt or are taking a sabbatical year – are still likely to be visiting colonies during the breeding season and therefore distributed in proximity to colonies when observed at sea. The closest similarity between the two methods appears to occur with shags, reflecting the extreme coastal distribution of this species with very few birds seen on at-sea surveys more than a few kilometres of the coast, matching what is found from GPS tracking.

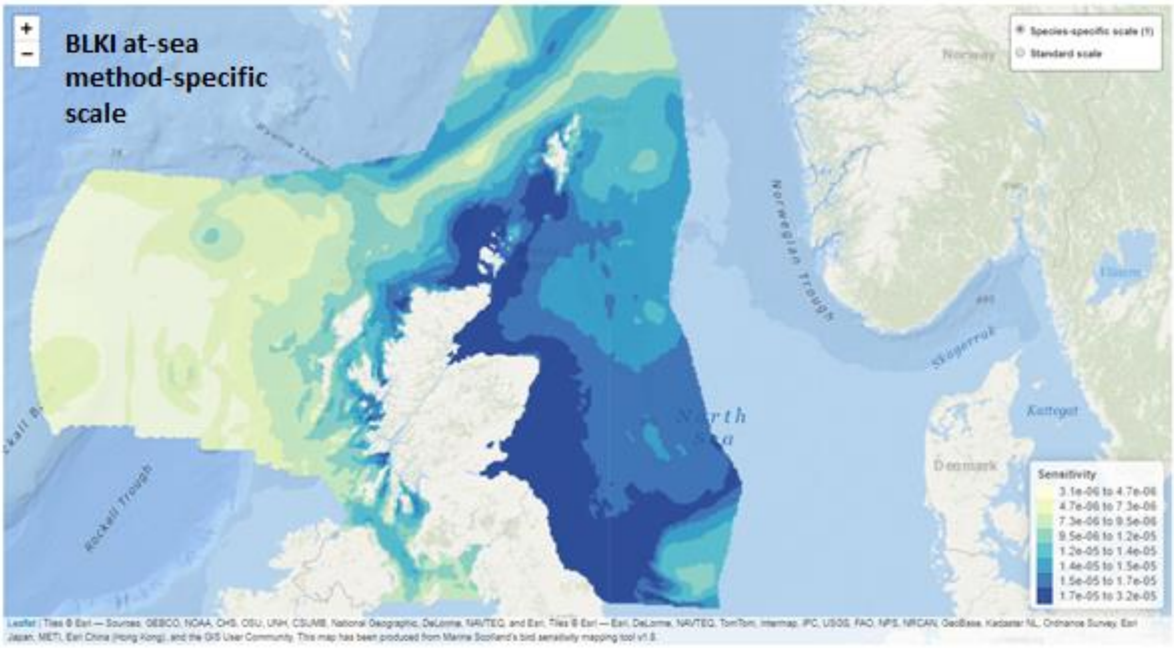
Set against this strong broad scale similarity in spatial patterning of UDs across the two methods, some differences are apparent at the finer scale. Overall, the decline in density with distance from colony is less strong in the utilisation distributions derived from at-sea survey data. In addition, there are hotspots at locations that are distant from coasts apparent in the at-sea survey maps that are not apparent in the GPS maps in all species except shags. An example includes an area to the north-west of Scotland, which has higher densities of kittiwakes that are not apparent from GPS tracking. A second example is the central North Sea, which has higher concentrations of kittiwakes and both auks in the at-sea maps compared to the GPS maps. Conversely, there are areas of high density in the GPS maps that are not apparent in the at-sea survey maps, such as the waters to the north and west of the Outer Hebrides associated with colonies including St Kilda, Flannan Isles and North Rona.

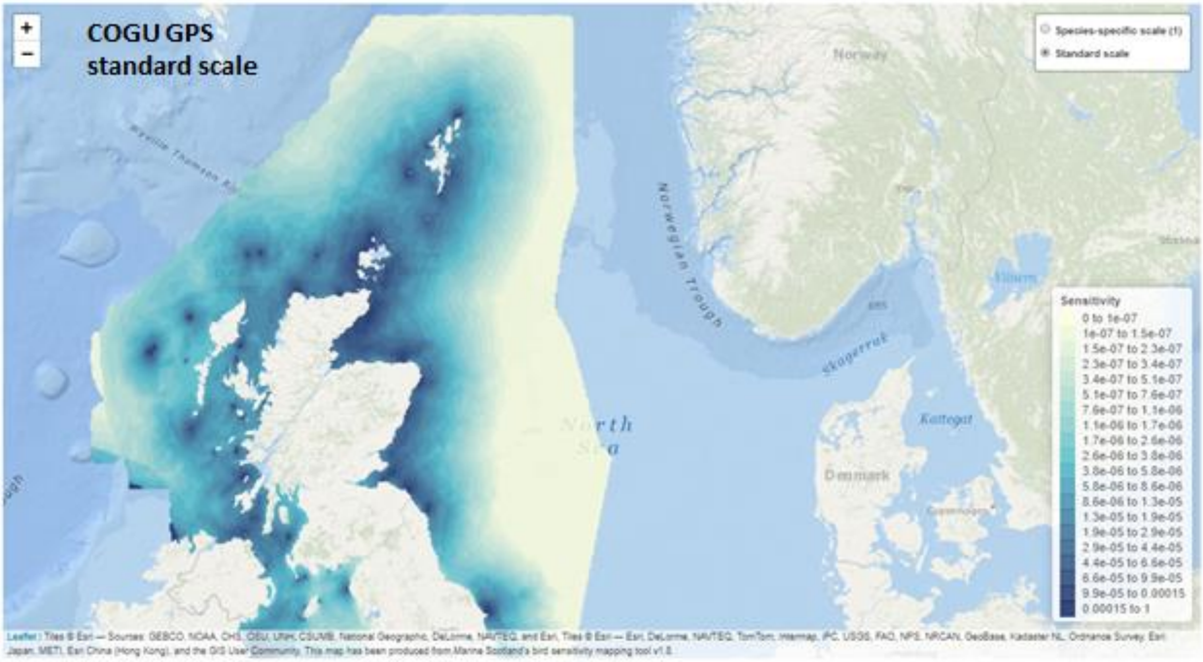
The ’standard’ scale maps show up differences in absolute UDs from the two data types. In general, there is stronger spatial variation and more evident distance to colony effects in the UDs derived from GPS tracking data, and a more ‘smoothed’ UD distribution over space in the at-sea survey UDs. This is particularly true for black-legged kittiwakes, and to a lesser extent common guillemots, with less pronounced differences between the two UDs for razorbills and shags.

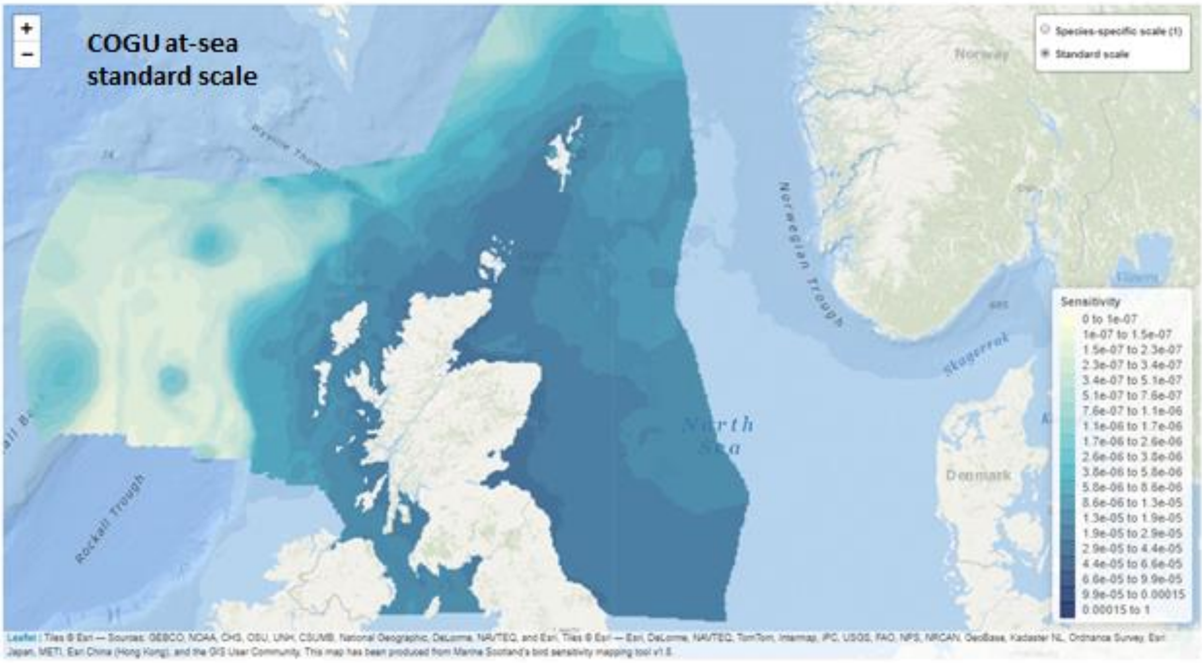

BLKI GPS
standard scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
Denmark
Sensitivity
0 to 1e-07
1e-07 to 1.5e-07
1.5e-07 to 2.3e-07
2.3e-07 to 3.4e-07
3.4e-07 to 5.1e-07
5.1e-07 to 7.6e-07
7.6e-07 to 1.1e-06
1.1e-06 to 1.7e-06
1.7e-06 to 2.6e-06
2.6e-06 to 3.8e-06
3.8e-06 to 5.8e-06
5.8e-06 to 8.6e-06
8.6e-06 to 1.3e-05
1.3e-05 to 1.9e-05
1.9e-05 to 2.9e-05
2.9e-05 to 4.4e-05
4.4e-05 to 6.6e-05
6.6e-05 to 9.9e-05
9.9e-05 to 0.00015
0.00015 to 1

