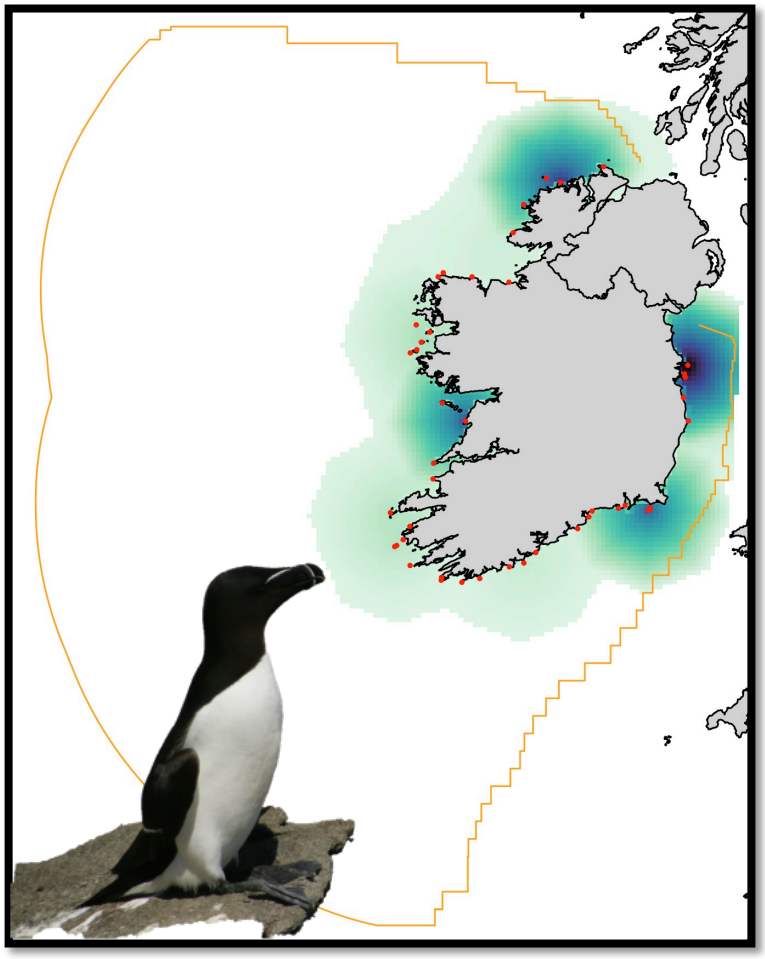
Modelling the at-sea distribution of Irish breeding seabird species based on colony count data

Manon Clairbaux & Mark Jessopp
University College Cork



UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh
School of
Biological, Earth and
Environmental Sciences

Rialtas na hÉireann
Government of Ireland

Background

Marine Protected Areas (MPAs), Special Protection Areas (SPAs), and Important Bird Areas (IBAs) have emerged as useful measures to protect marine species and ecosystems (Handley et al., 2020; Roberts et al., 2017). Globally, seabirds are one of the most threatened groups of birds, and efforts are being made to increase the number of protected areas to aid in their conservation. For effective designation of areas, information must be gathered on the at-sea distribution of species and identification of 'hotspots'. Such data can be obtained from at-sea surveys (e.g. Rogan et al., 2018), tracking studies (e.g. Davies et al., 2021), and statistical models based habitat associations (e.g. Wakefield et al., 2021). Although empirical data are highly valuable, their collection requires significant time and resources making them unevenly distributed in space and time. In those circumstances, predictive distribution modelling is a cost-effective method that can be used to identify seabird hotspots at an ocean basin scale level.

Such an approach using colony census data together with foraging ranges of seabird species (Grecian et al., 2012; Soanes et al., 2016; Thaxter et al., 2012) shows a reasonably good relationship with both tracking and at-sea survey data during the breeding season (Critchley et al. 2019). Such work was conducted by University College Cork in 2017, resulting in the production of the North Atlantic Predictive Seabird Atlas (http://seabirdatlas.ucc.ie/webgis/) depicting estimated densities of seabirds in Irish waters. This Atlas is accessible by the public and a range of stakeholders. However, the information contained in the Atlas is now out of date, being based on census data collected some 20 years ago. Comprehensive and contemporary data are now available, so it is opportune to update the predicted distributions.

Upon receiving data on Ireland's breeding seabird populations describing the estimated abundances and locations of each species, University College Cork intend to:

1. Apply the foraging radius model to estimate species-specific densities at a 5 x 5 km spatial resolution for Ireland's marine waters.
2. Provide such data in suitable formats to NPWS to undertake further analysis to inform the identification of important marine areas for seabirds during the breeding season.
3. Make data available and accessible to stakeholders interested in the conservation of Ireland's seabirds.

Methods

Contemporary data on colony locations and population sizes were provided by the NPWS for 24 seabird species breeding in Ireland (see Table 1). The bulk of this data are associated with Cummins et al. (2019) and output from more recent NPWS commissioned survey work also fed into these analyses.

We used the mean maximum foraging range of each species from the review by Woodward et al. (2019). Foraging range estimates were based on direct measures from tracking data, indirect measures based on average flight speed and trip duration, or from visual surveys. For each species, the maximum foraging range was then reported for each colony and averaged to obtain the mean maximum foraging range used in this study. Mean maximum foraging range values were preferred to maximum foraging range as outputs of the foraging radius model are generally in better agreement with results based on at-sea survey and tracking studies (Critchley et al., 2019; Grecian et al., 2012).

Mean maximum foraging range of Leach's storm petrel (*Oceanodroma leucorhoa*) was not included in Woodward et al. (2019) so a value was taken from Thaxter et al. (2012). In addition, we used the maximum foraging range for Little tern (*Sternula albifrons*) from Thaxter et al. (2012) and the one from Woodward et al. (2019) for Black guillemot (*Cepphus grylle*) as their mean maximum foraging range are of the order of the raster resolution (5 x 5 km), precluding the distribution modelling beyond the coast when the pixel centre on which the colony is located is considered as terrestrial.

A 5 × 5 km grid was generated covering the Irish EEZ (Exclusive Economic Zone) into which distributions would be projected. The spatial scale was based on a compromise between the scale of foraging ranges across seabird species and required computing power. For each colony of each species, the projected at-sea distribution was generated using the methodology of Critchley et al., 2018 (see Figure 1). First, the probability of occurrence within each grid square was calculated by taking the normalised inverse distance from each grid square to the colony (Step 1, Figure 1), so that all squares had a value of between 0 and 1 with the highest values being found closest to the colony. These values corresponded to the probability of a bird occurring in a given grid square, decreasing linearly with distance from the colony. Grid squares occurring over land were given a penalty such that it was considered too 'expensive' to travel over these cells, resulting in distributions being limited to cells whose centre point occurs over water. Distributions were then distance-weighted using a logarithmic decay function (Step 2, Figure 1) applied to the mean maximum foraging range for each species so that areas closer to the colony were of higher importance per unit area, accounting for non-foraging behaviours such as washing/preening or rafting (Wilson et al., 2009). Values were again normalised so that all grid squares summed to 1, i.e. 100% of the at-sea population, and then multiplied by estimates of the number of pairs (Step 3, Figure 1) to estimate abundance per grid square.

The resulting distributions show the number of individuals predicted to occur in each grid square assuming that on average, one half of a breeding pair will remain at the nest at any one time (e.g. during incubation and early chick rearing).

