Seabird Sensitivity Mapping Tool

Offshore Wind Evidence + Change Programme | THE CROWN ESTATE

orjip working to accelerate offshore consenting

Project Report

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1. Summary

1.1 Seabird Sensitivity Mapping Tool

1.1.1 This project was delivered through the Offshore Renewables Joint Industry Programme (ORJIP) for Offshore Wind. ORJIP for Offshore Wind is a collaborative initiative that aims to:

- Fund research to improve our understanding of the effects of offshore wind on the marine environment.
- Reduce the risk of not getting, or delaying consent for, offshore wind developments.
- Reduce the risk of getting consent with conditions that reduce viability of the project.

1.1.2 This project forms part of the Offshore Wind Evidence and Change programme, led by The Crown Estate in partnership with the Department for Energy Security and Net Zero and the Department for Environment, Food & Rural Affairs. The Offshore Wind Evidence and Change programme is an ambitious strategic research and data-led programme. Its aim is to facilitate the sustainable and coordinated expansion of offshore wind to help meet the UK's commitments to low carbon energy transition whilst supporting clean, healthy, productive and biologically diverse seas.

1.1.3 The UK and devolved Governments are committed to increasing the production of electricity from renewable sources, and the marine environment offers considerable potential with respect to harvesting renewable energy through wind, wave and tidal stream energy generators. However, the governments are 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), as devolved into UK law. Central to delivering these is the designation of important areas for species identified in the relevant Directives. 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 principally due to collisions, displacement from foraging habitat and barrier effects (Drewitt & Langston 2006; Larsen & Guillemette 2007; Scottish Government 2011; Searle et al. 2018). 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).

A critical component of sectoral plans, Strategic Environmental Assessments and 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 makes full use of recent improvements in the evidence base, notably in the estimation of seabird at-sea distributions in breeding and non-breeding seasons to service these needs. The project developed a fast, user-friendly tool to estimate the sensitivities of key seabird species to ORDs in UK waters and to produce spatially explicit risk estimates for all at-sea locations across a suite of species in both the breeding and non-breeding seasons.

1.1.4 This project builds upon the existing evidence base for seabird habitat use at sea to develop a fast, user-friendly tool to estimate the sensitivities of key seabird species to ORDs in all British Isles shelf seas. The tool produces estimates for the sensitivity and exposure of all at sea locations in UK waters for 13 seabird species (Atlantic puffin, Common guillemot, Razorbill, Black-legged kittiwake, European shag, European storm petrel, Great skua, Herring gull, Lesser black-backed gull, Northern gannet, Northern fulmar, Great black-backed gull and Red-throated diver) in both the breeding and non-breeding seasons, based on GPS tracking and at sea survey data. Note that default sensitivity scores are provided for 11 of the 13 species – users are required to enter their own sensitivity scores for two species: Great black-backed gull and Red-throated diver. Users may edit the default sensitivity scores for any of the 11 species. The tool also allows users to produce estimates for specific ORD footprints.

When used in 'map mode', the tool produces a map showing the spatial distribution of the seabird sensitivity scores covering all British Isles shelf seas (Fig. 1). This map can be produced for all breeding colonies of a species, or for a few selected breeding colonies of interest. These spatial maps will be useful for spatial planning, by quickly providing strategic information across UK waters for particular species and protected breeding colonies. In 'footprint' mode, the tool calculates the spatial risk score summed across an ORD footprint uploaded by the user (Figure 2). This output can be used to estimate bird sensitivities for specific ORD project proposals, for instance by ORD developers when preparing their assessment studies required by regulators.

1.1.5 The tool may also be used to estimate apportioning proportions for birds at-sea during the breeding season in either 'map mode' or 'footprint mode' (Figs 1 & 2) using two available methods: 1. The NatureScot Distance Decay and Foraging Range method (all species), and 2). The GPS tracking based method (only for Common guillemot, Black-legged kittiwake, Razorbill and European shag). Users are able to specify their own foraging range to use within method 1 (NatureScot Distance Decay and Foraging Range), or may use default values based on the mean-max (km) foraging ranges within Woodward et al. 2019.

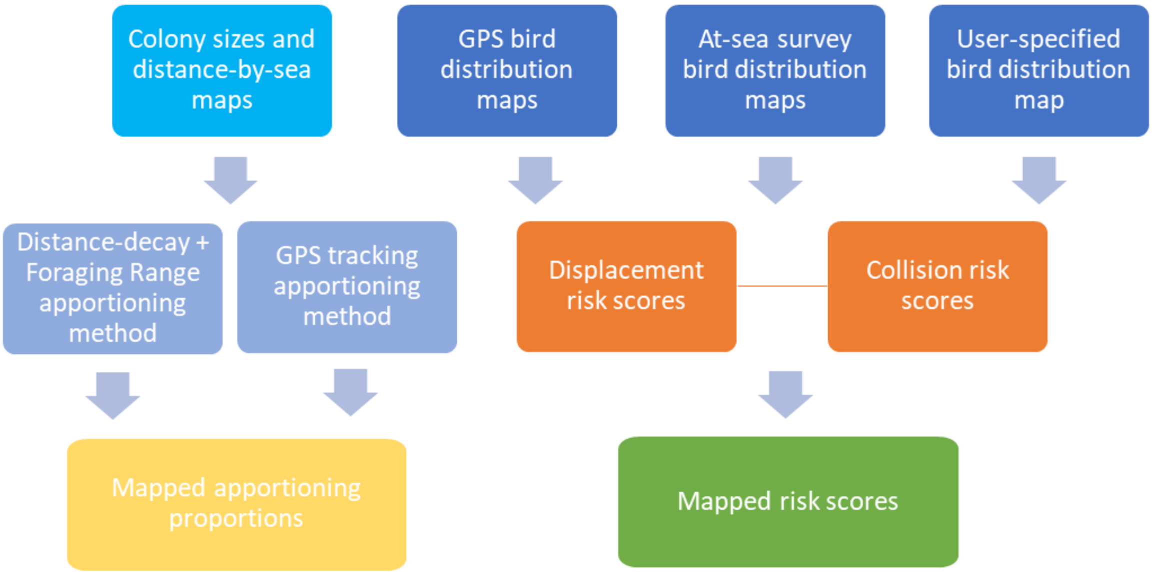

Figure 1. Summary of Seabird Sensitivity Mapping Tool (SSMT) functionality in 'Map Mode'.

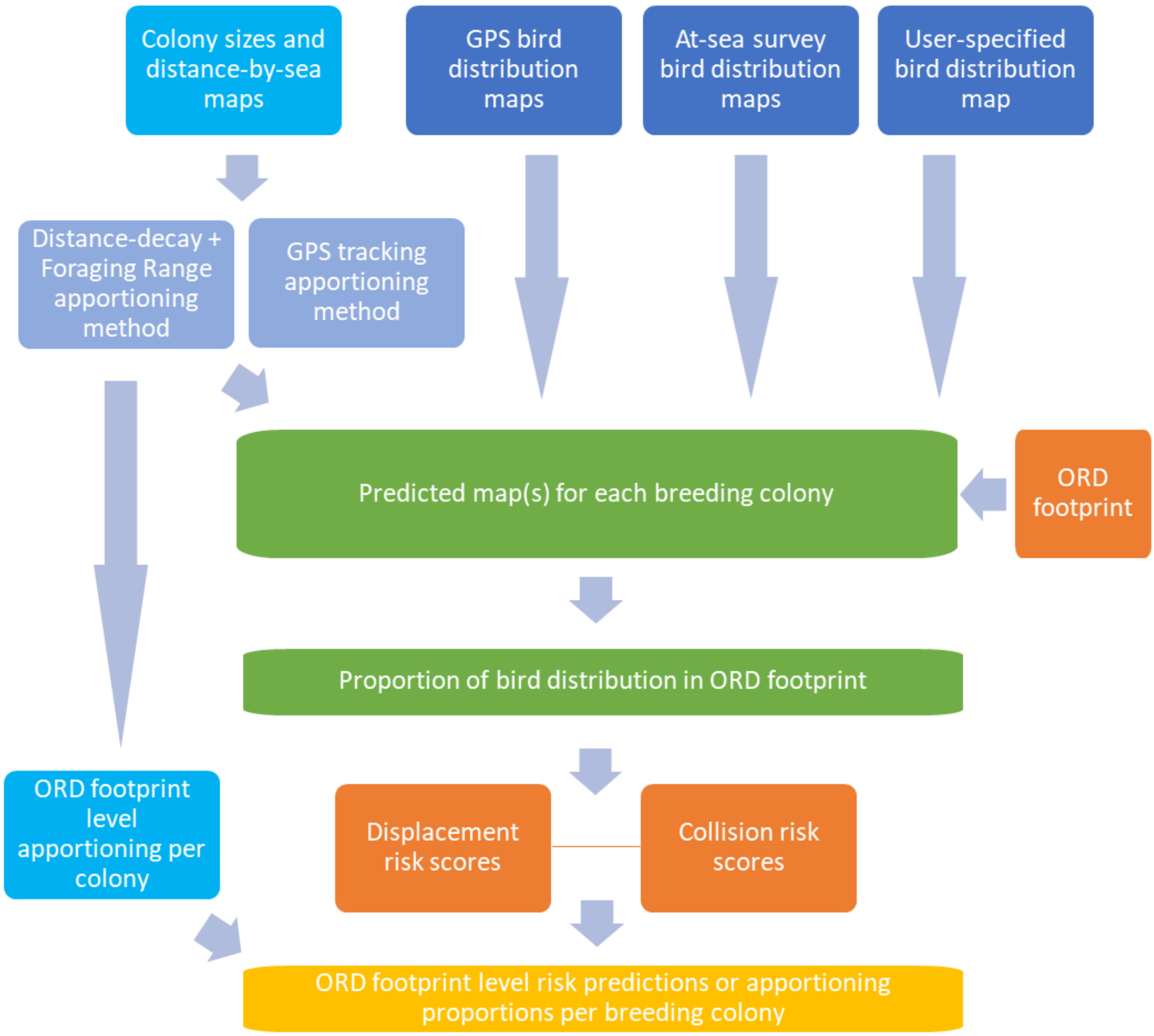

Figure 2. Summary of Seabird Sensitivity Mapping Tool (SSMT) functionality in 'Footprint Mode'.