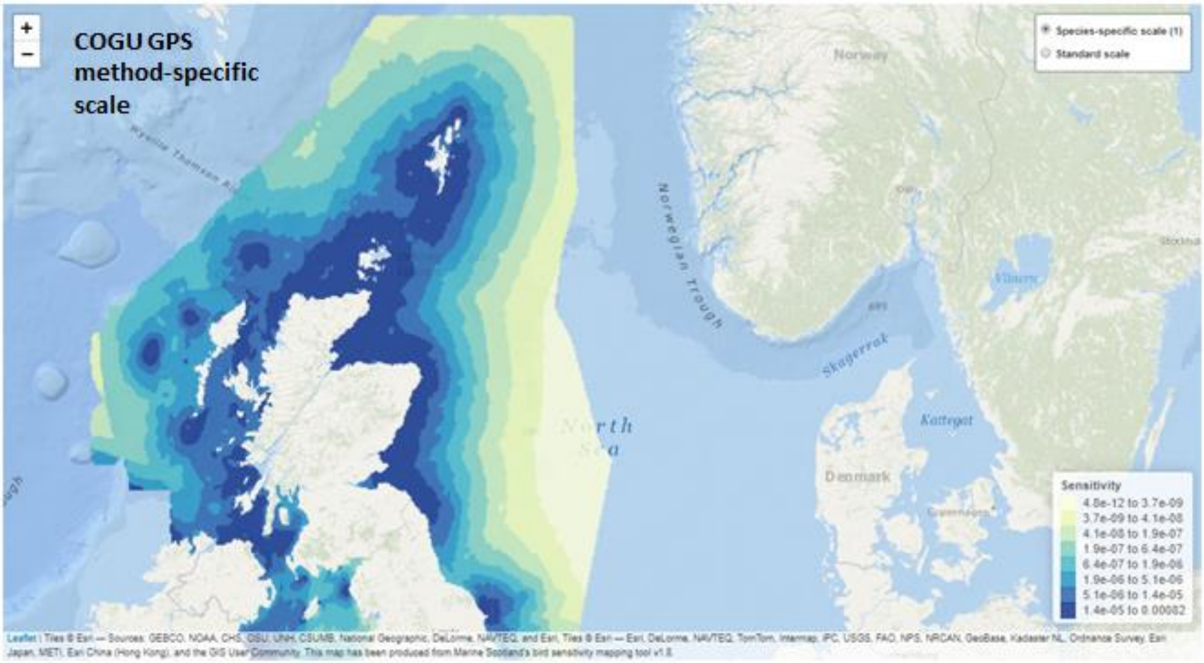

BLKI at-sea
standard scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
Rockall Trough
North Sea
Denmark
Sensitivity
0 to 1e-07
1e-07 to 1.5e-07
1.5e-07 to 2.3e-07
2.3e-07 to 3.4e-07
3.4e-07 to 5.1e-07
5.1e-07 to 7.6e-07
7.6e-07 to 1.1e-06
1.1e-06 to 1.7e-06
1.7e-06 to 2.6e-06
2.6e-06 to 3.8e-06
3.8e-06 to 5.8e-06
5.8e-06 to 8.6e-06
8.6e-06 to 1.3e-05
1.3e-05 to 1.9e-05
1.9e-05 to 2.9e-05
2.9e-05 to 4.4e-05
4.4e-05 to 6.6e-05
6.6e-05 to 9.9e-05
9.9e-05 to 0.00015
0.00015 to 1

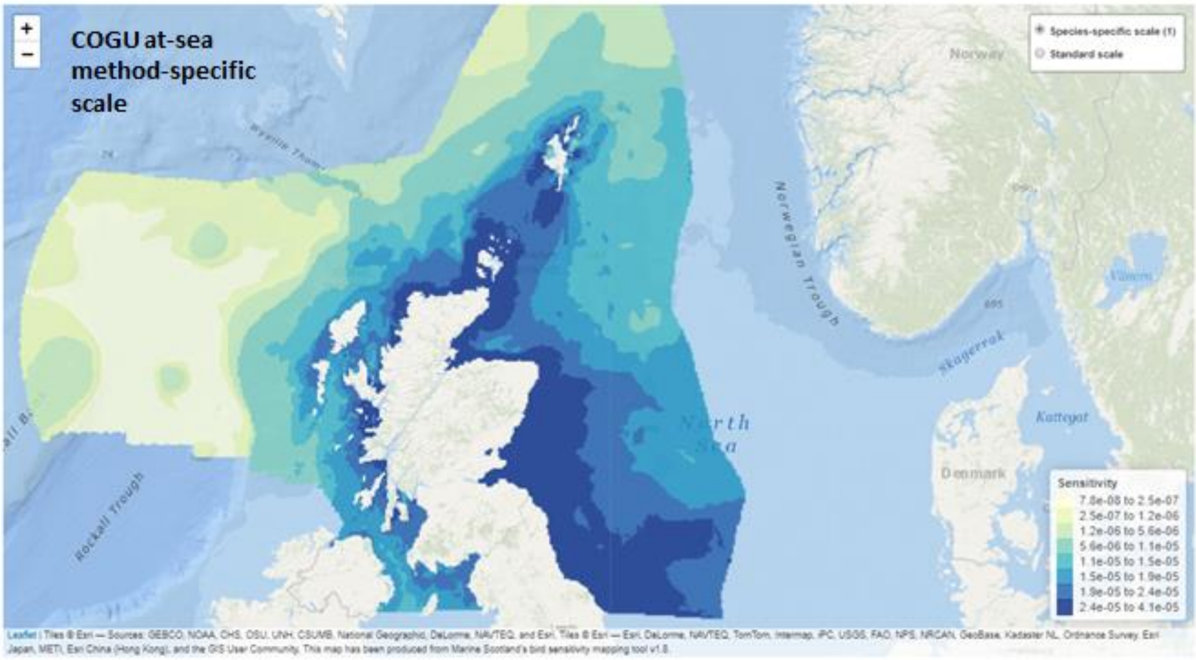

BLKI GPS
method-specific
scale
Species-specific scale (!)
Standard scale
Norwegian Trough
Skagerrak
Kattegat
Denmark
Sensitivity
1.5e-12 to 2.6e-08
2.6e-08 to 8.3e-08
8.3e-08 to 2e-07
2e-07 to 4.6e-07
4.6e-07 to 1.1e-06
1.1e-06 to 2.4e-06
2.4e-06 to 6.9e-06
6.9e-06 to 0.0000

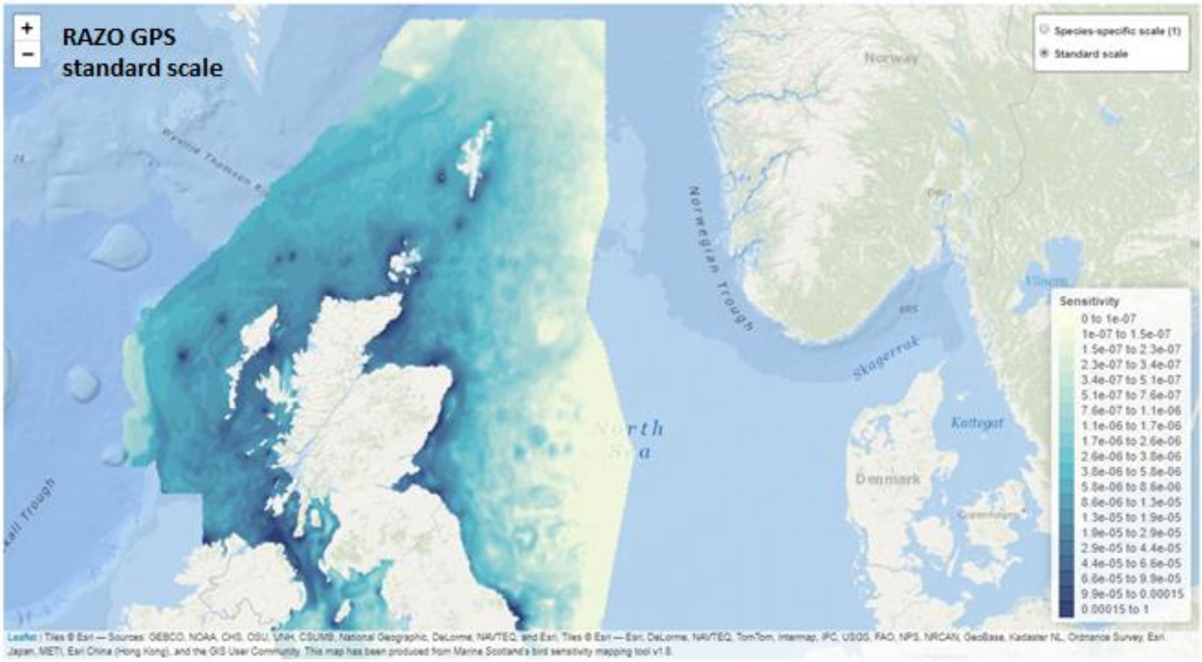

BLKI at-sea
method-specific
scale
Species-specific scale (!)
Standard scale
Norwegian Trough
Skagerrak
Kattegat
Denmark
Rockall Trough
North
Sea
Sensitivity
3.1e-06 to 4.7e-06
4.7e-06 to 7.3e-06
7.3e-06 to 9.5e-06
9.5e-06 to 1.2e-05
1.2e-05 to 1.4e-05
1.4e-05 to 1.5e-05
1.5e-05 to 1.7e-05
1.7e-05 to 3.2e-05