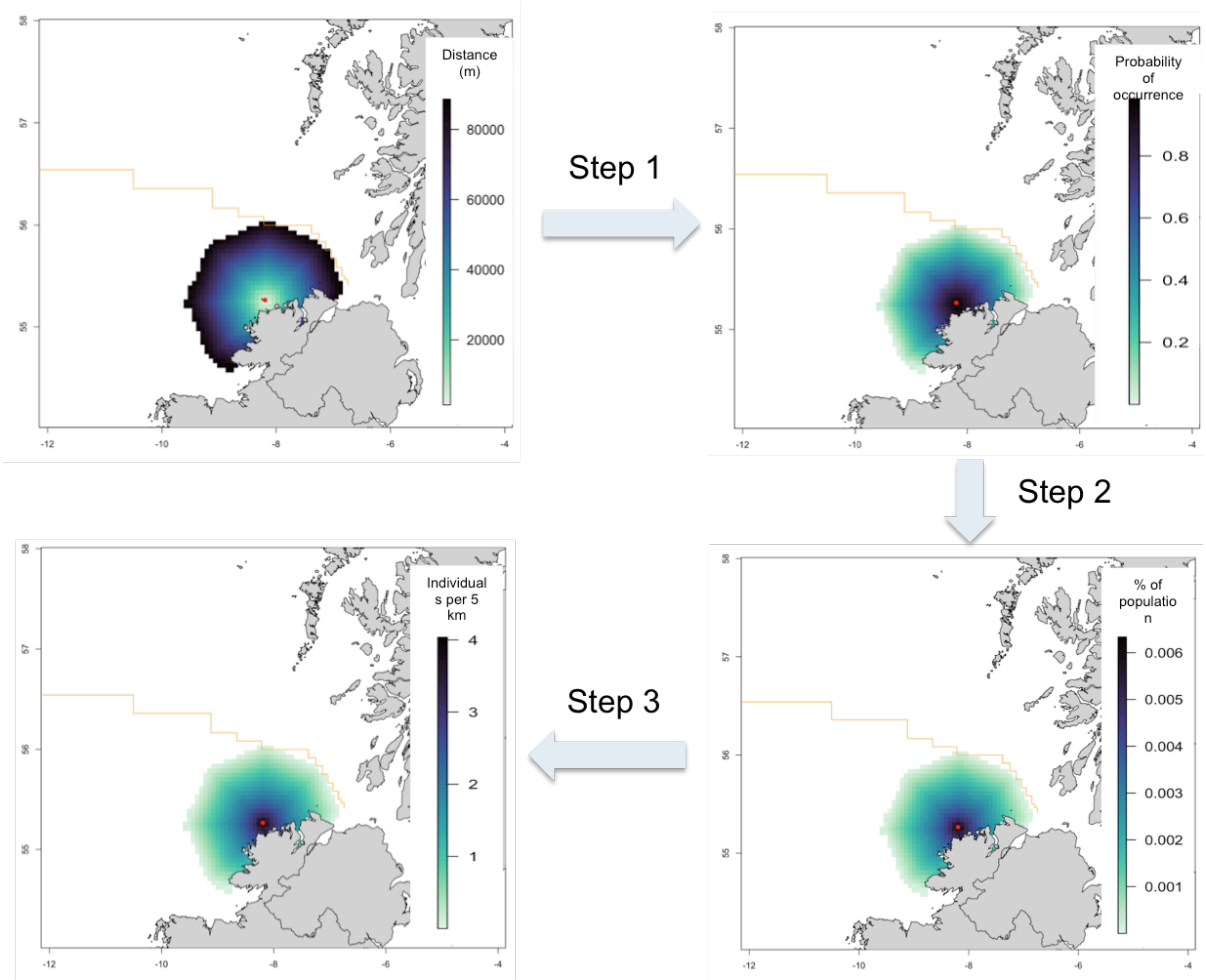


Figure 1. Illustrations of the methodological steps applied to one razorbill colony (red dot). The Irish EEZ limit is displayed in orange.

These steps were repeated for each individual colony and the distributions were then summed to generate a foraging radius distribution map for each of the 24 species over the entire study area (see Figure 2 and Appendix).

As individuals from urban colonies of Lesser black-backed gull (*Larus fuscus*), Herring gull (*Larus argentatus*) and Great black-backed gull (*Larus marinus*) are thought to feed predominantly inland (Spelt et al., 2019), they were excluded when modelling the overall projected distribution of those species. We generated projected distributions for urban populations separately, noting that many of these distributions predicted a significant marine component.

Table 1. Mean maximum foraging ranges of the 24 Irish seabird species considered. Values are presented as ± SD and the sample sizes are shown in parentheses. Values are from Woodward et al. (2019) except for Leach's storm petrel and Little tern (see Methods).

Species	Mean maximum foraging range (km)
Arctic tern (*Sterna paradisaea*)	25.7±14.8 (9)
Atlantic puffin (*Fratercula arctica*)	137.1±128.2 (7)
Black guillemot (*Cepphus grylle*)	8
Black headed gull (*Chroicocephalus ridibundus*)	18.5 (1)
Black-legged kittiwake (*Rissa tridactyla*)	156.1±144.5 (37)
Common guillemot (*Uria aalge*)	73.2±80.5 (16)
Common gull (*Larus canus*)	50 (1)
Common tern (*Sterna hirundo*)	18±8.9 (16)
Great cormorant (*Phalacrocorax carbo*)	25.6±8.3 (4)
European shag (*Phalacrocorax aristotelis*)	13.2±10.5 (17)
European storm petrel (*Hydrobates pelagicus*)	336 (1)
Great black-backed gull (*Larus marinus*)	73 (1)
Great skua (*Stercocarius skua*)	443±487.9 (3)
Herring gull (*Larus argentatus*)	58.8±26.8 (10)
Leach's storm petrel (*Oceanodroma leucorhoa*)	91.7±27.5 (3)
Lesser black-backed gull (*Larus fuscus*)	127±109 (18)
Little tern (*Sternula albifrons*)	11
Manx shearwater (*Puffinus puffinus*)	1346.8±1018.7 (6)
Mediterranean gull (*Ichtyaetus melanocephalus*)	20 (1)
Northern fulmar (*Fulmarus glacialis*)	542.3±657.9 (16)
Northern gannet (*Morus bassanus*)	315.2±194.2 (21)
Razorbill (*Alca torda*)	88.7±75.9 (16)
Roseate tern (*Sterna dougallii*)	12.6±10.6 (3)
Sandwich tern (*Thalasseus sandvicensis*)	34.3±23.2 (9)

Results

Projected at-sea distributions were generated for the 24 species where data were provided by NPWS (see Figure 2 and Appendix). For each species, data are provided in two formats:

1. A georeferenced raster file (.tiff) containing the number of individuals per pixel. The resolution is 5 x 5 km and the raster is projected using the coordinate reference system WGS84 UTM zone 29N to avoid distortions. The overall extent (xmin=10000, xmax=750000, ymin= 5200000, ymax=6400000 in WGS84 UTM zone 29N) covers the Irish EEZ.
2. A csv file (.csv) containing for each 5 x 5 km 'pixel' of the raster file (see above) its unique identifier ("cellnumber"), the coordinates of its centre ("Long" and "Lat" expressed in degrees (WGS84 projection)) and the number of individuals contained in the pixel ("Numberofindividual").