In summary, the tool brings together cutting-edge estimates for the habitat use of seabird species at sea, based upon both GPS tracking data studies and at sea survey studies. It allows users to estimate the source breeding colony for birds observed across all at sea locations in the shelf seas surrounding the British Isles. By combining these baseline data with scoring assessments for sensitivity of seabirds to both collision and displacement effects of ORD developments, it then allows users to produce maps for seabird sensitivity to ORD developments across these waters, and for specific ORD footprints specified by the user.

We anticipate this tool will greatly facilitate fast, user-friendly assessments of seabird sensitivity to new and ongoing ORD developments. It will improve the knowledge base upon which policy and planning decisions are based, potentially leading to better conservation outcomes for UK seabirds. This work is the result of a collaboration between seven research institutes, and was funded by the Scottish Government and The Crown Estate, and delivered through ORJIP.

2. Introduction

Under ORJIP OSW Stage 1, funded by Marine Scotland, the Carbon Trust facilitated the completion of the ‘Development of the Seabird Sensitivity Mapping Tool for Scotland’ (Phase 1) completed by the UKCEH in 2019 (Searle et al. 2019). The project developed a user-friendly sensitivity mapping tool objective hosted by Marine Scotland capable of estimating, for Scottish coastline waters: a) the relative importance of a location for individual seabird species and species groups, b) the likelihood of birds at that location being from a SPA population, and c) their sensitivity to offshore wind farm developments.

Following the completion of Phase 1, Marine Scotland and the Offshore Wind Evidence and Change programme, led by The Crown Estate in partnership with the Department for Business, Energy & Industrial Strategy and Department for Environment, Food & Rural Affairs, wished to further develop the tool, to improve on it under a Phase 2 for this project. This included increasing the geographical coverage, enhancing the tool’s functionality, undertaking validation of the tool’s performance and increasing its flexibility to enable other drivers of seabird population to be included such as bycatch. The work is organised in five work packages:

WP1: Extending Geographical Coverage (from Scottish waters to all UK shelf seas)

WP2: Improve the Scope of the Tool

WP3: Increase the Tool’s Flexibility

WP4: Future Proofing Tool

WP5: Tool Publication and Validation

The ultimate purpose of this improved Sensitivity Mapping Tool is to contribute to ORJIP’s remit of de-risking the consenting process for offshore wind and to contribute to the body of evidence and tools supporting delivery of offshore renewable energy whilst safeguarding wildlife, as developed through the Offshore Wind Evidence and Change programme (OWEC), led by The Crown Estate in partnership with the Department for Business, Energy & Industrial Strategy and Department for Environment, Food & Rural Affairs..

3. WP1: Extending Geographical Coverage

3.1 Task 1.1: Use the existing datasets on which the tool relies to extend the geographical coverage of the tool to include the rest of the United Kingdom.

3.1.1 We have extended the geographical area for which the tool is applicable to include all shelf seas around the British Isles and Ireland, including the Celtic Seas, North Sea, English Channel and Irish Sea (Fig. 1). As part of the Marine Ecosystems Research Programme (MERP), Bangor University and Sea Watch have produced density distribution maps on a monthly basis at a 10km resolution for the entire geographical area of interest (Waggitt et al., 2020). These maps underpin the at-sea derived bird distributions within the tool. With the recent release of necessary environmental parameters (temperature, salinity, current speeds) at a finer spatial scale (FOAM AMM15, Marine Environmental Monitoring Service), we have produced modelled outputs at 2.5km resolution within this project, including confidence intervals. Data-sharing agreements are being secured within the Marine Scotland Cumulative Effects Framework (CEF) project. The new maps have been produced using all freely available data, which contributes most of the data in UK waters (see Bradbury et al 2014).

3.1.2 The revised modelling process closely resembled those used in Waggitt et al (2020), although several amendments were made: (1) Different models were developed for seabirds in-flight and those on-the-water, (2) In both stages (Binomial and Poisson) platform (Boat versus Plane) was included as an additional explanatory variable in both stages to better account for difference in detection rates between surveys. Predicted densities were made using 'Boat' parameters, as these provided the most plausible population sizes, (3) In both stages, survey effort (Km2) was included as an additional explanatory variable rather than an offset to enable more complicated relationships with species presence / densities to be modelled. Both untransformed and log-transformed Survey Effort was considered. Negative relationships with Survey Effort were considered spurious and not permitted; (4) For practical reasons linked to computing power and the finer spatial-scale FOAM AMM15, sea-surface rather than depth-averaged temperatures were used, (5) Annual Temperature Variance was replaced with Annual Salinity as an explanatory variable, because it better identified Regions of Freshwater Input (ROFI) at a UK-scale (6) Simpson-Hunter Stratification Index (SI: Simpson and Sharples 2012) was included as a candidate explanatory variable, given its potentially high influence on seabird distribution (Scott et al 2010, Cox et al 2013), (7) In Waggitt et al (2020) the Front Index represented horizontal gradients in vertical temperature gradients. Here however, the Front Index represented the standardised absolute difference from SI values of 1.9. SI values of 1.9 (Simpson and Sharples 2012) identify the location of influential Tidal Fronts at a UK-scale (Scales et al 2014).

Whilst AMM15 is only available from 2019 onwards, the modelling processes required environmental conditions which detected consistently different water-masses. Whilst absolute temperature and salinity have changed substantially over the period of at-sea survey performance, spatial-differences in conditions would have remained similar. Therefore, AMM15 outputs from 2019 were used to calculate explanatory variables.

It is noted that some models produced some unlikely distributions, most notably the Manx Shearwater models which estimated moderate densities in the southern North Sea. Future models would consider additional or alternative explanatory variables which could better describe their distribution.

Example maps are show below (*Figure 3*) for Atlantic puffin.

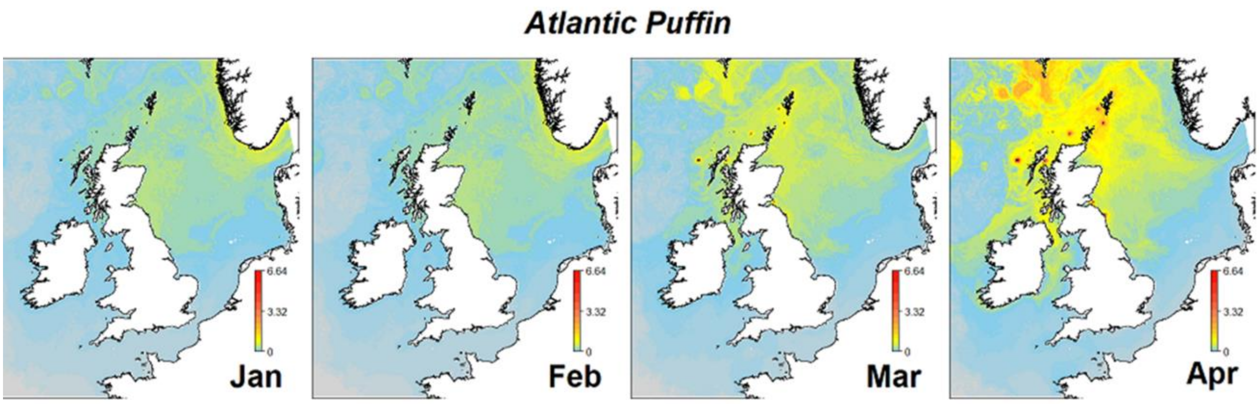

Figure 3. Example of monthly predicted distribution (January, February, March, April) for Atlantic puffin, estimated across the British Isles shelf seas at a resolution of 2.5km.

3.2 Task 1.2: Identify any other relevant datasets that would inform additional geographical coverage beyond Scotland

3.2.1 Alongside renewing data-sharing agreements, Bangor University and Sea Watch Foundation have approached existing providers seeking additional data collected since the NERC MERP. Additional data is being collated and collected within the OWEC POSEIDON project, and any updated seabird distribution maps developed during the POSEIDON project can be included within the seabird sensitivity mapping tool at a future date.

3.3 Task 1.3: Assess any identified data to determine consistency with project tool and create a data management plan for the data incorporation

3.3.1 All datasets handled during the project have documentation to describe the data, with key discovery-level metadata available through the Marine Scotland Cumulative Effects Framework (CEF) Data Library. Each dataset contains reference to contextual metadata including the structure, lineage and meaning of values to enable the effective utilisation of the data. Within the project, we implemented rigorous procedures to ensure that all data and codes were quality assured. The Marine Scotland CEF Data Library can be accessed here:

https://cef-librarybook.datalabs.ceh.ac.uk/

With the relevant data on seabird distributions located here:

https://cef-librarybook.datalabs.ceh.ac.uk/distrib.html

3.4 Task 1.4: Incorporate data into tool and remodel tool to extend its geographical coverage

3.4.1 The tool has been modified to use data from the wider spatial region (*Figure 3*). The changes required to the underlying tool code to achieve this were relatively minimal, and no changes to the structure of the user interface were required as a result. The underlying code, for both the calculations and the interface, was designed (for the purposes of futureproofing) to take the information on spatial extent directly from the spatial maps that are used as inputs, rather than having these hard-wired in to the code.