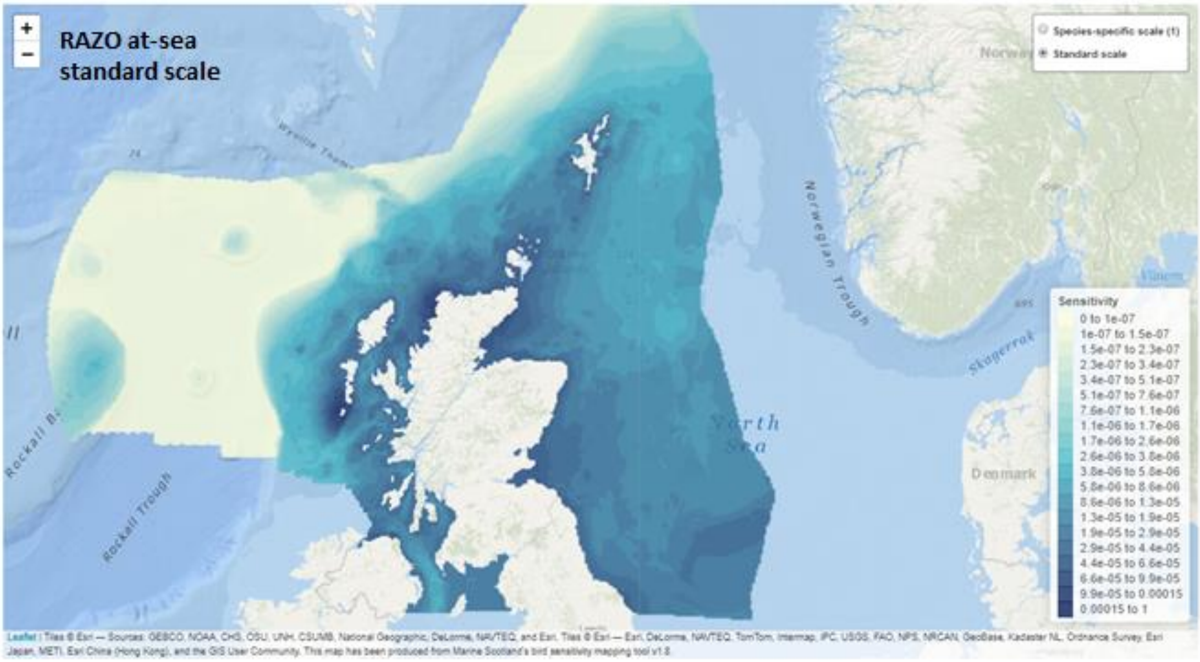

COGU GPS
standard scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
North Sea
Kattegat
Denmark
Sensitivity
0 to 1e-07
1e-07 to 1.5e-07
1.5e-07 to 2.3e-07
2.3e-07 to 3.4e-07
3.4e-07 to 5.1e-07
5.1e-07 to 7.6e-07
7.6e-07 to 1.1e-06
1.1e-06 to 1.7e-06
1.7e-06 to 2.6e-06
2.6e-06 to 3.8e-06
3.8e-06 to 5.8e-06
5.8e-06 to 8.6e-06
8.6e-06 to 1.3e-05
1.3e-05 to 1.9e-05
1.9e-05 to 2.9e-05
2.9e-05 to 4.4e-05
4.4e-05 to 6.6e-05
6.6e-05 to 9.9e-05
9.9e-05 to 0.00015
0.00015 to 1

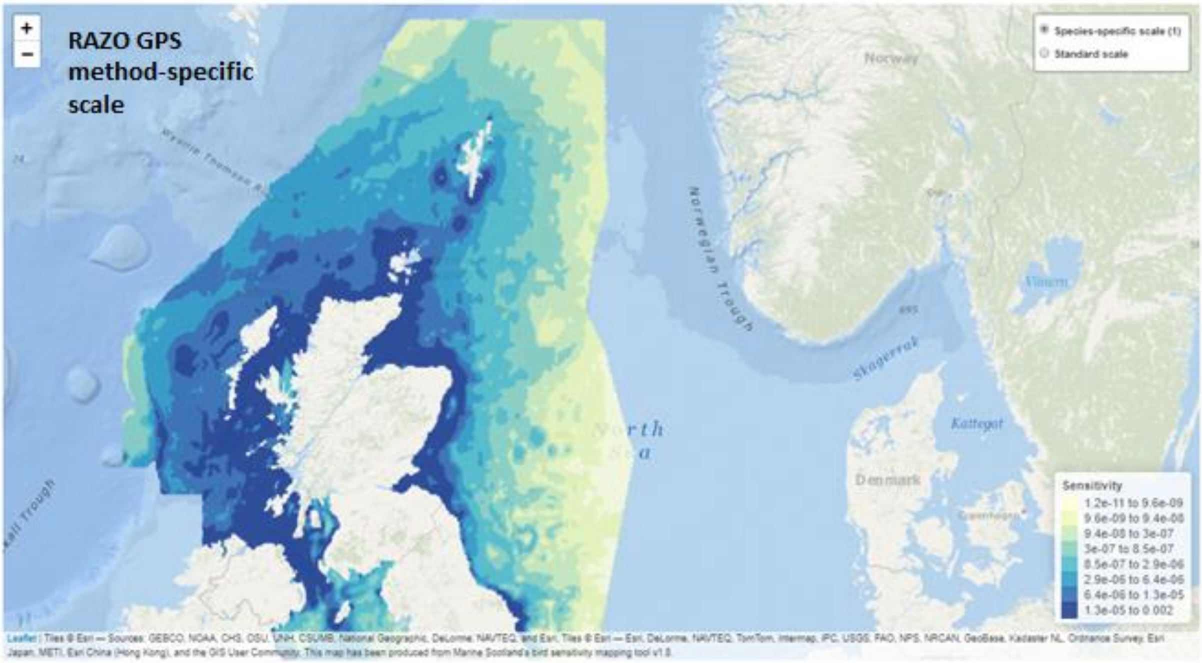

COGU at-sea
standard scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
North Sea
Denmark
Rockall Trough
Sensitivity
0 to 1e-07
1e-07 to 1.5e-07
1.5e-07 to 2.3e-07
2.3e-07 to 3.4e-07
3.4e-07 to 5.1e-07
5.1e-07 to 7.6e-07
7.6e-07 to 1.1e-06
1.1e-06 to 1.7e-06
1.7e-06 to 2.6e-06
2.6e-06 to 3.8e-06
3.8e-06 to 5.8e-06
5.8e-06 to 8.6e-06
8.6e-06 to 1.3e-05
1.3e-05 to 1.9e-05
1.9e-05 to 2.9e-05
2.9e-05 to 4.4e-05
4.4e-05 to 6.6e-05
6.6e-05 to 9.9e-05
9.9e-05 to 0.00015
0.00015 to 1