The unique identifier of each cell remains the same in all the .csv files provided, regardless of the species, allowing easy queries by identifier.

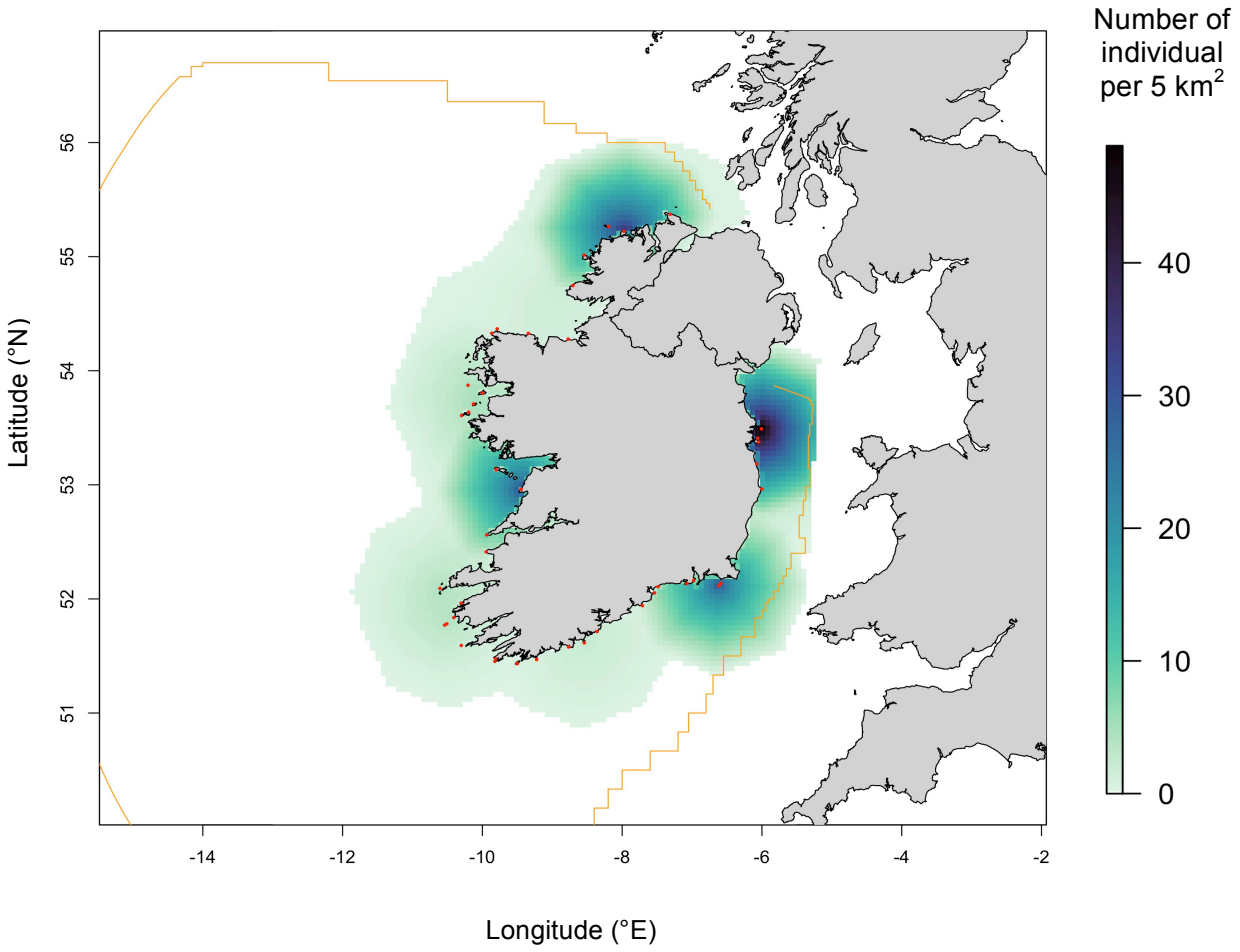


Figure 2. Projected at-sea distribution of razorbill. Red dots correspond to colony locations and the Irish EEZ limit is displayed in orange.

Updated projected distributions will be hosted on the UCC seabird Atlas. However, given that the Atlas interface is somewhat outdated, distributions will be provided to the Irish Marine Institute with appropriate metadata for inclusion in Ireland's Marine Atlas (https://atlas.marine.ie) which will help ensure longer term curation of the data and accessibility to the wider public.

Limitations

The distributions generated come with a number of limitations and caveats on their use. First, projected distributions are modelled outputs for breeding adults and will not reflect the distribution of juveniles or non-breeders. Furthermore, the modelled distributions presented here follow a simple relationship with foraging range, and cannot account for the many additional factors influencing seabird distribution including habitat preferences/limitations, prey distribution, and the distribution of anthropogenic activities that may vary within and across years. In addition, foraging range is based on a combination of studies from other areas that may affect the distance birds travel and are not specifically linked to the colonies they are applied to. Foraging range is also likely to vary with colony size (Jovani et al., 2016) which has not been accounted for in the projected distributions. The proportion of the population at sea at any one time will also vary with both time of day and season. However, the relative importance of each grid square will remain the same and the same hotspots will be identified.

Despite these limitations, the foraging radius approach has been shown to have a reasonable agreement with at-sea survey and tracking data (Critchley et al., 2019) and provide an easy way to estimate seabird distribution at broad scales where oceanic and ecological factors are lacking or where seabird species haven't been intensively studied.

References

Critchley, E. J., Grecian, W. J., Bennison, A., Kane, A., Wischnewski, S., Cañadas, A., … Jessopp, M. J. (2019). Assessing the effectiveness of foraging radius models for seabird distributions using biotelemetry and survey data. *Ecography*, *43*, 184–196. https://doi.org/10.1111/ecog.04653

Cummins, S., Lauder, C., Lauder, A. & Tierney, T. D. (2019) The Status of Ireland's Breeding Seabirds: Birds Directive Article 12 Reporting 2013 – 2018. Irish Wildlife Manuals, No. 114. National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Ireland

Davies, T. E., Carneiro, A. P. B., Tarzia, M., Wakefield, E., Hennicke, J. C., Frederiksen, M., … Dias, M. P. (2021). Multispecies tracking reveals a major seabird hotspot in the North Atlantic. *Conservation Letters*, *14*(5), 1–14. https://doi.org/10.1111/conl.12824

Grecian, W. J., Witt, M. J., Attrill, M. J., Bearhop, S., Godley, B. J., Grémillet, D., … Votier, S. C. (2012). A novel projection technique to identify important at-sea areas for seabird conservation: An example using Northern gannets breeding in the North East Atlantic. *Biological Conservation*, *156*, 43–52. https://doi.org/10.1016/j.biocon.2011.12.010

Handley, J. M., Pearmain, E. J., Oppel, S., Carneiro, A. P. B., Hazin, C., Phillips, R. A., … Dias, M. P. (2020). Evaluating the effectiveness of a large multi-use MPA in protecting Key Biodiversity Areas for marine predators. *Diversity and Distributions*, *26*(6), 715–729. https://doi.org/10.1111/ddi.13041

Jovani, R., Lascelles, B., Garamszegi, L. Z., Mavor, R., Thaxter, C. B., & Oro, D. (2016). Colony size and foraging range in seabirds. *Oikos*, *125*(7), 968–974. https://doi.org/10.1111/oik.02781