4. WP2a: Improve the Scope of the Tool

4.1 Task 2a.1: Separate different bird species behaviours

4.1.1 Using GPS and TDR tracking data from seabird colonies around the coast of Britain and Ireland during May-July 2010–14, members of the project team (RSPB; Cleasby et al. 2022) have developed new models for estimating the spatial patterns in diving behaviour for three species during the breeding season -- Common guillemot, European shag, and Razorbill. Statistical analysis employed species distribution models, similar to methods used by Wakefield et al. (2017) that produced the GPS maps currently utilised within the Seabird Sensitivity Mapping Tool. Models predict an Utilisation Distribution (UD) to map the expected distribution of diving behaviour during the breeding season for each UK breeding site (breeding sites were defined as those listed in the UK-wide Seabird 2000 census). Breeding site level UDs, weighted by colony size, have also been aggregated to create a single, UK-wide UD map for each species. For Guillemots and Razorbills, UDs were calculated at a 1 km2 resolution, whereas for Shags resolution was 0.5 km2 . These novel maps for breeding season diving behaviour (Cleasby et al. 2022) have been included in the new tool, and are available for use within sensitivity to displacement calculations. This enables a more precise mapping of displacement sensitivity hotspots than in the previous version of the tool, in which displacement sensitivity was assessed against UDs for birds performing all behaviours (which is more relevant to both displacement and barrier effects).

4.1.2 The revised at-sea survey maps, divided into birds in flight and birds on the water, derived from regional at-sea survey data that are used within the tool have accompanying quantifications of uncertainty. Uncertainty associated with parameters in GEE-GLM species distribution models (see Waggitt et al. 2020) were used to provide overall estimates of uncertainty in animal densities (see Gilles et al., 2016). We used this approach to estimate 95% confidence intervals around

GEE-GLM outputs using 1000 simulated estimates on parameters. These intervals were derived by applying the tool calculations to the bootstrap samples produced by the models of at-sea survey data, and then summarising across bootstrap samples. We have now included an option within the tool for users to view these estimates of uncertainty, in both ‘map’ and ‘footprint’ mode (when using at-sea maps, for all species). This means, for example, that users may view lower and upper 95% confidence intervals, as well as mean estimates.

4.2 Task 2a.2: Allow for superimposing of a footprint(s) over the map layer

4.2.1 We have extended tool functionality to allow users to upload windfarm footprints, or other shapefiles, in ‘map mode’, thereby allowing for different footprint polygons to be superimposed over map outputs generated by the tool in this mode. Users may then download images (.png files) of mapped output with or without the footprint/polygon, using a toggle switch in the interface.

4.3 Task 2a.3: Develop the tool to compute monthly outputs, as well as ‘user defined breeding season months’ to make compatible with collision risk model.

4.3.1 The tool has been extended so that users have the option to extract information at the monthly level, or for seasons defined by the user (by combining months together), when using outputs derived from at-sea survey data. The underlying spatial maps used by the tool already contain monthly outputs, so this extension did not require any substantive change to the tool calculations, however it involved changing the interface such that users can directly access the maps for individual months, and also have the potential to aggregate values across monthly maps to derive summaries for user-defined seasons.

4.3.2 The outputs derived from GPS data only relate to the breeding period, and the nature of the statistical modelling used to estimate spatial distributions from these data does not permit a breakdown of results into individual months within this period, so monthly outputs and user-defined seasonal outputs are only available within the tool when the option to use outputs derived from at-sea survey data has been selected.

4.4 Task 2a.4: Identify and include additional key species if data is available such as the Great black-backed gull

4.4.1 A number of other marine bird species regularly inhabit UK seas, and are vulnerable to human activities at least regionally or seasonally. These include: Great black-backed gull, Red-throated diver, Red-breasted merganser, Long-tailed duck, European eider, and Common scoter. Most of these are non-colonial and therefore not appropriate for application of a colony apportioning tool. However, atsea distribution maps can be derived on a monthly basis covering either the entire region or specific areas of importance to a particular species. We have developed detection functions for two of these species from the available survey data, from which density and abundance estimates were derived using the same methodologies as applied to the other marine birds (Waggitt et al. 2020) – Great black-backed gull and Red-throated diver. These new maps are now available within the tool, with the two species added to the user interface to allow users to map spatial patterns, and where possible, use estimate bird densities to estimate and map sensitivities to different pressures.

4.4.2 Note that this project did not cover the estimation of sensitivity scores for these two species, therefore no default sensitivity scores are supplied for either species, and users must enter their own values in the tool interface. For Red-throated diver, it is not possible to perform apportioning to breeding colonies – impacts from offshore wind on this species in UK waters are primarily restricted to the non-breeding season, and non-breeding season apportioning is not currently available within the tool (see Section 4.5 below). Spatial maps for each species are shown below (*Figure 4* & *Figure 5*).

4.4.3

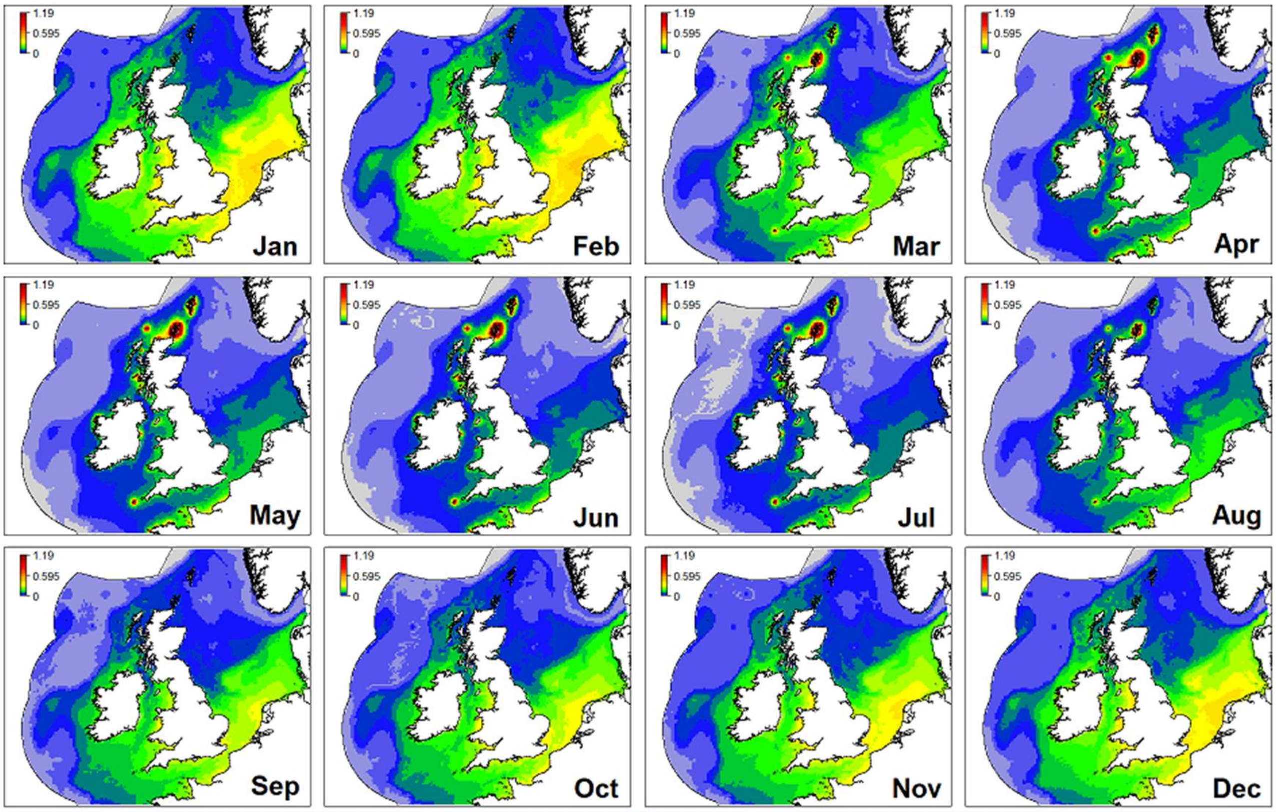

Figure 4. Predicted distribution of Great black-backed gull in shelf seas around the British Isles, derived per month, at a 2.5km resolution.