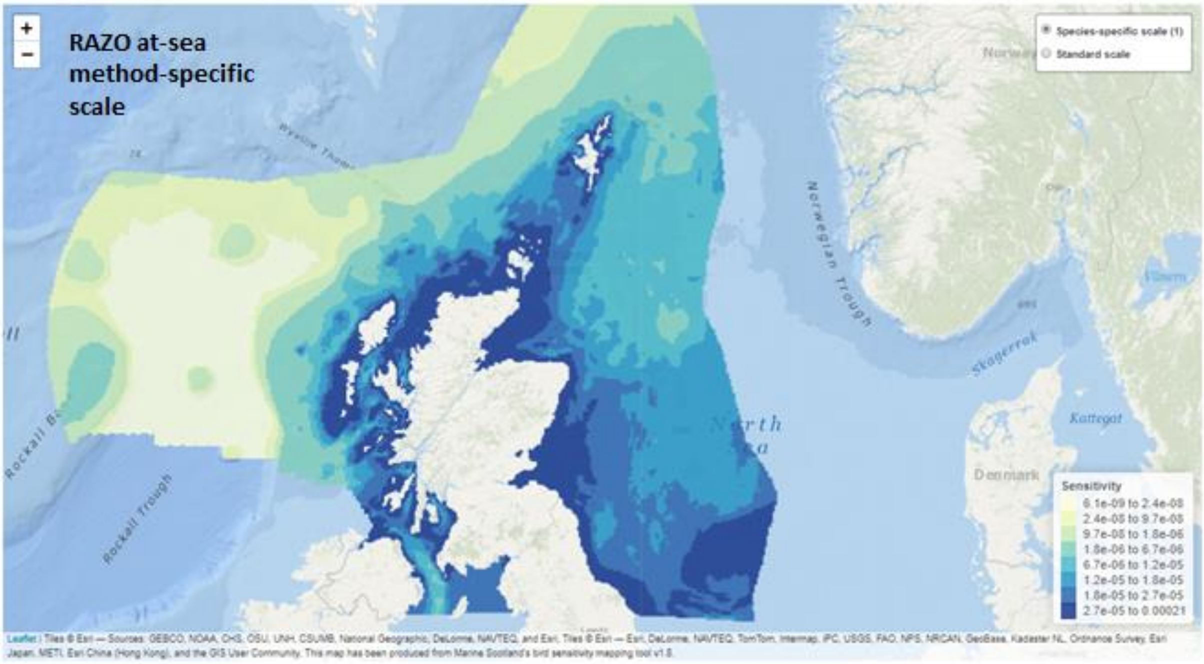

COGU GPS
method-specific
scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
Kattegat
North Sea
Denmark
Sensitivity
4.8e-12 to 3.7e-09
3.7e-09 to 4.1e-08
4.1e-08 to 1.9e-07
1.9e-07 to 6.4e-07
6.4e-07 to 1.9e-06
1.9e-06 to 5.1e-06
5.1e-06 to 1.4e-05
1.4e-05 to 0.00002
Leaflet | Tiles © Esri — Sources: GEBCO, NOAA, CHS, OSU, UNH, CSUMB, National Geographic, DeLorme, NAVTEQ, and Esri, Tiles © Esri — Esri, DeLorme, NAVTEQ, TomTom, Intermap, iPC, USGS, FAO, NPS, NRCAN, GeoBase, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), and the GIS User Community. This map has been produced from Marine Scotland's bird sensitivity mapping tool v1.8.

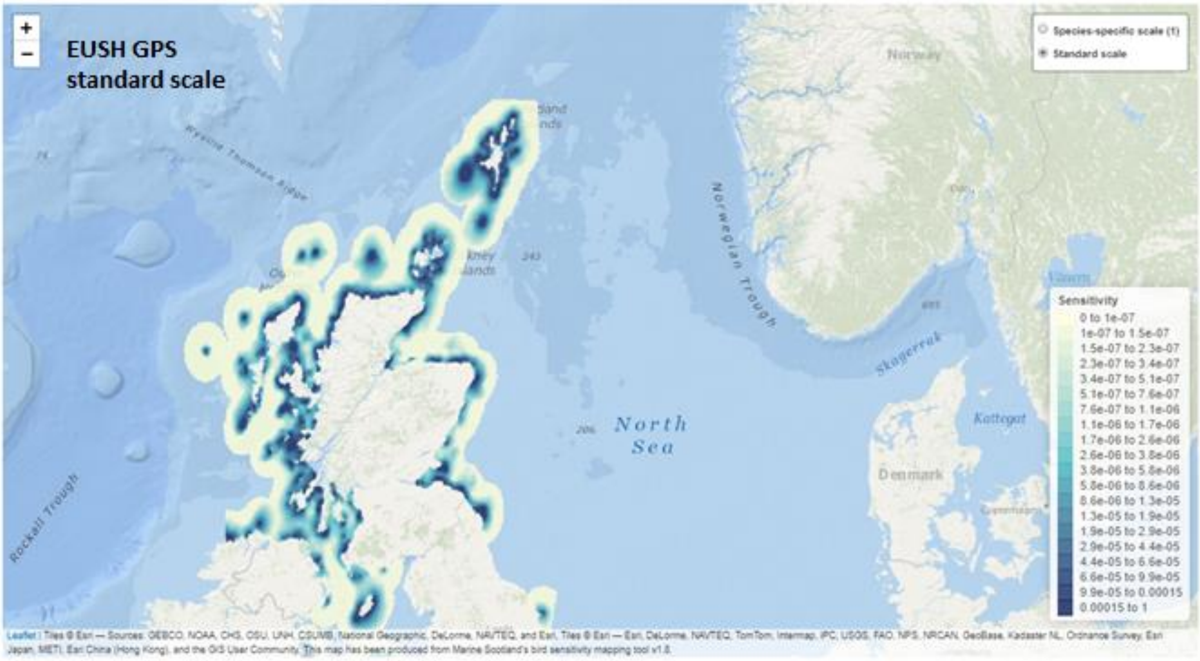

COGU at-sea
method-specific
scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
Kattegat
North Sea
Denmark
Rockall Trough
Sensitivity
7.8e-08 to 2.5e-07
2.5e-07 to 1.2e-06
1.2e-06 to 5.6e-06
5.6e-06 to 1.1e-05
1.1e-05 to 1.5e-05
1.5e-05 to 1.9e-05
1.9e-05 to 2.4e-05
2.4e-05 to 4.1e-05
Leaflet | Tiles © Esri — Sources: GEBCO, NOAA, CHS, OSU, UNH, CSUMB, National Geographic, DeLorme, NAVTEQ, and Esri, Tiles © Esri — Esri, DeLorme, NAVTEQ, TomTom, Intermap, iPC, USGS, FAO, NPS, NRCAN, GeoBase, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), and the GIS User Community. This map has been produced from Marine Scotland's bird sensitivity mapping tool v1.8.


RAZO GPS
standard scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
Kattegat
Denmark
North Sea
Rockall Trough
Sensitivity
0 to 1e-07
1e-07 to 1.5e-07
1.5e-07 to 2.3e-07
2.3e-07 to 3.4e-07
3.4e-07 to 5.1e-07
5.1e-07 to 7.6e-07
7.6e-07 to 1.1e-06
1.1e-06 to 1.7e-06
1.7e-06 to 2.6e-06
2.6e-06 to 3.8e-06
3.8e-06 to 5.8e-06
5.8e-06 to 8.6e-06
8.6e-06 to 1.3e-05
1.3e-05 to 1.9e-05
1.9e-05 to 2.9e-05
2.9e-05 to 4.4e-05
4.4e-05 to 6.6e-05
6.6e-05 to 9.9e-05
9.9e-05 to 0.00015
0.00015 to 1
Leaflet | Tiles © Esri — Sources: GEBCO, NOAA, CHS, OSU, UNH, CSUMB, National Geographic, DeLorme, NAVTEQ, and Esri, Tiles © Esri — Esri, DeLorme, NAVTEQ, TomTom, Intermap, iPC, USGS, FAO, NPS, NRCAN, GeoBase, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), and the GIS User Community. This map has been produced from Marine Scotland's bird sensitivity mapping tool v1.8.


RAZO at-sea
standard scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
Denmark
North Sea
Rockall Bank
Rockall Trough
Sensitivity
0 to 1e-07
1e-07 to 1.5e-07
1.5e-07 to 2.3e-07
2.3e-07 to 3.4e-07
3.4e-07 to 5.1e-07
5.1e-07 to 7.6e-07
7.6e-07 to 1.1e-06
1.1e-06 to 1.7e-06
1.7e-06 to 2.6e-06
2.6e-06 to 3.8e-06
3.8e-06 to 5.8e-06
5.8e-06 to 8.6e-06
8.6e-06 to 1.3e-05
1.3e-05 to 1.9e-05
1.9e-05 to 2.9e-05
2.9e-05 to 4.4e-05
4.4e-05 to 6.6e-05
6.6e-05 to 9.9e-05
9.9e-05 to 0.00015
0.00015 to 1
Leaflet | Tiles © Esri — Sources: GEBCO, NOAA, CHS, OSU, UNH, CSUMB, National Geographic, DeLorme, NAVTEQ, and Esri, Tiles © Esri — Esri, DeLorme, NAVTEQ, TomTom, Intermap, iPC, USGS, FAO, NPS, NRCAN, GeoBase, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), and the GIS User Community. This map has been produced from Marine Scotland's bird sensitivity mapping tool v1.8.


RAZO GPS
method-specific
scale
Species-specific scale (1)
Standard scale
Norwegian Trough
Skagerrak
Kattegat
Denmark
Sensitivity
1.2e-11 to 9.6e-09
9.6e-09 to 9.4e-08
9.4e-08 to 3e-07
3e-07 to 8.5e-07
8.5e-07 to 2.9e-06
2.9e-06 to 6.4e-06
6.4e-06 to 1.3e-05
1.3e-05 to 0.002


RAZO at-sea
method-specific
scale
Species-specific scale (1)
Standard scale
Norwegian Trough
Skagerrak
Kattegat
Rockall Trough
Denmark
Sensitivity
6.1e-09 to 2.4e-08
2.4e-08 to 9.7e-08
9.7e-08 to 1.8e-06
1.8e-06 to 6.7e-06
6.7e-06 to 1.2e-05
1.2e-05 to 1.8e-05
1.8e-05 to 2.7e-05
2.7e-05 to 0.00021