Roberts, C. M., O'Leary, B. C., Mccauley, D. J., Cury, P. M., Duarte, C. M., Lubchenco, J., … Castilla, J. C. (2017). Marine reserves can mitigate and promote adaptation to climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(24), 6167–6175. https://doi.org/10.1073/pnas.1701262114

Rogan, E., Breen, P., Mackey, M., Cañadas, A., Scheidat, M., Geelhoed, S. C. V, & Jessopp, M. (2018). *Aerial surveys of cetaceans and seabirds in Irish waters : occurrence, distribution and abundance in 2015-2017*. 1827, IMARES Onderzoeksformatie,: Department of Communications, Climate Action & Environment. Retrieved from https://edepot.wur.nl/468225

Soanes, L. M., Bright, J. A., Angel, L. P., Arnould, J. P. Y., Bolton, M., Berlincourt, M., … Green, J. A. (2016). Defining marine important bird areas: Testing the foraging radius approach. *Biological Conservation*, *196*, 69–79. https://doi.org/10.1016/j.biocon.2016.02.007

Spelt, A., Williamson, C., Shamoun-Baranes, J., Shepard, E., Rock, P., & Windsor, S. (2019). Habitat use of urban-nesting lesser black-backed gulls during the breeding season. Scientific reports, 9(1), 1-11.

Thaxter, C. B., Lascelles, B., Sugar, K., Cook, A. S. C. P., Roos, S., Bolton, M., … Burton, N. H. K. (2012). Seabird foraging ranges as a preliminary tool for identifying candidate Marine Protected Areas. *Biological Conservation*, *156*, 53–61. https://doi.org/10.1016/j.biocon.2011.12.009

Wakefield, E. D., Miller, D. L., Bond, S. L., le Bouard, F., Carvalho, P. C., Catry, P., … Matthiopoulos, J. (2021). The summer distribution, habitat associations and abundance of seabirds in the sub-polar frontal zone of the Northwest Atlantic. *Progress in Oceanography*, *198*, 102657. https://doi.org/https://doi.org/10.1016/j.pocean.2021.102657

Wilson, L. J., McSorley, C. A., Gray, C. M., Dean, B. J., Dunn, T. E., Webb, A., & Reid, J. B. (2009). Radio-telemetry as a tool to define protected areas for seabirds in the marine environment. *Biological Conservation*, *142*(8), 1808–1817. https://doi.org/https://doi.org/10.1016/j.biocon.2009.03.019

Woodward, I., Thaxter, C. B., Owen, E., & Cook, A. S. C. P. (2019). *Desk-based revision of seabird foraging ranges used for HRA screening*.

Appendix

Files provided to NPWS:

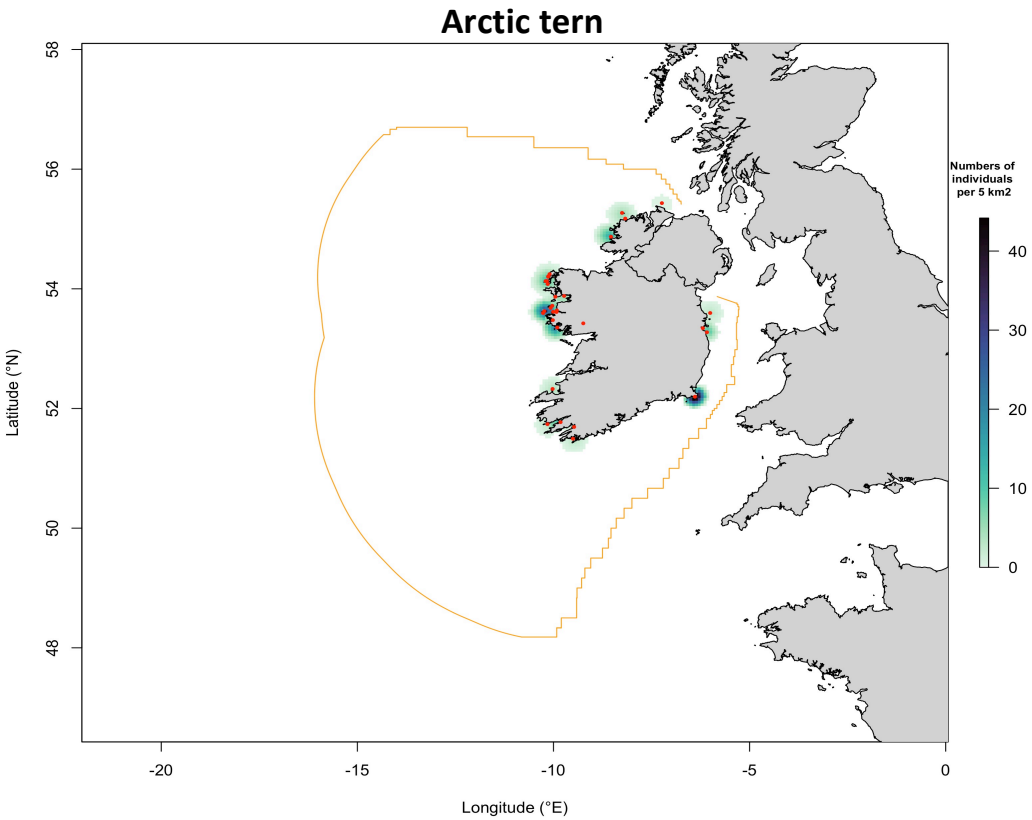
- Arctic tern_distrib.tiff
- Arctic tern_distrib_dataframe.csv
- Atlantic puffin_distrib.tiff
- Atlantic puffin_distrib_dataframe.csv
- Black guillemot_distrib.tiff
- Black guillemot_distrib_dataframe.csv
- Black headed gull_distrib.tiff
- Black headed gull_distrib_dataframe.csv
- Common guillemot_distrib.tiff
- Common guillemot_distrib_dataframe.csv
- Common gull_distrib.tiff
- Common gull_distrib_dataframe.csv
- Common tern_distrib.tiff
- Common tern_distrib_dataframe.csv
- Cormorant_distrib.tiff
- Cormorant_distrib_dataframe.csv
- European shag_distrib.tiff
- European shag_distrib_dataframe.csv
- European storm petrel_distrib.tiff
- European storm petrel_distrib_dataframe.csv
- Great black-backed gull urban_distrib.tiff
- Great black-backed gull urban_distrib_dataframe...
- Great black-backed gull_distrib.tiff
- Great black-backed gull_distrib_dataframe.csv
- Great skua_distrib.tiff
- Great skua_distrib_dataframe.csv
- Herring gull urban_distrib.tiff
- Herring gull urban_distrib_dataframe.csv
- Herring gull_distrib.tiff
- Herring gull_distrib_dataframe.csv
- Kittiwake_distrib.tiff
- Kittiwake_distrib_dataframe.csv
- Leach's storm petrel_distrib.tiff
- Leach's storm petrel_distrib_dataframe.csv
- Lesser black-backed gull urban_distrib.tiff