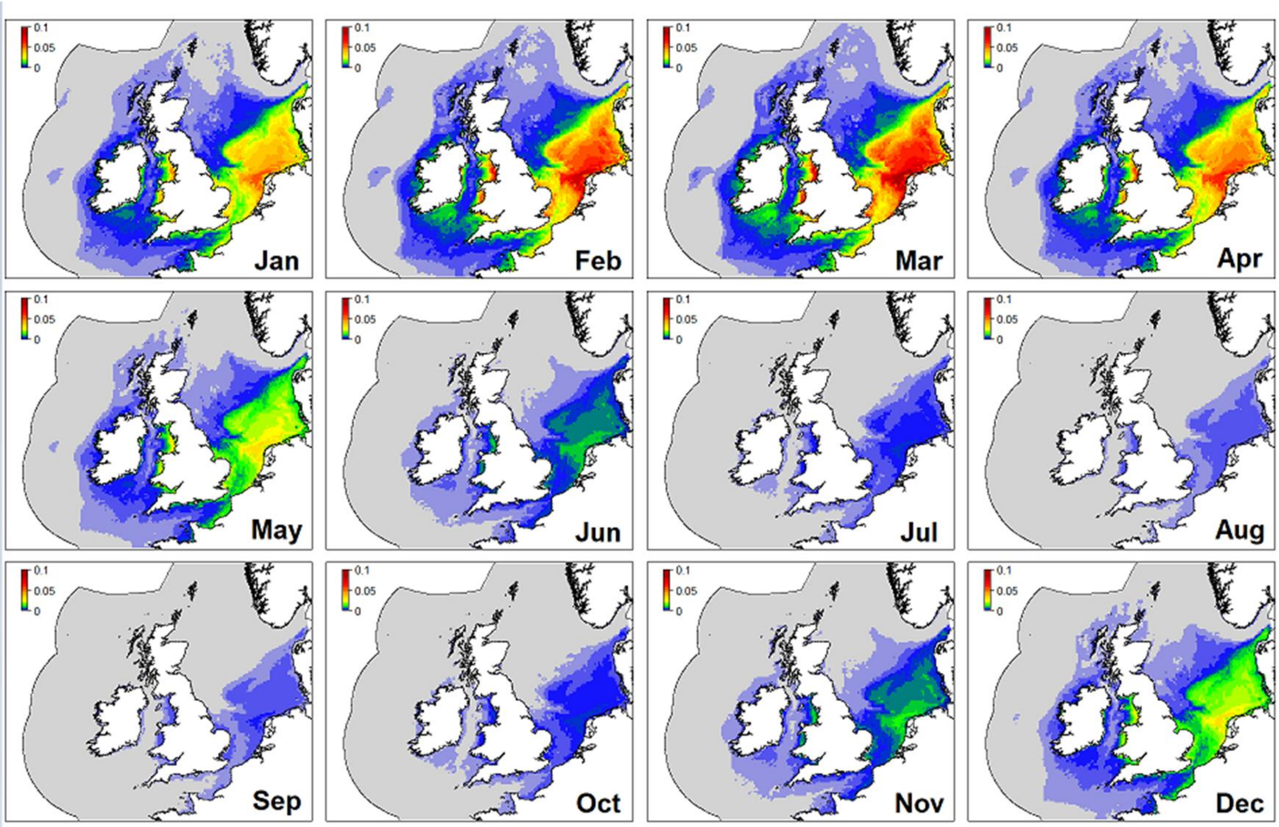

Figure 5. Predicted distribution of Red-throated diver in shelf seas around the British Isles, derived per month, at a 2.5km resolution.

4.5 Task 2a.5: Provide instructions on how the tool could be extended to include apportioning for the non-breeding season/s (winter and potentially separate passage periods) were methods to be made available in future

4.5.1 A key limitation of the tool is that it only incorporates breeding season apportioning, reflecting the sparsity of methods for apportioning in the non-breeding season. The tool could be extended in the future to include apportioning for the non-breeding season or other defined periods such as passage periods for migratory species. The mechanisms for doing this are dependent upon appropriate analyses of colony-specific non-breeding season distribution data. Incorporation of non-breeding apportioning is, in principle, a straightforward extension to the SSMT, so the work involved in achieving this in practice will depend largely on the detailed format of the results of any analyses.

The ORJIP ‘AppSaS’ (Apportionning Seabirds at Sea) project has produced a draft tool for apportioning in the non-breeding season for two species, guillemot and Razorbill, based upon spatial analyses of multi-colony geolocator data. This tool quantifies the effect of locational uncertainty upon the estimation of spatial distribution – the locational uncertainty in geolocator data is typically substantially larger than in GPS tracking data, so the quantification of this uncertainty is an important part of the tool. The draft AppSaS tool allows flexibility over the specification of months and seasons, which could be readily aligned with the SSMT, and also incorporates BDMPS estimates as an alternative.

In the remainder of this section we focus on a more detailed description as to how this tool could be incorporated into the SSMT. The main pieces of work involved in incorporating the AppSaS tool into the SSMT would be:

1) Incorporation of all of the data that underpin the AppSaS tool into the CEF Data Store
2) The SSMT user interface would need to be expanded to incorporate non-breeding season apportioning tools.
3) The R code that underpins the SSMT tool would need to be expanded to also incorporate non-breeding season apportioning tools
4) Testing would need to be expanded and re-run

The CEF, which incorporates the SSMT and has additional functionality for performing non-breeding season apportioning using BDMPS, has been designed to try to make these processes as transparent and clear as possible. The draft AppSaS tool has also used CEF Data Store datasets and functions wherever possible, to facilitate this process. The geolocator-based maps used by the AppSaS tool are not in the CEF Data Store, so the main work under (1) would involve adding these to the Data Store and creating relevant meta-data.

Implementation of (2) would in principle be a straightforward modification of the existing functionality within the SSMT, in which additional options would be added, for relevant species, to the "apportioning type" drop-down menu, although if the SSMT is translated from Seabird 2000 subsites into SPAs (see below) that would also have implications for the interface.

The refinements to the underlying code, (3), ought to be relatively straightforward in principle, but are likely to run into two substantive practical issues that may be challenging, and hence time consuming, to resolve:

a) the CEF was built using version 4.0.4, whereas the draft AppSaS tool has used a more recent version of R (4.2.1). This difference arises from a combination of reasons, including the functionality required, as well as the timescales of the projects, but the differences in versions reflect a period in which key spatial R packages (sf, terra) have underdone substantial development. Work will be needed, after release of the CEF, to bring the CEF, and thereby the SSMT, in line with a more recent version of R, and this will be a pre-requisite for incorporating the draft AppSaS tool into the CEF.

b) the AppSaS tool uses a large dataset, and is currently more computationally intensive than the SSMT, and may be too intensive to feasibly be incorporated into Shiny. This could potentially be resolved by finding ways to increase the computational efficiency of the AppSaS calculations, and/or by restructuring subsequent versions of the SSMT/CEF (e.g., by moving apportioning into the part of the CEF that is not implemented within Shiny, although this would involve restructuring the CEF workflow and would make the SSMT less interactive)

c) the AppSaS draft tool is built around SPAs, as is BDMPS, but the SSMT is built around Seabird 2000 subsites, because these were the colony definitions used in Wakefield et al. (2017), and, until 2023, represented the most recent census of all colonies. The most natural way to align these would be to align the SSMT with SPAs, but this has challenges relating to the difficulties in aligning Seabird 2000 subsites to SPA boundaries. A key issue is whether any alignment would also occur in conjunction with an alignment to the new seabird census data – if it would, that would avoid this issue, but there would still be the difficulty associated with the Wakefield et al. (2017) having been derived using Seabird 2000.

4.5.2 Based on agreement with the project steering group, the tool contains default values for foraging ranges for each species (where available from Woodward et al. 2019), as well as allowing users to set bespoke foraging ranges for individual species. These values reflect the ‘mean-max’ foraging range for each species, as specified within Woodward et al. 2019. Default values are visible within the tool interface for users to select. Alternatively, users may input bespoke foraging ranges, thereby allowing exploration of the sensitivity of tool outputs to different assumptions about foraging ranges for each species.

4.6 Summary of full tool functionality

This project has added a range of new functionality to the previous version of the Seabird Sensitivity Mapping Tool (Figs 6 & 7).

4.6.1 Broadly, when used in ‘map mode’, the tool produces a map showing the spatial distribution of the seabird sensitivity scores, for all breeding colonies of a species, or for a few selected breeding colonies of interest (Figure 6). In Map Mode, the tool may also be used to estimate and map apportioning proportions for birds at-sea during the breeding season using two available methods (Figure 6): 1. The NatureScot Distance Decay and Foraging Range method (all species), and 2). The GPS tracking based method (only for Common guillemot, Black-legged kittiwake, Razorbill and European shag). Users are able to specify their own foraging range to use within method 1 (NatureScot Distance Decay and Foraging Range), or may use default values based on the mean-max (km) foraging ranges within Woodward et al. (2019). Underpinning this broad functionality are a range of alternative datasets for mapping bird distributions (derived from GPS tracking data or from at-sea survey data), methods for performing apportioning (using the NatureScot Distance-decay and Foraging Range method, or the Marine Scotland GPS tracking-derived method), and pressure types for assigning risk (collision, displacement, or both) (Figure 6). Functionality is available for consideration of risk across various time-periods (e.g., months) or seasons, and for the inclusion of uncertainty estimates when distribution maps derived from at-sea survey data are used (Figure 6).