EUSH GPS
standard scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
North
Sea
Kattegat
Denmark
Rockall Trough
Sensitivity
0 to 1e-07
1e-07 to 1.5e-07
1.5e-07 to 2.3e-07
2.3e-07 to 3.4e-07
3.4e-07 to 5.1e-07
5.1e-07 to 7.6e-07
7.6e-07 to 1.1e-06
1.1e-06 to 1.7e-06
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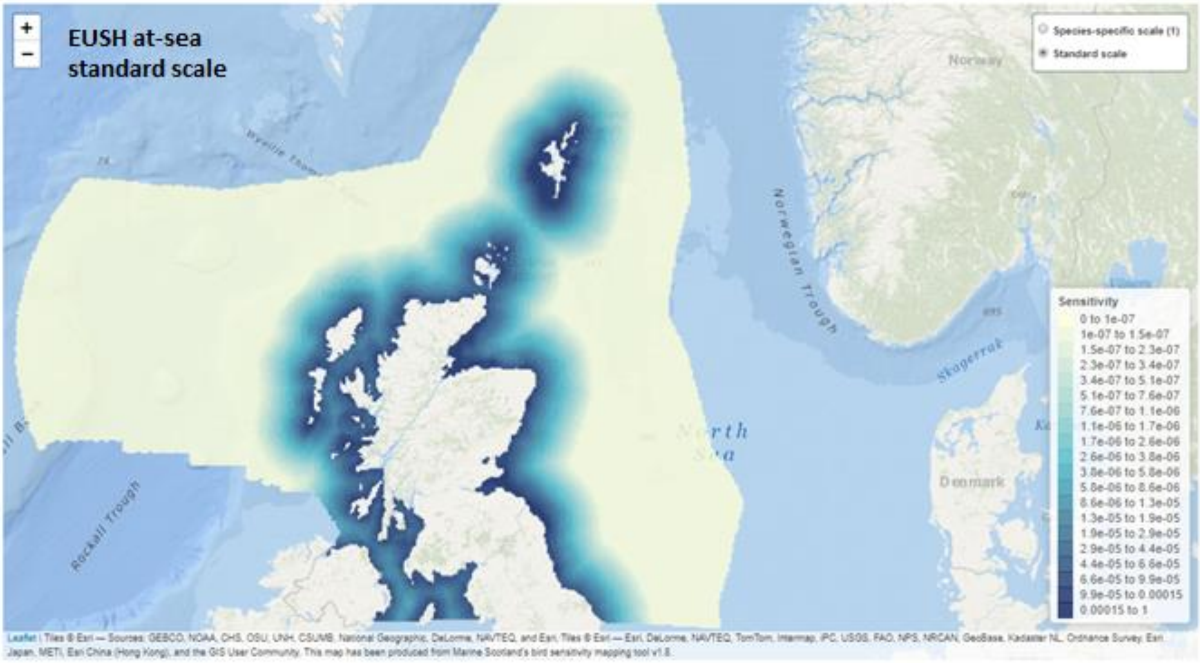
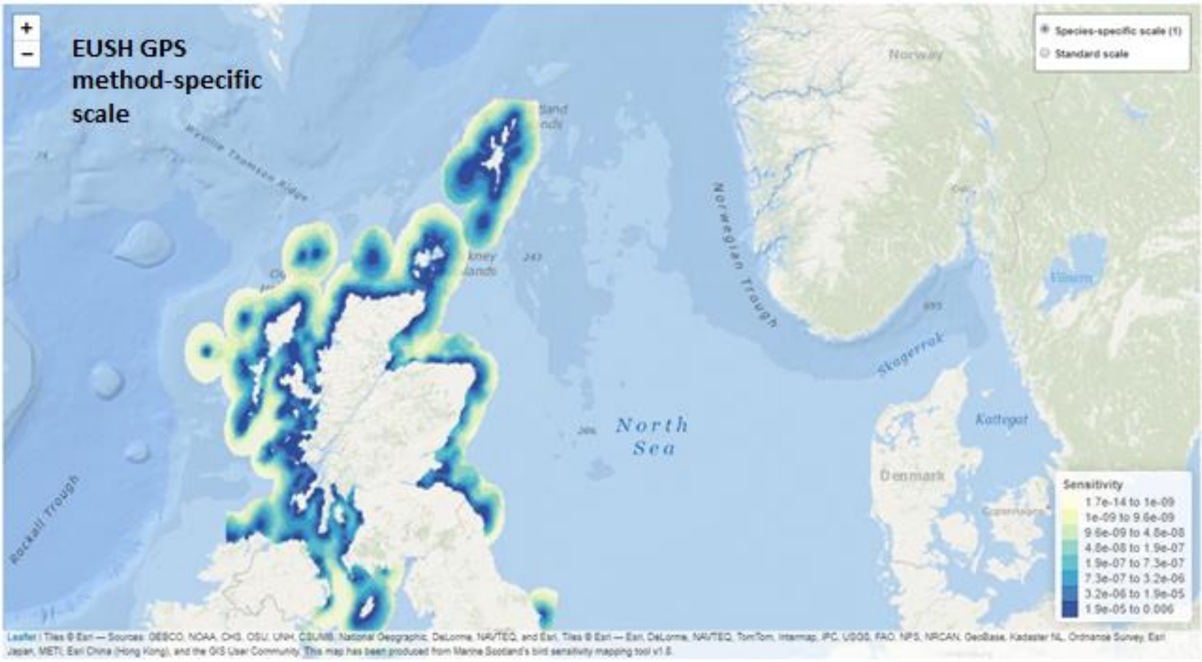
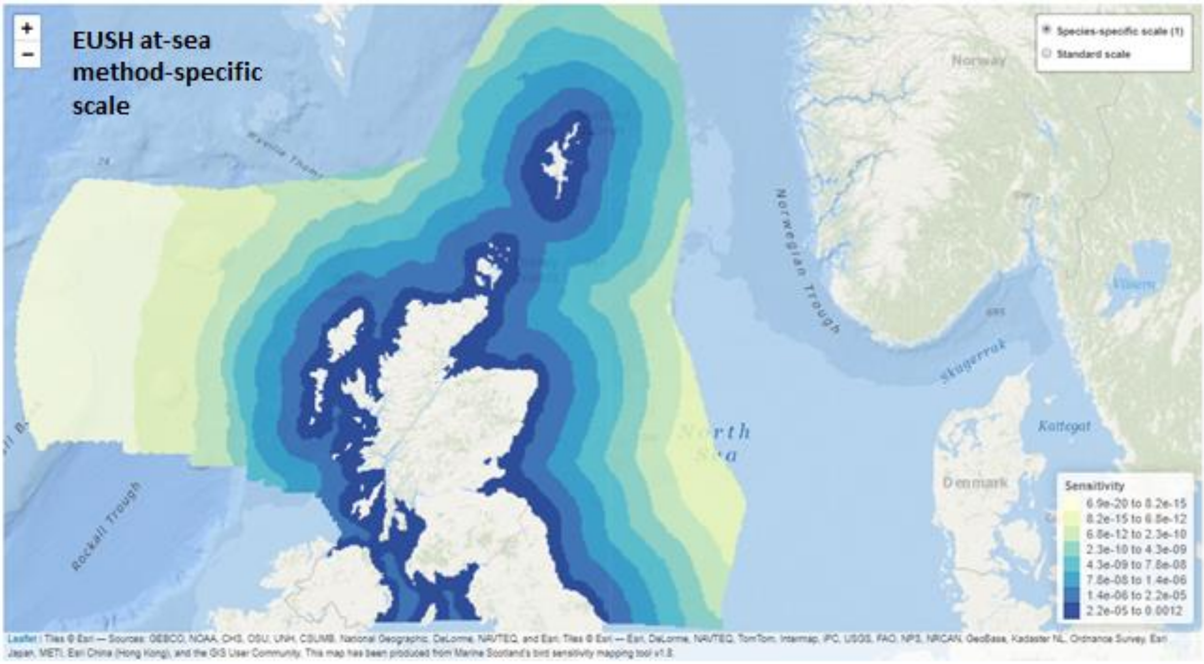
2.6e-06 to 3.8e-06
3.8e-06 to 5.8e-06
5.8e-06 to 8.6e-06
8.6e-06 to 1.3e-05
1.3e-05 to 1.9e-05
1.9e-05 to 2.9e-05
2.9e-05 to 4.4e-05
4.4e-05 to 6.6e-05
6.6e-05 to 9.9e-05
9.9e-05 to 0.00015
0.00015 to 1


EUSH at-sea
standard scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
Denmark
Rockall Trough
Sensitivity
0 to 1e-07
1e-07 to 1.5e-07
1.5e-07 to 2.3e-07
2.3e-07 to 3.4e-07
3.4e-07 to 5.1e-07
5.1e-07 to 7.6e-07
7.6e-07 to 1.1e-06
1.1e-06 to 1.7e-06
1.7e-06 to 2.6e-06
2.6e-06 to 3.8e-06
3.8e-06 to 5.8e-06
5.8e-06 to 8.6e-06
8.6e-06 to 1.3e-05
1.3e-05 to 1.9e-05
1.9e-05 to 2.9e-05
2.9e-05 to 4.4e-05
4.4e-05 to 6.6e-05
6.6e-05 to 9.9e-05
9.9e-05 to 0.00015
0.00015 to 1


EUSH GPS
method-specific
scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
North
Sea
Kattegat
Denmark
Rockall Trough
Sensitivity
1.7e-14 to 1e-09
1e-09 to 9.6e-09
9.6e-09 to 4.8e-08
4.8e-08 to 1.9e-07
1.9e-07 to 7.3e-07
7.3e-07 to 3.2e-06
3.2e-06 to 1.9e-05
1.9e-05 to 0.006


EUSH at-sea
method-specific
scale
Species-specific scale (1)
Standard scale
Norway
Norwegian Trough
Skagerrak
Kattegat
Denmark
Rockall Trough
Sensitivity
6.9e-20 to 8.2e-15
8.2e-15 to 6.8e-12
6.8e-12 to 2.3e-10
2.3e-10 to 4.3e-09
4.3e-09 to 7.8e-08
7.8e-08 to 1.4e-06
1.4e-06 to 2.2e-05
2.2e-05 to 0.0012