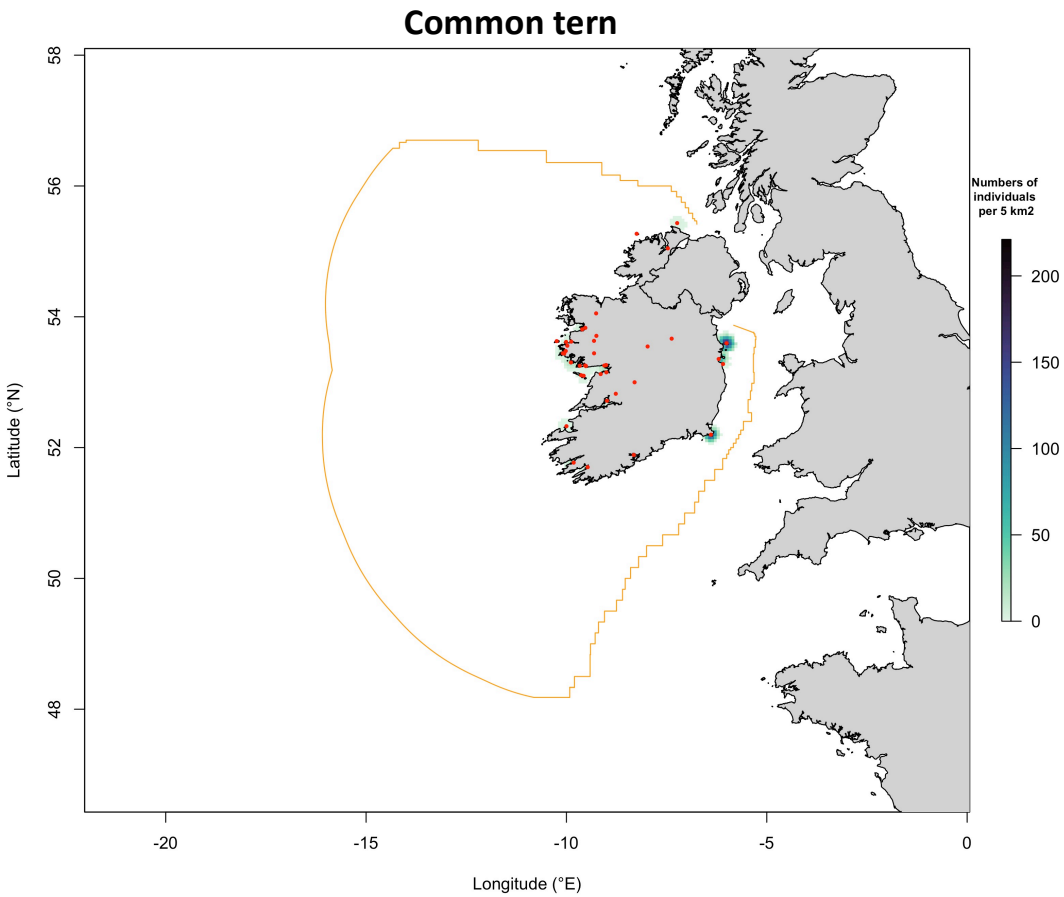
- Lesser black-backed gull urban_distrib_datafram...
- Lesser black-backed gull_distrib.tiff
- Lesser black-backed gull_distrib_dataframe.csv
- Little tern_distrib.tiff
- Little tern_distrib_dataframe.csv
- Manx shearwater_distrib.tiff
- Manx shearwater_distrib_dataframe.csv
- Mediterranean gull_distrib.tiff
- Mediterranean gull_distrib_dataframe.csv
- Northern fulmar_distrib.tiff
- Northern fulmar_distrib_dataframe.csv
- Northern gannet_distrib.tiff
- Northern gannet_distrib_dataframe.csv
- Razorbill_distrib.tiff
- Razorbill_distrib_dataframe.csv
- Roseate tern_distrib.tiff
- Roseate tern_distrib_dataframe.csv
- Sandwich tern_distrib.tiff
- Sandwich tern_distrib_dataframe.csv

Metadata associated with projected distribution files:

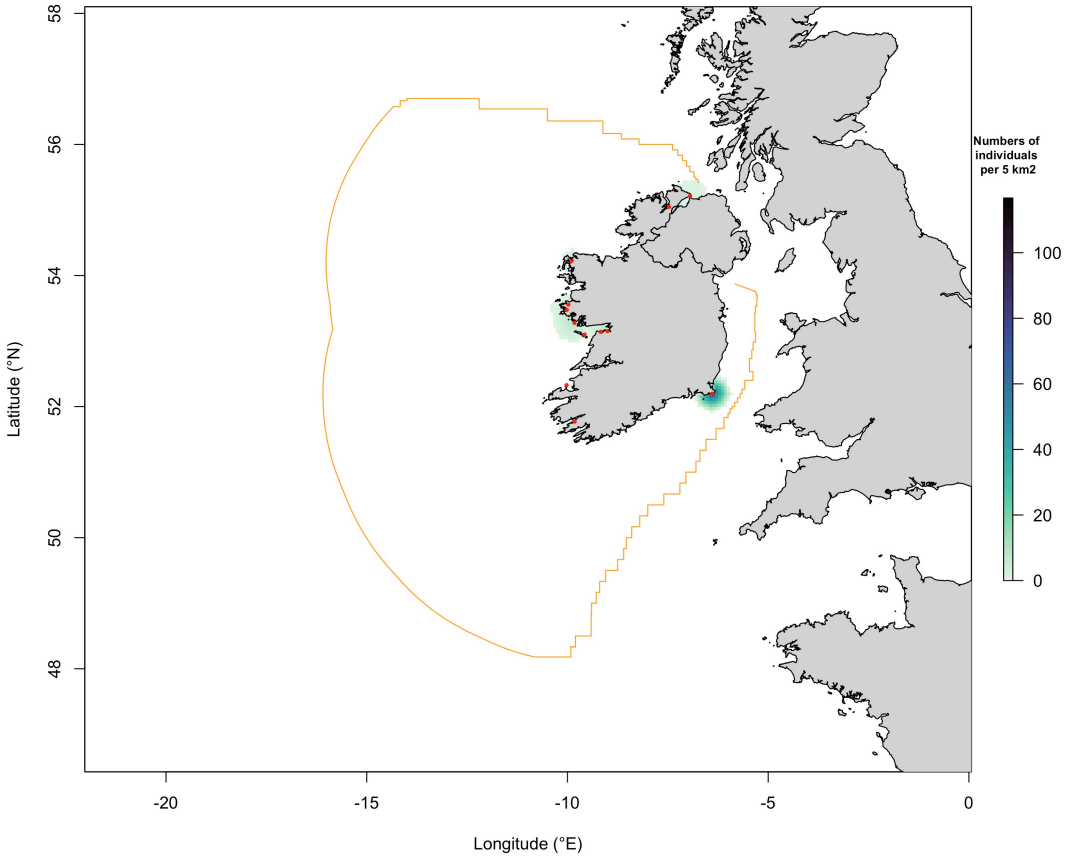
Extent (in WGS84 UTM zone 29N): Longitude: xmin=10000, xmax=750000,; Latitude: ymin= 5200000, ymax=6400000
Projection: UTM 29N
Units: Numbers of individuals
Resolution: 5 x 5 km
Source of the average maximum foraging distance used: Woodward et al., 2019 (see method for few exceptions)

Projected at-sea distribution of the 24 species considered. Red dots correspond to colony locations and the Irish Exclusive Economic Zone limit is displayed in orange.