4.6.2 In ‘footprint’ mode, the tool calculates the spatial risk score summed across an ORD footprint uploaded by the user. Functionality in this mode is similar to that in Map Mode, but with risk estimates and apportioning proportions calculated at the scale of a single ORD footprint (Figure 7). Underpinning this broad functionality are a range of alternative datasets for mapping bird distributions (derived from GPS tracking data or from at-sea survey data), methods for performing apportioning (using the NatureScot Distance-decay and Foraging Range method, or the Marine Scotland GPS tracking-derived method), and pressure types for assigning risk (collision, displacement, or both) (Figure 7). Functionality is available for consideration of risk across various time-periods (e.g., months) or seasons, and for the inclusion of uncertainty estimates when distribution maps derived from at-sea survey data are used (Figure 7). In addition, when in Footprint Mode, the tool is also able to calculate a measure of ‘absolute exposure’, which relates to the proportion of time that birds (from a single colony, multiple selected colonies, or all colonies), with a particular behaviour (either flying only, or all behaviours combined), spend within the ORD footprint (Figure 7):

- Proportion of time spent in footprint (flying only)
- Proportion of time in footprint that is spent flying
- Proportion of time spent in footprint (all behaviours)
- Density per km^2 for flying birds in footprint
- Density per km^2 for all birds in footprint

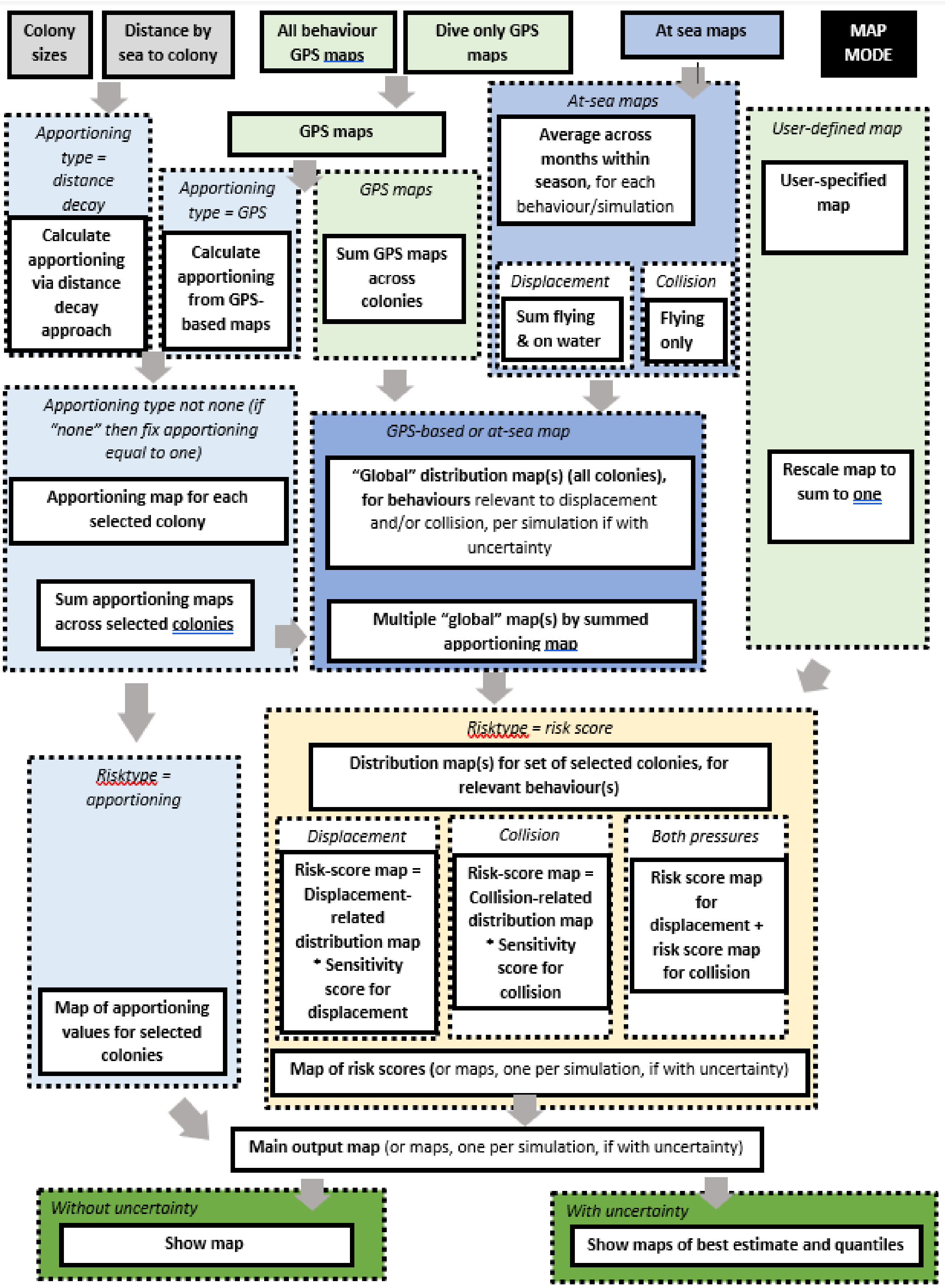

Figure 6. Full tool functionality in Map Mode.

4.6.3 .

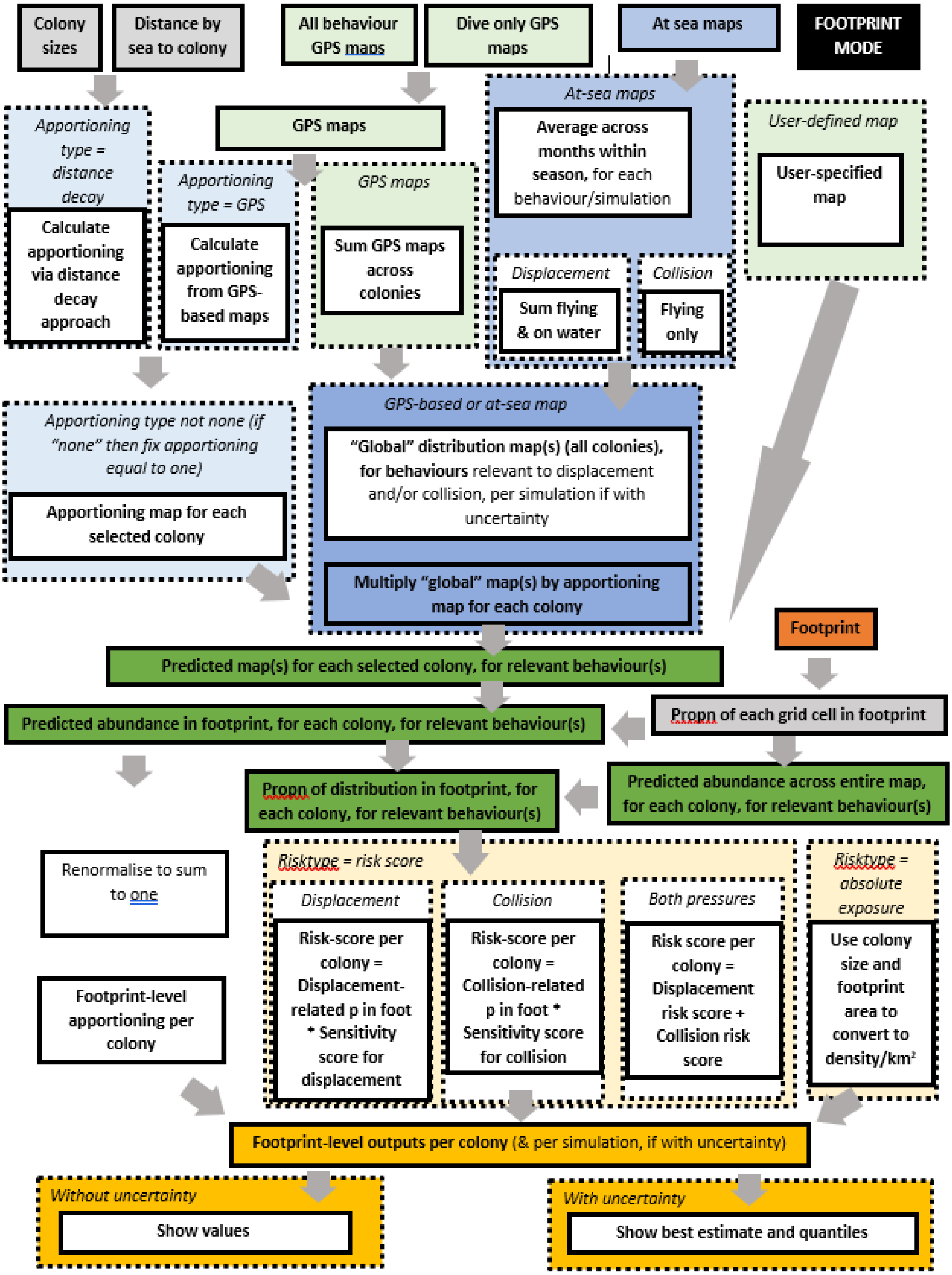

Figure 7. Full functionality in Footprint Mode.

5. WP3: Increase the Tool's Flexibility

5.1 Task 3.1: Document how distribution data could be updated (GPS and at-sea survey)

5.1.1 Alongside the first version of the tool, we provided a guidance document outlining how updated distribution data (either GPS or at-sea survey data) could be incorporated into the tool, as new versions of existing data products, and new sources of data, become available. Upon the decision to include the SSMT within the Marine Scotland CEF project, such updates are now covered within guidance associated with this work, in relation to the CEF Data Library and associated functionality.

5.2 Task 3.2: Accept other at-sea survey data and GPS data if possible

5.2.1 We have refined and extended the tool so that it is possible for users to upload their own spatial maps of estimated bird distributions, rather than using the spatial maps contained within the tool itself (housed in the Marine Scotland CEF Data Library). Specifically, users may upload either:

a) a gridded map of overall (un-apportioned) estimated relative abundance, covering whichever spatial region the user specifies; or
b) a gridded map(s) of colony-specific relative abundance, for a single colony

The first type of spatial map can be derived from at-sea survey data, either regional survey data, or survey data collected by developers within the vicinity of a proposed wind farm footprint. The second may be derived from GPS tracking data. The restriction to only upload a single map was necessary to prevent the user-interface becoming excessively complicated, and because allowing multiple maps would have required additional functionality to check for, and resolve, inconsistencies between these maps. The calculations using user-defined maps operate in the same way as for other forms of map within the tool, but the practical implications of only one map being uploaded per run are that: (a) if the maps are colony-specific then only one colony at a time may be considered, and (b) only a single pressure (collision or displacement) may be considered.