8.3 Internal comparison – footprint

8.3.1 Methods

To assess internal consistency within the tool, across the different bird utilisation distributions (GPS and at-sea) and different apportioning methods ('MERP' and 'SNH) we generated estimates for one of the four species (black-legged kittiwake) for which both at-sea and GPS data are available. We generated tool estimates for four SPAs in the Forth-Tay region (Isle of May, St. Abbs, Fowlsheugh and Boddam) using the sensitivity mapping tool in "footprint" mode to estimate risk using fictional wind farms located within the Forth-Tay area. In each case we used the tool to calculate the displacement risk score for the breeding season, using all possible combinations of global spatial distribution method (GPS, at sea), apportioning method (SNH, MSS) and breeding season definition (MERP or SNH). For GPS data the distinction between MERP and SNH is not relevant, so six risk scores were calculated for each colony-footprint calculation:

- **merp.GPS.SNH**: GPS bird distribution and SNH apportioning
- **merp.GPS.MSS**: GPS bird distribution and MSS apportioning
- **merp.Atsea.SNH**: MERP breeding season definition, at-sea bird distribution and SNH apportioning
- **scot.Atsea.SNH**: SNH breeding season definition, at-sea bird distribution and SNH apportioning method
- **merp.Atsea.MSS**: MERP breeding season definition, at-sea bird distribution and MSS apportioning method
- **scot.Atsea.MSS**: SNH breeding season definition, at-sea bird distribution and MSS apportioning method

8.3.2 Results

Correlations between scores using the various tool inputs and options were high across all options.

Scores produced using GPS bird distributions and either the MSS or SNH apportioning methods were highly correlated (0.967, Table 8.3.2.1), as were scores produced using at-sea bird distributions and either the MSS or SNH apportioning methods (MERP breeding season definition: 0.943; SNH breeding season definition: 0.943; Table 8.3.2.1).

Correlations between scores obtained from either GPS or at-sea bird distributions and the same apportioning method were also highly correlated, although slightly less so when using the SNH method for apportioning birds to colonies (SNH apportioning method: MERP breeding season = 0.904 & SNH breeding season =0.904; MSS apportioning method: MERP breeding season = 0.964 & SNH breeding season = 0.964; Table 8.3.2.1).

Finally, when both different bird distributions and different apportioning methods were used, correlations between scores were good. Correlations for both breeding season definitions (MERP and SNH) between scores from GPS bird distributions and SNH apportioning versus scores from at-sea bird distributions and MSS apportioning had a correlation of 0.877 (Table 8.3.2.1).

Table 8.3.2.1. Correlation scores between the different bird distribution, breeding season definitions and apportioning methods available within the tool for black-legged kittiwakes breeding in the Forth-Tay region.

	merp.GPS.SNH	merp.GPS.MSS	merp.Atsea.SNH	scot.Atsea.SNH	merp.Atsea.MSS	scot.Atsea.MSS
merp.GPS.SNH	1	0.967	0.904	0.904	0.877	0.877
merp.GPS.MSS	0.967	1	0.941	0.941	0.964	0.964
merp.Atsea.SNH	0.904	0.941	1	1	0.943	0.943
scot.Atsea.SNH	0.904	0.941	1	1	0.942	0.943
merp.Atsea.MSS	0.877	0.964	0.943	0.942	1	1
scot.Atsea.MSS	0.877	0.964	0.943	0.943	1	1

Individual correlations between scores for footprints generated using the different methods within the tool were also good. Correlation at the individual footprint level demonstrated by an approximate 1:1 relationship between scores when plotted (Fig. 8.3.2.1).

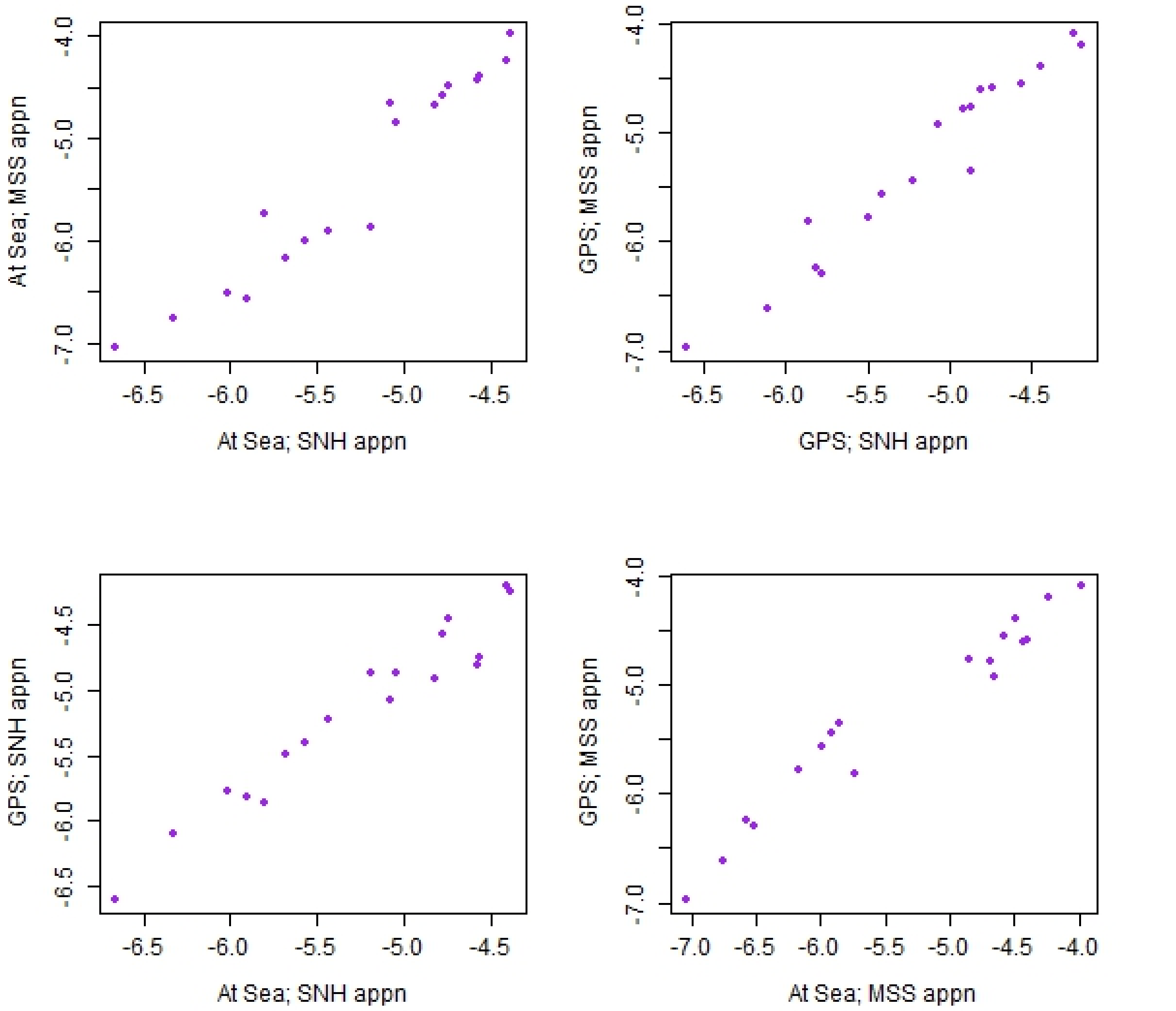


Figure 8.3.2.1**.** Scores generated by the Seabird Sensitivity Mapping Tool for different input data on bird distributions (GPS or at-sea survey) and apportioning methods (MSS or SNH) for black-legged kittiwakes breeding in the Forth-Tay region and a series of fictional OWFs. Scores shown for at-sea bird distributions and MSS versus SNH apportioning (top left); GPS bird distributions and MSS versus at-sea apportioning (top right); SNH apportioning method and GPS versus at-sea bird distributions (bottom left), and for MSS apportioning method and GPS versus at-sea bird distributions (bottom right).

8.4 SeabORD

8.4.1 Methods

For two species, black-legged kittiwake and Atlantic puffin, we compared the footprint-level risk scores obtained using the Seabird Sensitivity Mapping Tool (via each of the six different methods) against estimates of excess mortality derived for the same species-colony-footprints using a stochastic individual based model, SeabORD. In all SeabORD runs, we assumed a 60% displacement susceptible rate, and assumed that all individuals susceptible to displacement, were also susceptible to barrier effects. We used the 'perimeter' method to simulate barrier-affected bird movement around windfarms, and assumed a 0.5km border around each windfarm footprint, and 5km border into which affected birds were displaced (see SeaboRD project report and guidance for full information (https://data.marine.gov.scot/dataset/finding-out-fate-displaced-birds). For each species-colony-footprint combination we recorded the estimated averaged additional mortality arising from each windfarm, with upper and lower 95% prediction intervals.

We then visually compared the risk scores generated using the Seabird Sensitivity Mapping Tool against the additional mortality estimates derived from SeabORD.

8.4.2 Results

Puffins at Forth Islands

We ran two tests for puffins, first using fictional OWFs C_small, C_medium and C_large (Fig. 8.4.2.1) to see if the estimates from the Seabird Sensitivity Mapping tool correlated predictably with the SeabORD estimates. These three fictional OWFs were deliberately designed to be in approximately the same location, but to increase in size, therefore both tools should predict an increasing impact with size due to displacement effects.