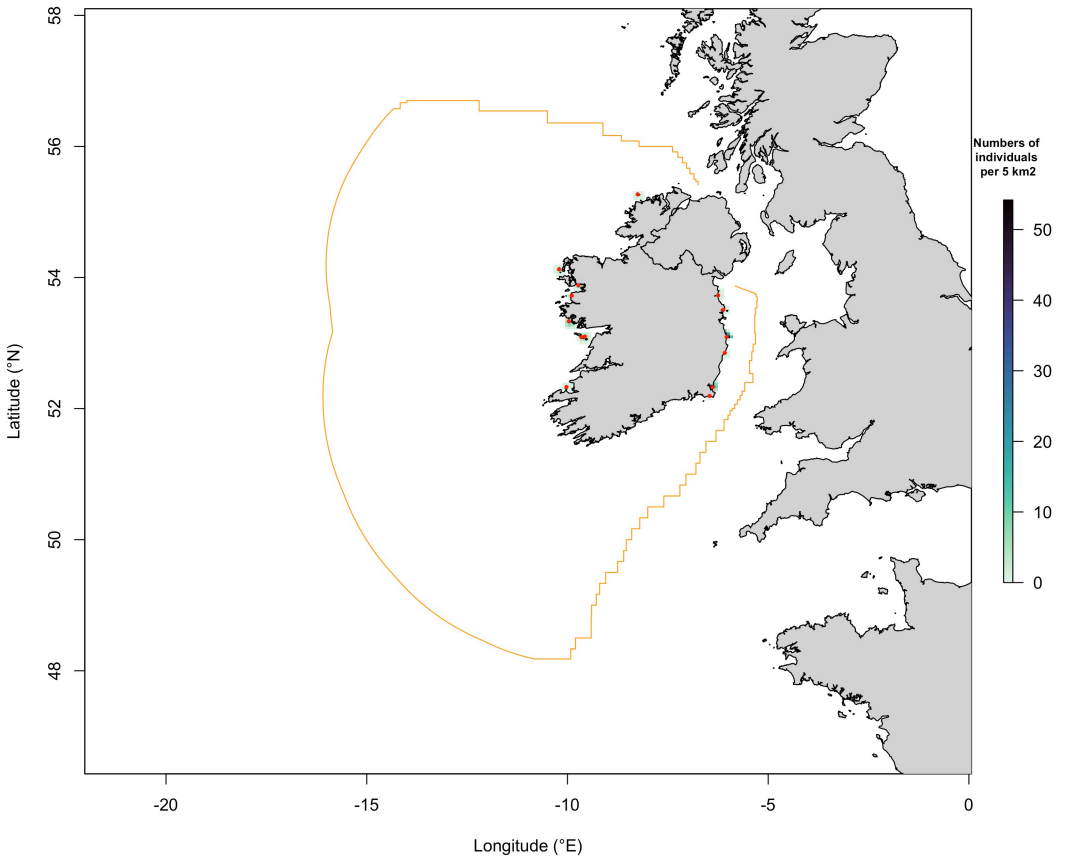


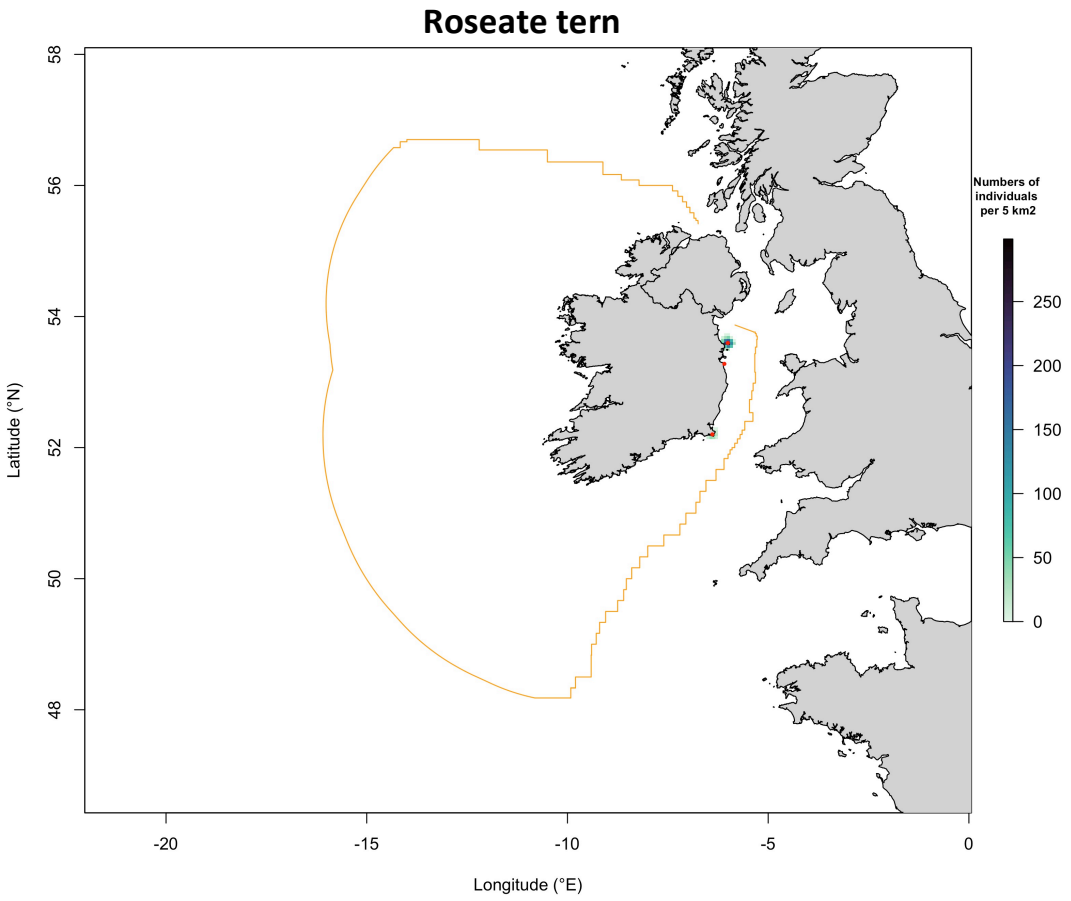


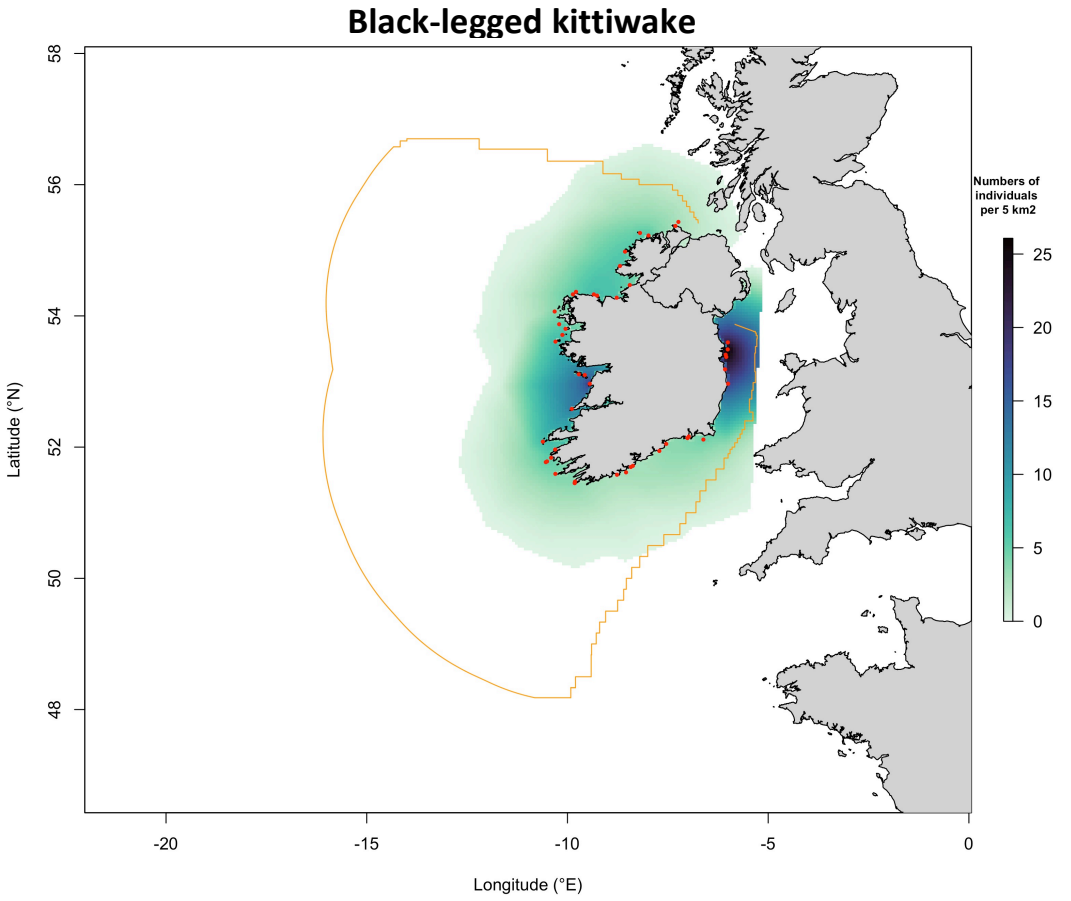
Sandwich tern



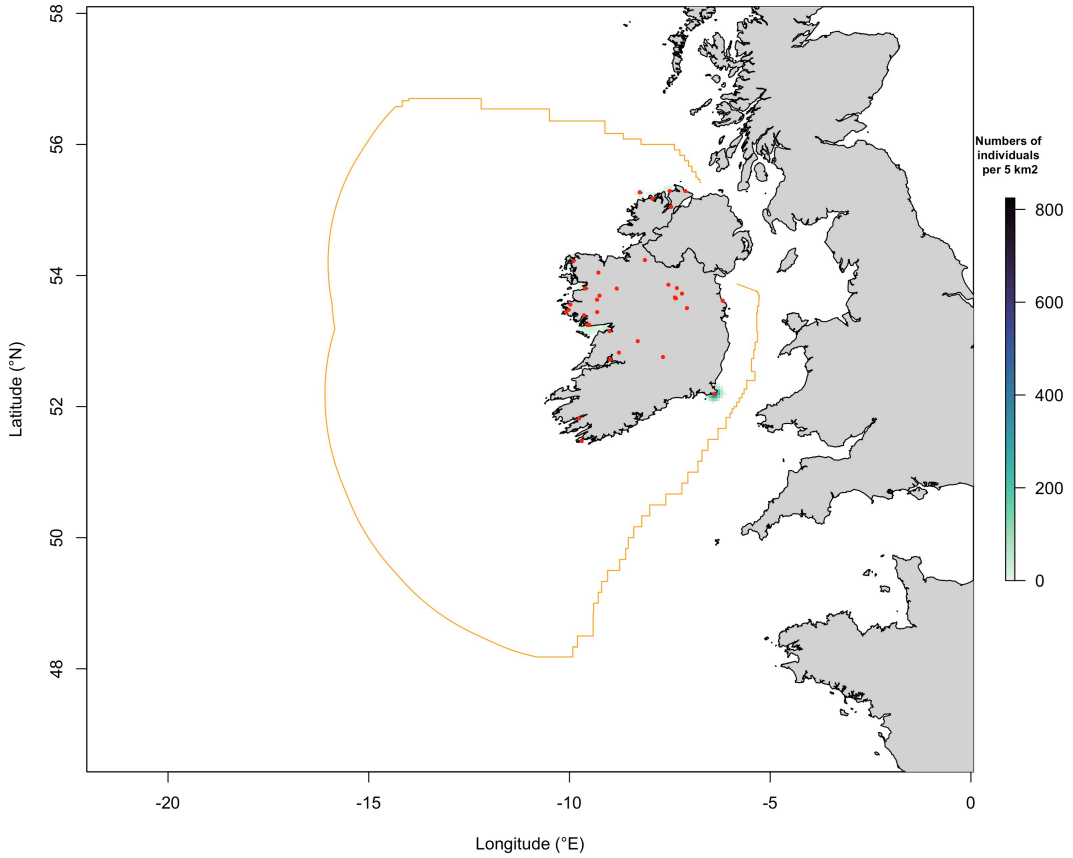