Users may upload their own spatial inputs as raster files, in GeoTIFF format, via the user interface. The tool checks for obvious errors in the files that are being imported (e.g., negative abundance values, spatial locations that lie outside the new geographical scale of the tool), and prevents users from proceeding with the calculations if these checks have not been passed.

Spatial inputs provided by users feed into the sensitivity calculations in the same way as the existing maps within the tool. The results of these calculations may then be visualised through the user interface as for the existing spatial datasets.

5.3 Task 3.3: Users to input own sensitivity scores so that different sectors and technologies could be added with updated scores

5.3.1 The tool has been adapted so that users now have the option to modify the default sensitivity scores for each species and pressure (note that default sensitivity scores are not provided for the two new species added to the tool in this project – Great black-backed gull and Red-throated diver). This modification is enacted through the user interface. Users may adjust sensitivity scores to suit their own needs, and these edited scores are then used within the subsequent sensitivity calculations in the tool. Default sensitivity scores are derived and specified in the original Phase 1 report (sections 3 & 4: https://www.gov.scot/publications/development-of-a-seabird-sensitivity-mapping-tool-for-scotland-final-report/).

6. WP5: Tool Publication and Validation

6.1 Task 5.1: Securing any data agreements required for tool publication

6.1.1 The project partners (UKCEH, RSPB, Bangor University, Sea Watch Foundation) are currently working with Marine Scotland to ensure any data agreements required for tool publication are secured, and enacted through the Marine Scotland CEF project.

6.1.2 The at-sea derived maps for bird distributions used only open-access data, therefore no formal new data agreements are required.

6.2 Task 5.2: Supporting uploading of tool to a suitable host e.g. Shiny Servers, as agreed with Marine Scotland

6.2.1 Upon agreement with the project steering group, the tool has been incorporated into the Marine Scotland Cumulative Effects Framework (CEF), and will be published online as part of this project. The CEF will be openly available, and hosted for an interim period on UKCEH systems, before eventual transfer to Marine Scotland servers, or other such location, as determined by Marine Scotland.

6.3 Task 5.3: Providing technical support for a period of 6 months post-publication for any unexpected bugs

6.3.1 Upon server deployment of the tool within the Marine Scotland CEF, any subsequently identified errors in the working of the R code or Shiny tool, as covered by the initial technical specification, will be analysed and a suitable fix provided on a timescale to be negotiated between CEH, BioSS and Marine Scotland (or others, as appropriate). Note that this warranty period does not cover any requests made outwith the technical specification (i.e., requests for new amendments to the delivered tool). The warranty period will last for six months. We have provided a dedicated email address giving tool users access to a support helpdesk (CEFramework@ceh.ac.uk). Users will have access to support for the tool via this helpdesk for six months after deployment. The email address will be linked to issue tracking software (monitored by at least two people) enabling a timely response to queries.

6.4 Task 5.4: Tool validation - An Independent review

6.4.1 Prof Jason Matthiopoulos, Glasgow University, has conducted an independent review of the methodology underpinning the tool. This included a review of the risk sensitivity scoring methodology, and the implementation of the sensitivity scores within the tool, as combined with underlying bird distribution data. The review includes future recommendations for adapting the methodology to improve the tool and make it more robust. The full report is an Appendix A.

6.4.2 The R code underpinning the tool's functionality was also subject to an independent review by domain experts – specifically scientific computing and app developers for R and Shiny (DMP Statistical Solutions). This review subjected the R code to various levels of review. Initially the overall robustness was tested under a suite of inputs and user-interactions. A medium-scale comparison was made between code blocks and the stated design intentions i.e., are the calculations being performed as expected with intended inputs? This involved testing the I/O of individual functions under expected use. Additionally, the possibility of unexpected yet currently permissible inputs was examined. A general line-by-line inspection was also conducted. The resulting review reported any identified calculation errors, inefficiencies, and general recommendations relevant to reproducibility and future maintenance. The full report is available in Appendix B. A summary of the response to the review in below (Table **1**).

Table 1. Summary of response to issues identified during independent review of R code.

Issue and proposed change	DMP Testing revealed specific	Amount of work to resolve	Importance	Actions taken (26 May 2023)

	issue and solution			
Setting ap.method=NULL causes code to crash: resolve	Yes	Trivial	Essential - a bug	Previously fixed
Remove stray browser() statement	Yes	Trivial	Essential - causes tool to halt	Fixed and checked
Change raster::area(sf::as_Spatial to sf::st_area	Yes	Trivial	Desirable - useful for futureproofing- as "raster" will become depreciated	Changed - sufficiently straightforward that it made sense to implement this now even though it is not strictly essential
Various inconsistencies or ambiguities within the documentation need correcting	Yes	Moderate	Essential - good practice, and necessary for any future testing	Corrected
Substantial performance improvements could be made to snhapp.multiloc()	Yes	.	Desirable - not essential as tool now runs sufficiently fast that computational time is not a substantive practical issue	None - desirable rather than essential so out of scope, but would be useful as future work
Error handling needs various improvements	Yes	Substantive	Desirable - would be good practice and useful for futureproofing to include this, but not essential as, in practice, the R functions are only called by the user interface code, which itself contains error handling	None - desirable rather than essential so out of scope, but would be useful as future work

Issues with inconsistencies in input data, leading to errors (a) non-numeric argument to binary operator, (b) Number of colonies in GPS map data does not match number of colonies in colony size data, [c] "Type", is missing as a column name of object tooldat$colony.meta	Partly, but a full exploration of this was out of scope for DMP testing	N/A - specific issues raised are relatively easy to fix, but testing flagged potential for other issues which would be harder to resolve	Essential - bugs	Specific issues flagged by DMP have been resolved. Additional checks on data subsequently included as part of a restructuring of the data generation module within the CEF, and further issues identified by those checks have been resolved.

6.4.43

6.5 Task 5.5: Tool validation - Sensitivity of tool outputs to input data & Task 5.6 Sensitivity of tool outputs to sensitivity scoring approach

6.5.1 We conducted a sensitivity analysis of the tool using two species – Common guillemot and Razorbill, comprising several components:

a. Random generation of hypothetical offshore windfarm footprints to use (Figure 8);
b. Generation of a CSV file containing each of the scenarios to consider within sensitivity testing
c. R code to load (a) and (b) into R package underpinning the tool, to then loop through the sensitivity scenarios, running the SSMT tool for each, and generating a data frame containing the results

In generating the hypothetical offshore windfarm footprints we used the following approach:

1. Extracted all footprints from the CEF Data Store
2. Restricted attention only to those whose area exceeds 20km^2
3. Randomly selected 7 footprints from this set
4. Found the midpoint of each footprint, and perturbed it by 10km, in either a north or south direction (the choice is random) – to try to keep distance to coast roughly fixed and to try to avoid the perturbed footprints overlapping with land
5. Found the area of each footprint, and perturbed it by multiplying by either 0.5 or 1.5 (the choice is random)

6. Created 7 simulated footprints (Figure 8), by creating square polygons with the midpoints as in (4) and the widths as in the square root of the areas in (5)
7. Restructuring the resulting object to have exactly the same format as the EMODNET data

We then used a set of scenarios to vary the following tool parameters or datasets to assess sensitivity of tool outputs for two species (Common guillemot and Razorbill):

- Foraging range (mean max, mean max + 1SD, mean max + 2SD, max max; all from Woodward et al. 2019)
- Choice of apportioning method (NatureScot Foraging Range Distance Decay method, or alternatively the GPS tracking derived method)
- Choice of distribution data for seabirds (GPS tracking[all behaviours, diving only] or at-sea survey data[birds in flight, birds on sea])
- Choice of seasonal definition (BDMPS seasonal definitions or NatureScot seasonal definitions)

Tool outputs were assessed in footprint mode, and comprised consideration of the predicted sensitivity scores (with scores for all species set to equal 1 to ease in interpretation of results).