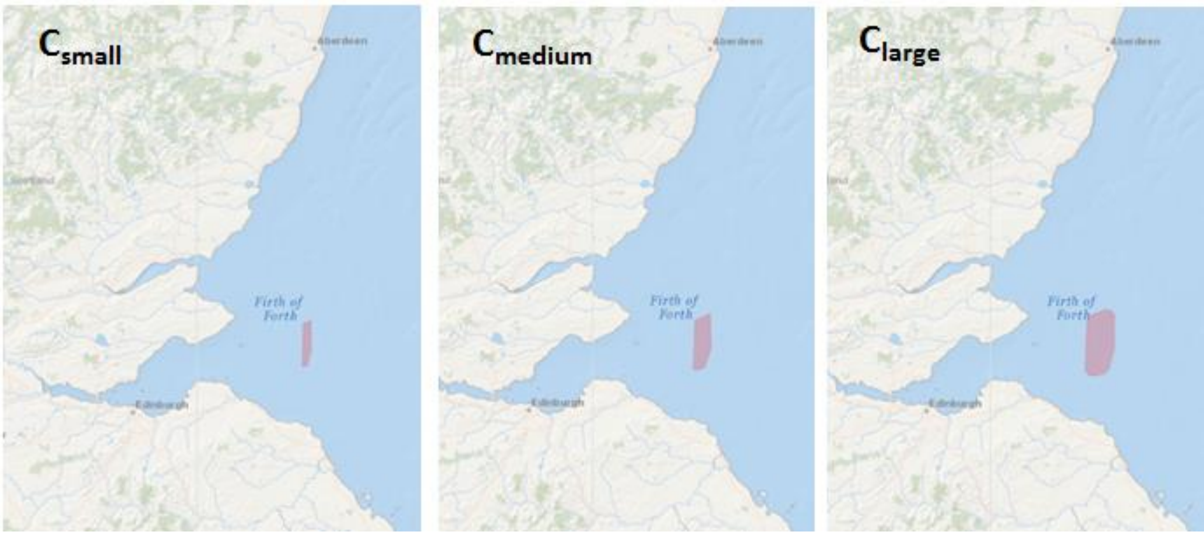


Figure 8.4.2.1. Location and size of three fictional OWFs in the Forth-Tay used in tool validation. OWFs were designed to be in the same location with increasing size (C_{small} – C_{medium} – C_{large}).

Estimates from both the Seabird Sensitivity Mapping and SeabORD tools showed an increasing size of effect with the increase in OWF size (C_small to C_large; Table 8.4.2.1). This resulted in a positive correlation in the predicted size of effect between the two tools (C_S, C_M, C_L; Fig. 8.4.2.2). All four methods used within the Seabird Sensitivity Mapping tool showed a similar pattern of increasing effect with OWF size (ae.merp.Atsea.SNH: summed exposure estimate using 'MERP' breeding season definition and SNH apportioning method; ae.scot.Atsea.SNH: summed exposure estimate using 'SNH' breeding season definition and SNH apportioning method; rs.merp.Atsea.SNH: summed sensitivity score using 'MERP' breeding season definition and SNH apportioning method; rs.scot.Atsea.SNH: summed sensitivity score using 'SNH' breeding season definition and SNH apportioning method; Table 8.4.2.1). Estimates for both summed exposure and sensitivity were very similar between results derived from either of the two different breeding season month definitions ('MERP' and 'SNH').

Table 8.4.2.1. Exposure scores ('ae.') and Sensitivity scores ('rs.') for Atlantic puffins breeding on the Forth Islands for five fictional OWFs using the various methods and input data in the Seabird Sensitivity Mapping Tool (ae.merp.Atsea.SNH: exposure score using MERP breeding season definition, at-sea bird distribution and SNH apportioning; ae.scot.Atsea.SNH: exposure score using SNH breeding season definition, at-sea bird distribution and SNH apportioning; rs.merp.Atsea.SNH: sensitivity score using MERP breeding season definition, at-sea bird distribution and SNH apportioning; rs.scot.Atsea.SNH: sensitivity score using SNH breeding season definition, at-sea bird distribution and SNH apportioning). Corresponding scores from the individual based simulation model, SeabORD, are also shown for each OWF footprint, including the mean, SD and upper and lower 95% confidence intervals for predicted additional adult mortality arising from the OWF.

	ORJIP Tool				SeaBORD.mean			
Footprint	**ae.merp.Atsea.SNH**	**ae.scot.Atsea.SNH**	**rs.merp.Atsea.SNH**	**rs.scot.Atsea.SNH**	**mean**	**SD**	**L95**	**U95**
WFC_large	0.019	0.020	0.010	0.010	2.855	0.390	1.930	3.780
WFC_medium	0.009	0.010	0.005	0.005	2.253	0.309	1.519	2.986
WFC_small	0.004	0.004	0.002	0.002	1.796	0.278	1.138	2.455
WFE	0.012	0.012	0.006	0.006	0.657	0.168	0.260	1.055
WFD	0.013	0.014	0.007	0.007	0.222	0.033	0.145	0.300

We also ran two additional fictional OWFs (D and E, Fig 8.4.2.3) to see how ORJIP tool estimates compared with those from SeabORD when OWFs were located in different places and with different shapes.

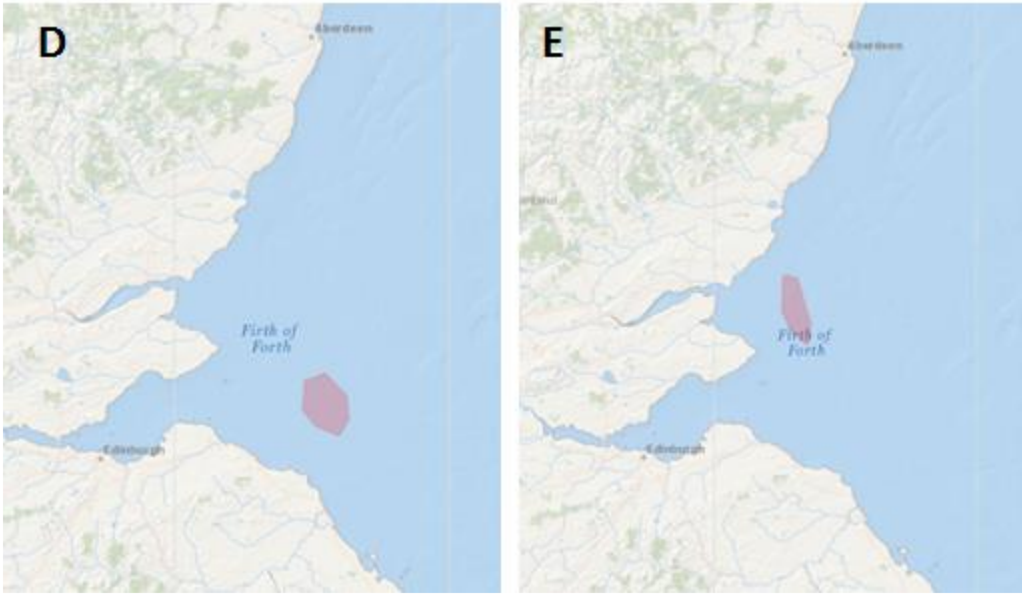


Figure 8.4.2.3. Location and size of two additional fictional OWFs in the Forth-Tay used in tool validation. OWFs were designed to be of similar size, but in different locations in relation to breeding colonies and bird densities.

Estimates from the ORJIP tool were similar for both WFD and WFE, and estimates derived using either the 'MERP' or 'scot' breeding season month definitions were also similar (Table 8.4.2.1). However, when compared to the SeabORD estimates there is not a positive correlation between the strength of the SeabORD estimates and the ORJIP tool estimates; SeabORD estimates larger effects for WFE then for WFD, whereas the ORJIP tool estimates for both exposure and sensitivity are very similar for both OWFs (Fig. 8.4.2.2). The increase in estimated impact from SeabORD for WFE over WFD is primarily due to increased barrier effects caused by WFE, blocking birds from the Forth Islands from accessing areas with high predicted bird densities, thereby incurring additional energetics costs to fly around the footprint. However, because the ORJIP tool bases its estimates on bird density only, and does not account for barrier effects, estimates from this tool change little between the two OWFs.