Little tern



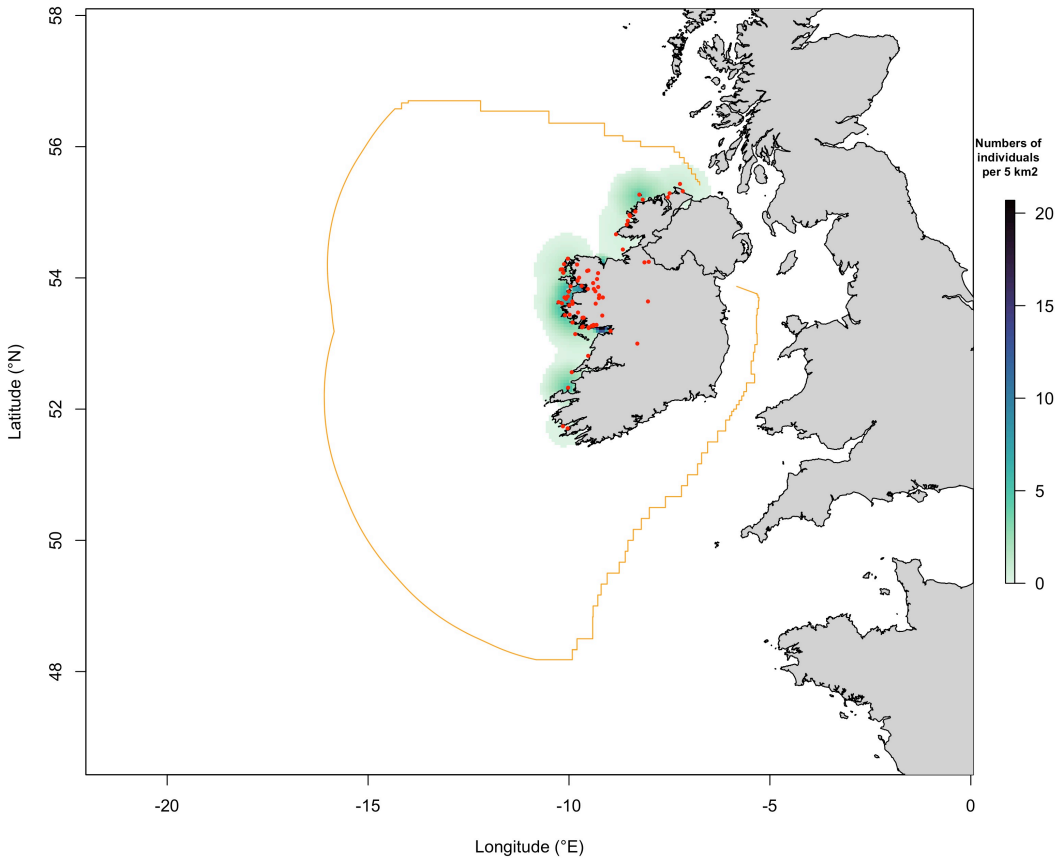

Roseate tern
Latitude (°N)
58
56
54
52
50
48
-20
-15
-10
-5
0
Longitude (°E)
Numbers of individuals per 5 km2
250
200
150
100
50
0