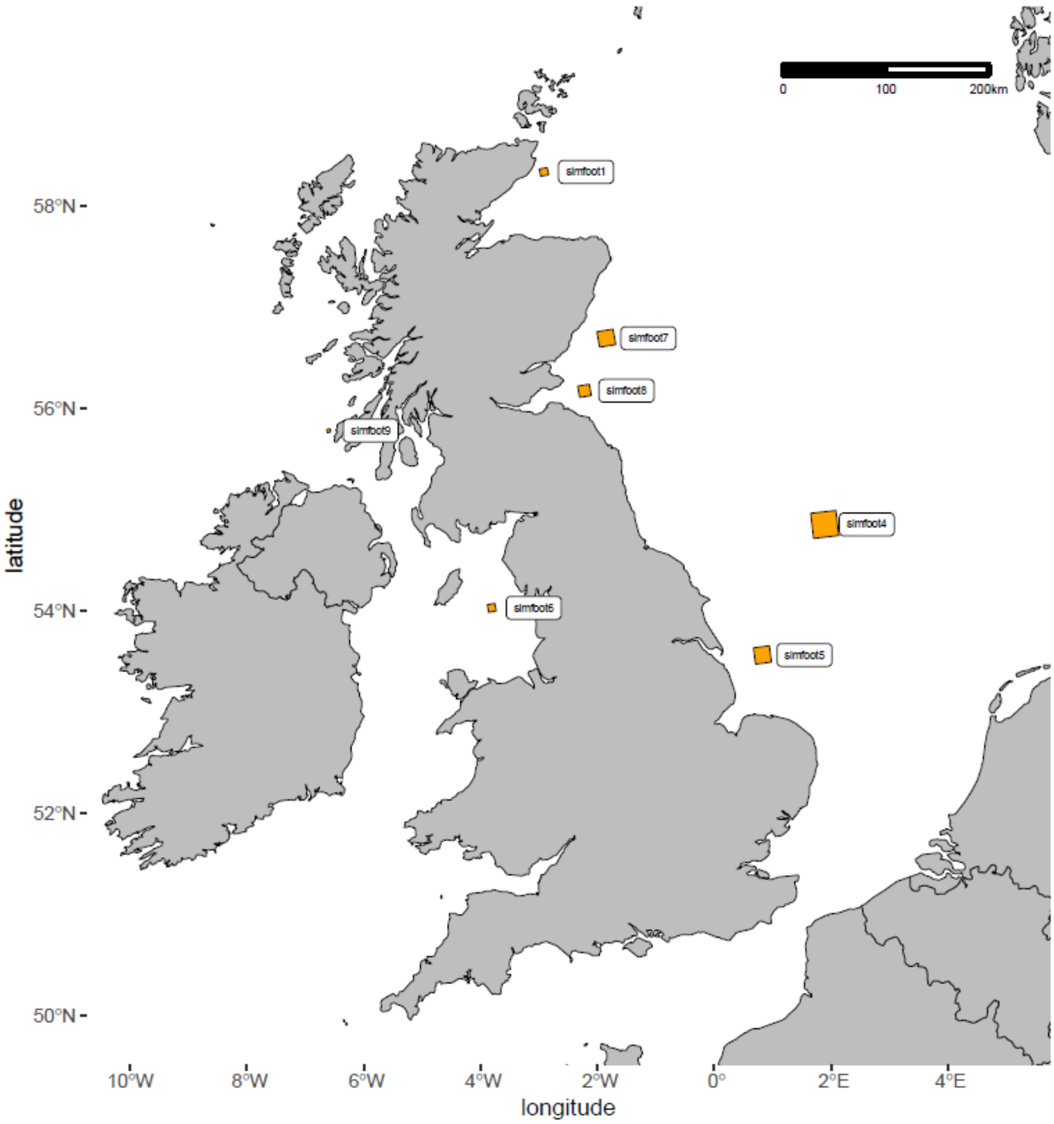

Figure 8. The seven simulated offshore wind farm footprints generated to use in the sensitivity analysis of the mapping tool.

6.5.2 Common guillemot high level summary for un-apportioned results

Mean sensitivity scores averaged over the seven simulated footprints were generally of a similar magnitude for the ten high level summaries of alternative combinations within the tool (Table **2**). Mean scores based on NatureScot seasonal definitions tended to be smaller than those resulting from use of the broadly equivalent BDMPS definition, but only marginally so, and this was not necessarily reflected in the upper 95% quantiles or maximum values (Table **2**). Mean scores derived from at-sea based bird distribution maps using displacement/barrier pressures tended to be higher than those derived from collision, but again this was not necessarily reflected in the upper 95% quantiles or maximum values (Table **2**).

This reflects differences in the underlying at-sea bird distribution maps for collision (birds in flight only) versus displacement and barrier effects (all birds). In contrast, no obvious differences were found between the use of GPS-derived maps from all behaviours versus those from only diving behaviours (Table **2**). The highest sensitivity scores arose when at-sea bird distribution maps were applied in the breeding season (NatureScot and BDMPS definitions) for displacement and barrier pressures (Table **2**).

Table 2. Summary of results for Common guillemot. Results show mean, SD, upper 95% quantile and maximum values for sensitivity scores, averaged over all simulated footprints. Results are un-apportioned, so represent summed sensitivity scores over all birds predicted to use the footprint area. Ten different combinations of variables were included, comparing underlying bird distribution (GPS or At-sea), ***if*** GPS then either considering all behaviours or diving only behaviours, pressure type (DB: displacement & barrier, CO: collision), seasonal period.

Map	GPS Map type	pressure	Seasonal period	Mean	SD	95%q	max
GPS	All behaviours	DB	--	0.00030	0.00023	0.00054	0.00069
GPS	Diving behaviours	DB	--	0.00025	0.00025	0.00049	0.00075
Atsea	--	CO	BDMPS: Non-breeding	0.00032	0.00024	0.00058	0.00069
Atsea	--	CO	NatureScot: Winter period	0.00025	0.00026	0.00050	0.00076
Atsea	--	CO	BDMPS: Breeding	0.00037	0.00025	0.00062	0.00066
Atsea	--	CO	NatureScot: Breeding period	0.00034	0.00028	0.00065	0.00072
Atsea	--	DB	BDMPS: Non-breeding	0.00039	0.00027	0.00068	0.00070
Atsea	--	DB	NatureScot: Winter period	0.00034	0.00029	0.00066	0.00073
Atsea	--	DB	BDMPS: Breeding	0.00073	0.00087	0.00177	0.00186
Atsea	--	DB	NatureScot: Breeding period	0.00071	0.00097	0.00191	0.00246

6.5.3 Razorbill high level summary for un-apportioned results

Similar to Common guillemot, mean sensitivity scores averaged over the seven simulated footprints were generally of a similar magnitude for the ten high level summaries of alternative combinations within the tool (Table **3**). Mean scores based on NatureScot seasonal definitions tended to be smaller than those resulting from use of the broadly equivalent BDMPS definition, but only marginally so, and this was not necessarily reflected in the upper 95% quantiles or maximum values (Table

3). Mean scores derived from at-sea based bird distribution maps using displacement/barrier pressures tended to be higher than those derived from collision, but again this was not necessarily reflected in the upper 95% quantiles or maximum values (Table 3). This reflects differences in the underlying at-sea bird distribution maps for collision (birds in flight only) versus displacement and barrier effects (all birds). In contrast, no obvious differences were found between the use of GPS-derived maps from all behaviours versus those from only diving behaviours (Table 3). In contrast to guillemots, the highest sensitivity scores arose when at-sea bird distribution maps were applied in the BDMPS breeding and non-breeding seasons for displacement and barrier pressures (Table 3).

Table 3. Summary of results for Razorbill. Results show mean, SD, upper 95% quantile and maximum values for sensitivity scores, averaged over all simulated footprints. Results are un-apportioned, so represent summed sensitivity scores over all birds predicted to use the footprint area. Ten different combinations of variables were included, comparing underlying bird distribution (GPS or At-sea), ***if*** GPS then either considering all behaviours or diving only behaviours, pressure type (DB: displacement & barrier, CO: collision), seasonal period.

Map	GPS Map type	pressure	Seasonal period	Mean	SD	95%q	max
GPS	All behaviours	DB	--	0.00032	0.00028	0.00062	0.00087
GPS	Diving behaviours	DB	--	0.00026	0.00031	0.00055	0.00091
Atsea	--	CO	BDMPS: Non-breeding	0.00032	0.00029	0.00061	0.00089
Atsea	--	CO	NatureScot: Winter period	0.00025	0.00031	0.00056	0.00092
Atsea	--	CO	BDMPS: Breeding	0.00038	0.00025	0.00060	0.00070
Atsea	--	CO	NatureScot: Breeding period	0.00032	0.00027	0.00065	0.00076
Atsea	--	DB	BDMPS: Non-breeding	0.00040	0.00026	0.00065	0.00072
Atsea	--	DB	NatureScot: Winter period	0.00031	0.00028	0.00065	0.00077
Atsea	--	DB	BDMPS: Breeding	0.00043	0.00050	0.0010	0.00121
Atsea	--	DB	NatureScot: Breeding period	0.00033	0.00038	0.00080	0.00084

6.5.4 Common guillemot high level summary for apportioned results

Essentially no difference in mean sensitivity scores across footprints and colonies was found when comparison seabird distributions derived from GPS tracking data for all behaviours versus only diving behaviours (Table **4**). Similarly, there were no notable differences in mean sensitivity scores depending on the seasonal definition used (BDMPS versus NatureScot; Table **4**). Interestingly, the foraging metric also did not result in noticeable differences in average sensitivity scores across all footprints and colonies (Table **4**), with any differences presumably being averaged out across the different characteristics of the seven hypothetical footprints and their relationship with alternative breeding colonies. There was some tendency for average sensitivity scores derived from displacement and barrier pressures using at-sea bird distribution maps to be greater than those for collision (Table **4**), again likely due to the inclusion of all birds in at-sea derived maps for displacement and barrier effects as opposed to only birds in flight for collision.

Table 4. Summary of results for Common guillemot. Results show mean, SD, upper 95% quantile and maximum values for sensitivity scores, averaged over all simulated footprints and breeding colonies. Results are apportioned, so represent averaged sensitivity scores across all breeding colonies for the species. Twenty-six different combinations of variables were included, comparing apportioning method (MS: GPS-based apportioning, NS: Foraging range and distance decay method), underlying bird distribution ('map': GPS or At-sea), ***if*** GPS then either considering all behaviours or diving only behaviours, pressure type (DB: displacement & barrier, CO: collision), seasonal period, and number of comparisons per combination (N).