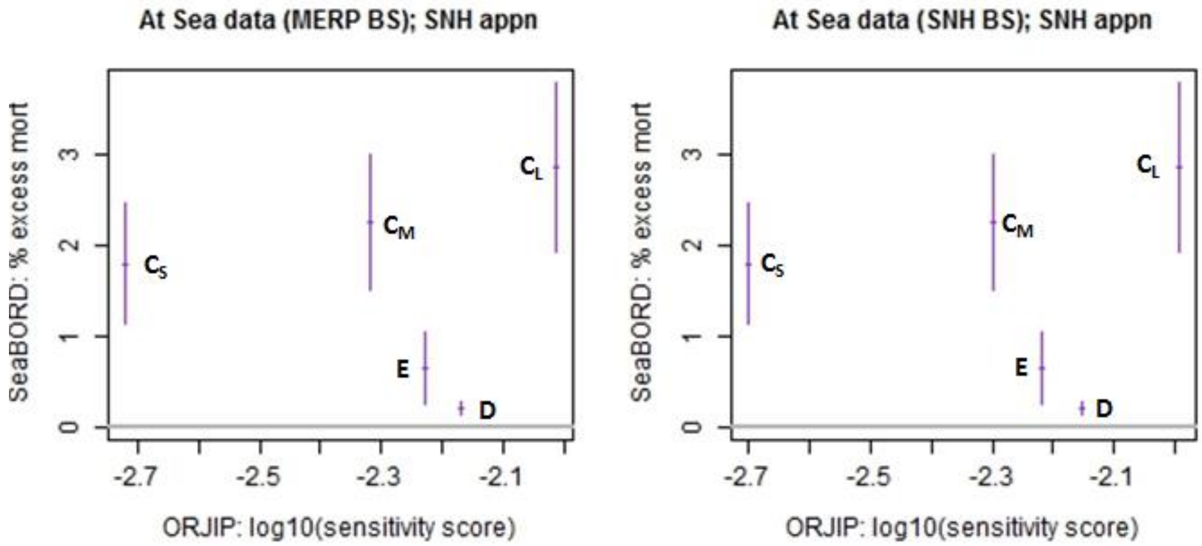
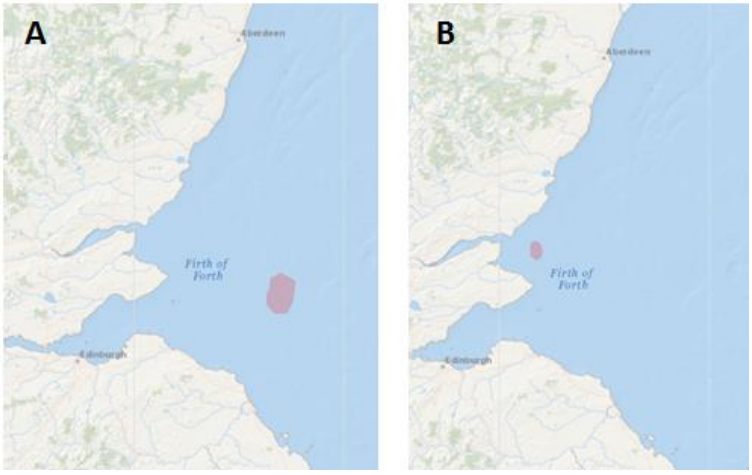


Figure 8.4.2.2. Estimated sensitivity scores from the Seabird Sensitivity Mapping Tool and additional mortality estimates from the SeabORD model for Atlantic puffins breeding in the Forth-Tay region. Scores were estimated for five fictional OWFs and are shown for each of the different breeding colony-OWF combinations.

Black-legged kittiwake

For black-legged kittiwakes, we compared estimates for risk arising from five fictional OWFs for birds breeding at four colonies in the Forth-Tay region (Wind farm A, Wind farm B, Wind farm C_{medium}, Wind farm D and Wind farm E).



Correlation between sensitivity scores from the Seabird Sensitivity Mapping Tool and the individual based simulation tool, SeabORD, were generally good. When very low sensitivity scores were predicted by the mapping tool, the SeabORD model also predicted negligible additional adult mortality (Fig. 8.4.2.3). As the sensitivity scores from the mapping tool increased, the additional mortality from the SeabORD model also tended to increase (Fig. 8.4.2.3). No large impacts for additional adult mortality were predicted by the SeabORD model, and correspondingly all sensitivity scores from the mapping tool were also small.

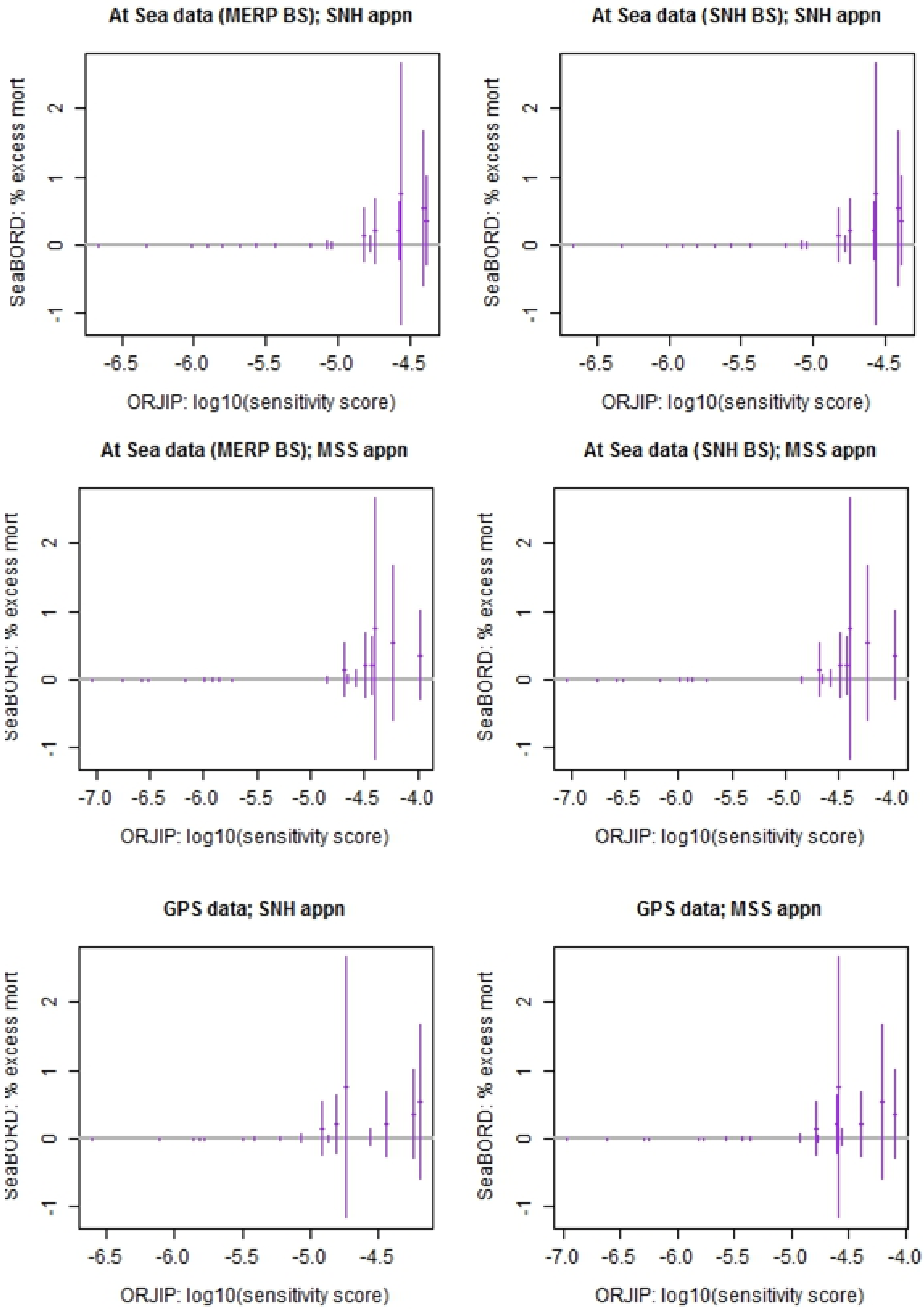


Figure 8.4.2.3. Estimated sensitivity scores from the Seabird Sensitivity Mapping Tool and additional mortality estimates from the SeabORD model for black-legged kittiwakes breeding at four colonies in the Forth-Tay region. Scores were estimated for five fictional OWFs and are shown for each of the different breeding colony-OWF combinations.

9 Further work

- **Defining bird behaviours from GPS tracking data:** currently the bird utilisation distributions from GPS tracking data (Wakefield et al. 2017) are not split into different behaviours, such as flight. This has limited the use of these estimates within the tool, for instance preventing calculations relating solely to collision risk to be made. In the future, estimates from GPS tracking data will be broken down into different behavioural categories, separating out flight behaviour, and notably, foraging behaviour. These advances should be incorporated within the tool when they become available.

- **Improved version of SNH apportioning method:** the current SNH apportioning method makes some very strong biological assumptions (assuming, in particular, that the relationship between distance to colony and bird density is identical for all species), and allows no quantification of uncertainty. This method could be extended to allow existing data (e.g. published information on mean-mean, mean-max and max-max foraging ranges) to be used in estimating the rate of decay of bird density with distance for each species, even for species that lack GPS tracking data, and in quantifying the uncertainty associated with this estimation.

- **Inclusion of uncertainty estimates with maps**: in the current version of the tool we have not had the resources to include the ability to map uncertainty in tool outputs. Currently, uncertainty estimates are available for bird utilisation distributions derived from at-sea survey data (Waggitt et al. *in review*), and these uncertainty estimates could be included in tool calculations to provide upper and lower bounds for risk estimates. Valid spatial maps for uncertainty estimates are not currently available for the GPS tracking derived bird utilisation distributions (Wakefield et al. 2017), and so any new modelling of GPS tracking data to derive bird utilisation distributions should attempt to include full quantification of uncertainty, which could then be included in this tool.

- **Extension to all UK waters:** the bird utilisation distributions underpinning the tool, and the apportioning methods, are available for all UK waters, however a decision was taken by the PSG in this project to limit the scope of the tool to Scottish waters only. Enlarging the scope of the tool to cover all UK waters would enable more assessments to be made, and would also largely deal with any edge effects that arise from assessments made near the southern border of the Scottish waters, as currently implemented in the tool.

- **Refinement of Certain et al (2015) risk framework:** the framework proposed by Certain et al. (2015) could be refined to better estimate collision and displacement risks. For instance, by reducing the risk of collision by including scores for displacement from structures in the collision risk equations.

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