App method	map	GPS map type	Foraging range metric	Pressure	Seasonal period	N	Mean	SD	95%q	max
MS	GPS	All behaviours	--	DB	NA	4739	0.00046	0.00287	0.00002	0.0445
MS	GPS	Diving behaviours	--	DB	NA	4739	0.00046	0.00288	0.00002	0.0453
MS	Atsea	--	--	CO	BDMPS: Breeding	4739	0.00042	0.00263	0.00003	0.0355
MS	Atsea	--	--	CO	NS: Breeding period	4739	0.00042	0.00261	0.00004	0.0363
MS	Atsea	--	--	CO	BDMPS: Breeding	4739	0.00046	0.00287	0.00002	0.0445
MS	Atsea	--	--	CO	NS: Breeding period	4739	0.00046	0.00288	0.00002	0.0453
NS	Atsea	--	MeanMax	CO	BDMPS: Breeding	4739	0.00042	0.00263	0.00003	0.0355
NS	Atsea	--	MeanMax+1SD	CO	BDMPS: Breeding	4739	0.00042	0.00261	0.00004	0.0363
NS	Atsea	--	MeanMax+2SD	CO	BDMPS: Breeding	4767	0.00034	0.00242	0.00001	0.0340
NS	Atsea	--	MaxMax	CO	BDMPS: Breeding	4767	0.00040	0.00242	0.00000	0.0356

NS	Atsea	--	MeanMax	CO	NS: Breeding period	4767	0.00025	0.00122	0.00033	0.0227
NS	Atsea	--	MeanMax+1SD	CO	NS: Breeding period	4767	0.00025	0.00124	0.00033	0.0233
NS	Atsea	--	MeanMax+2SD	CO	NS: Breeding period	4767	0.00027	0.00124	0.00037	0.0167
NS	Atsea	--	MaxMax	CO	NS: Breeding period	4767	0.00026	0.00122	0.00038	0.0155
MS	Atsea	--	--	DB	BDMPS: Breeding	4767	0.00051	0.00409	0.00000	0.0576
MS	Atsea	--	--	DB	NS: Breeding period	4767	0.00051	0.00412	0.00000	0.0587
MS	Atsea	--	--	DB	BDMPS: Breeding	4767	0.00047	0.00387	0.00000	0.0584
MS	Atsea	--	--	DB	NS: Breeding period	4767	0.00047	0.00385	0.00000	0.0590
NS	Atsea	--	MeanMax	DB	BDMPS: Breeding	4767	0.00039	0.00233	0.00000	0.0408
NS	Atsea	--	MeanMax+1SD	DB	BDMPS: Breeding	4767	0.00039	0.00237	0.00000	0.0418
NS	Atsea	--	MeanMax+2SD	DB	BDMPS: Breeding	4767	0.00037	0.00220	0.00000	0.0290
NS	Atsea	--	MaxMax	DB	BDMPS: Breeding	4767	0.00036	0.00216	0.00000	0.0281
NS	Atsea	--	MeanMax	DB	NS: Breeding period	4767	0.00031	0.00173	0.00022	0.0312
NS	Atsea	--	MeanMax+1SD	DB	NS: Breeding period	4767	0.00031	0.00176	0.00022	0.0319
NS	Atsea	--	MeanMax+2SD	DB	NS: Breeding period	4767	0.00030	0.00162	0.00017	0.0223
NS	Atsea	--	MaxMax	DB	NS: Breeding period	4767	0.00029	0.00158	0.00016	0.0204

6.5.5 Razorbill high level summary for apportioned results

Essentially no difference in mean sensitivity scores across footprints and colonies was found when comparison seabird distributions derived from GPS tracking data for all behaviours versus only diving behaviours (Table **5**). Similarly, there were no notable differences in mean sensitivity scores depending on the seasonal definition used (BDMPS versus NatureScot; Table **5**, Table **4**). Interestingly, the foraging metric also did not result in noticeable differences in average sensitivity scores across all footprints and colonies (Table **5**), with any differences presumably being averaged out across the different characteristics of the seven hypothetical footprints and their relationship with alternative breeding colonies. However, for one set of conditions, where at-sea maps were used to assess collision sensitivity scores using the BDMPS breeding seasonal period, there was a consistent decline in average sensitivity scores as the foraging range increased (from MeanMax to MaxMax; Table **5**), presumably reflecting a tendency for lower apportioning proportions per colony when foraging ranges are large and birds observed within footprints are estimated to derive from a larger number of breeding colonies. There was some tendency for average sensitivity scores derived from displacement and barrier pressures using at-sea bird distribution maps to be greater than those for collision (Table **5**), again likely due to the inclusion of all birds in at-sea derived maps for displacement and barrier effects as opposed to only birds in flight for collision.

Table 5. Summary of results for Razorbill. Results show mean, SD, upper 95% quantile and maximum values for sensitivity scores, averaged over all simulated footprints and breeding colonies. Results are apportioned, so represent averaged sensitivity scores across all breeding colonies for the species. Twenty-six different combinations of variables were included, comparing apportioning method (MS: GPS-based apportioning, NS: Foraging range and distance decay method), underlying bird distribution (‘map’: GPS or At-sea), ***if*** GPS then either considering all behaviours or diving only behaviours, pressure type (DB: displacement & barrier, CO: collision), seasonal period, and number of comparisons per combination (N).

App method	map	GPS map type	Foraging range metric	Pressure	Seasonal period	N	Mean	SD	95%q	max
MS	GPS	All behaviours	--	DB	NA	5971	0.00037	0.00202	0.00019	0.0398
MS	GPS	Diving behaviours	--	DB	NA	5971	0.00035	0.00191	0.00020	0.0371
MS	Atsea	--	--	CO	BDMPS: Breeding	5971	0.00038	0.00200	0.00023	0.0361
MS	Atsea	--	--	CO	NS: Breeding period	5971	0.00035	0.00186	0.00023	0.0322
MS	Atsea	--	--	CO	BDMPS: Breeding	5971	0.00037	0.00202	0.00019	0.0398

MS	Atsea	--	--	CO	NS: Breeding period	5971	0.00035	0.00191	0.00020	0.0371
NS	Atsea	--	MeanMax	CO	BDMPS: Breeding	5971	0.00038	0.00200	0.00023	0.0361
NS	Atsea	--	MeanMaxP+1SD	CO	BDMPS: Breeding	5971	0.00035	0.00186	0.00023	0.0322
NS	Atsea	--	MeanMax+2SD	CO	BDMPS: Breeding	6083	0.00023	0.00145	0.00007	0.0221
NS	Atsea	--	MaxMax	CO	BDMPS: Breeding	6083	0.00016	0.00112	0.00004	0.0222
NS	Atsea	--	MeanMax	CO	NS: Breeding period	6083	0.00024	0.00125	0.00029	0.0245
NS	Atsea	--	MeanMax+1SD	CO	NS: Breeding period	6083	0.00023	0.00115	0.00029	0.0216
NS	Atsea	--	MeanMax+2SD	CO	NS: Breeding period	6083	0.00026	0.00133	0.00034	0.0235
NS	Atsea	--	MaxMax	CO	NS: Breeding period	6083	0.00024	0.00120	0.00033	0.0191
MS	Atsea	--	--	DB	BDMPS: Breeding	6083	0.00043	0.00325	0.00000	0.0490
MS	Atsea	--	--	DB	NS: Breeding period	6083	0.00042	0.00317	0.00000	0.0461
MS	Atsea	--	--	DB	BDMPS: Breeding	6083	0.00044	0.00331	0.00000	0.0457
MS	Atsea	--	--	DB	NS: Breeding period	6083	0.00042	0.00322	0.00000	0.0444
NS	Atsea	--	MeanMax	DB	BDMPS: Breeding	6083	0.00034	0.00209	0.00000	0.0373
NS	Atsea	--	MeanMax+1SD	DB	BDMPS: Breeding	6083	0.00033	0.00198	0.00000	0.0341
NS	Atsea	--	MeanMax+2SD	DB	BDMPS: Breeding	6083	0.00035	0.00208	0.00000	0.0340
NS	Atsea	--	MaxMax	DB	BDMPS: Breeding	6083	0.00032	0.00194	0.00000	0.0291
NS	Atsea	--	MeanMax	DB	NS: Breeding period	6083	0.00027	0.00155	0.00021	0.0301
NS	Atsea	--	MeanMaxPlus1SD	DB	NS: Breeding period	6083	0.00025	0.00144	0.00020	0.0270
NS	Atsea	--	MeanMax+2SD	DB	NS: Breeding period	6083	0.00028	0.00157	0.00024	0.0280
NS	Atsea	--	MaxMax	DB	NS: Breeding period	6083	0.00026	0.00144	0.00022	0.0233

6.5.6 Sensitivity analysis summary

The sensitivity analysis did not reveal any obvious or substantial differences in tool outputs in relation to the various options and datasets available within the tool. Any differences in outputs were consistent with underlying differences in datasets or underpinning functionality. Because the optimal set of options and datasets to use within the tool will vary by species and context, expert ornithological advice should be sought when choosing between tool options, and we recommend producing outputs derived from various relevant options for comparison.

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7. Appendix A

7.1 Summary of independent review of tool methodology

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Review of Report:

Searle, K. et al. (2021) Development of a Seabird Sensitivity Mapping Tool for Scotland. Offshore Renewables Joint Industry Programme (ORJIP). Centre for Ecology and Hydrology.

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7.1.1

8. Appendix B

8.1 Summary of independent code review

SSMT Testing

Bruno Caneco, Carl Donovan - DMP Stats

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