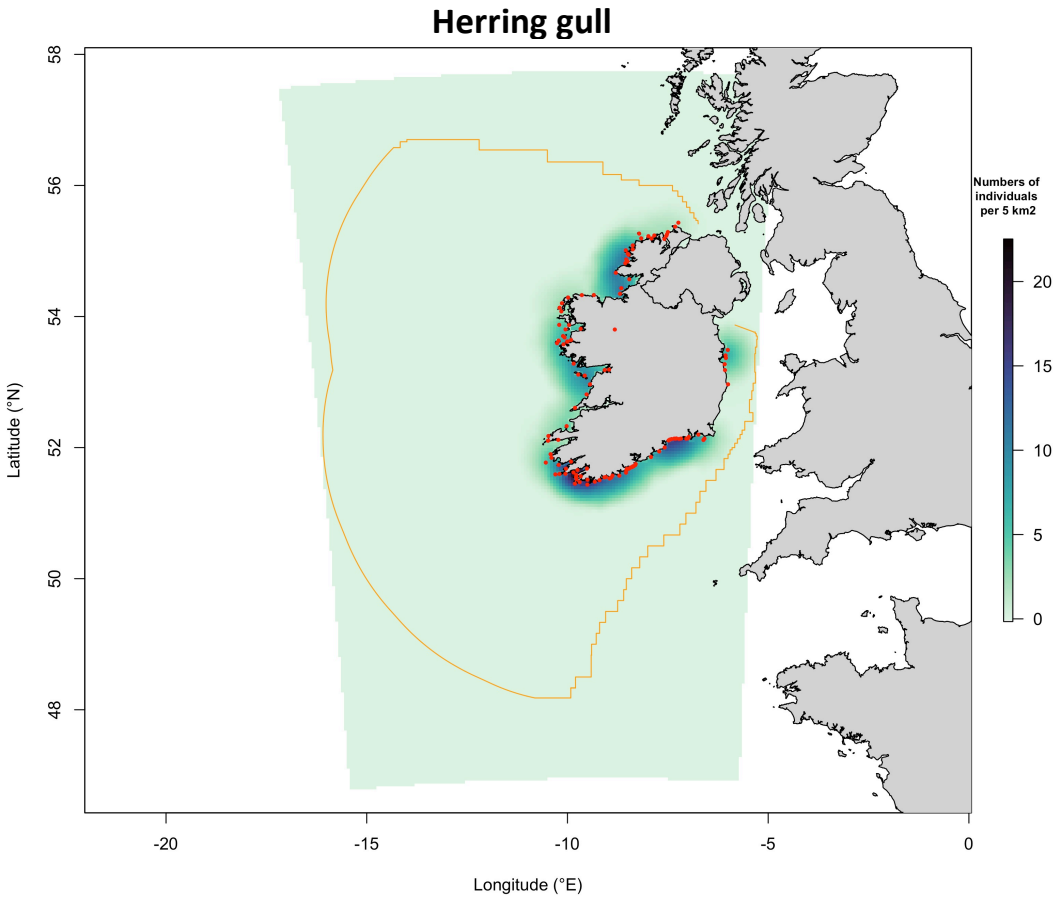

Black-legged kittiwake
Latitude (°N)
58
56
54
52
50
48
-20
-15
-10
-5
0
Longitude (°E)
Numbers of individuals per 5 km2
25
20
15
10
5
0

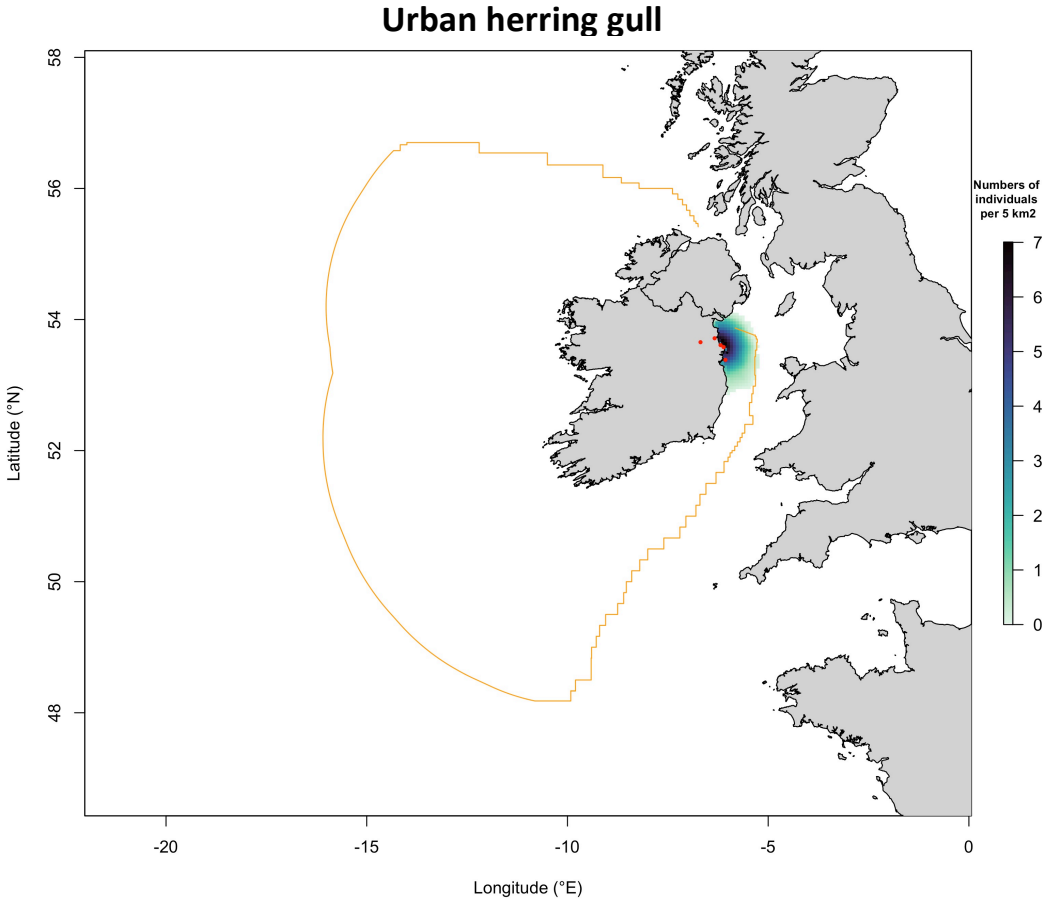
Black headed gull



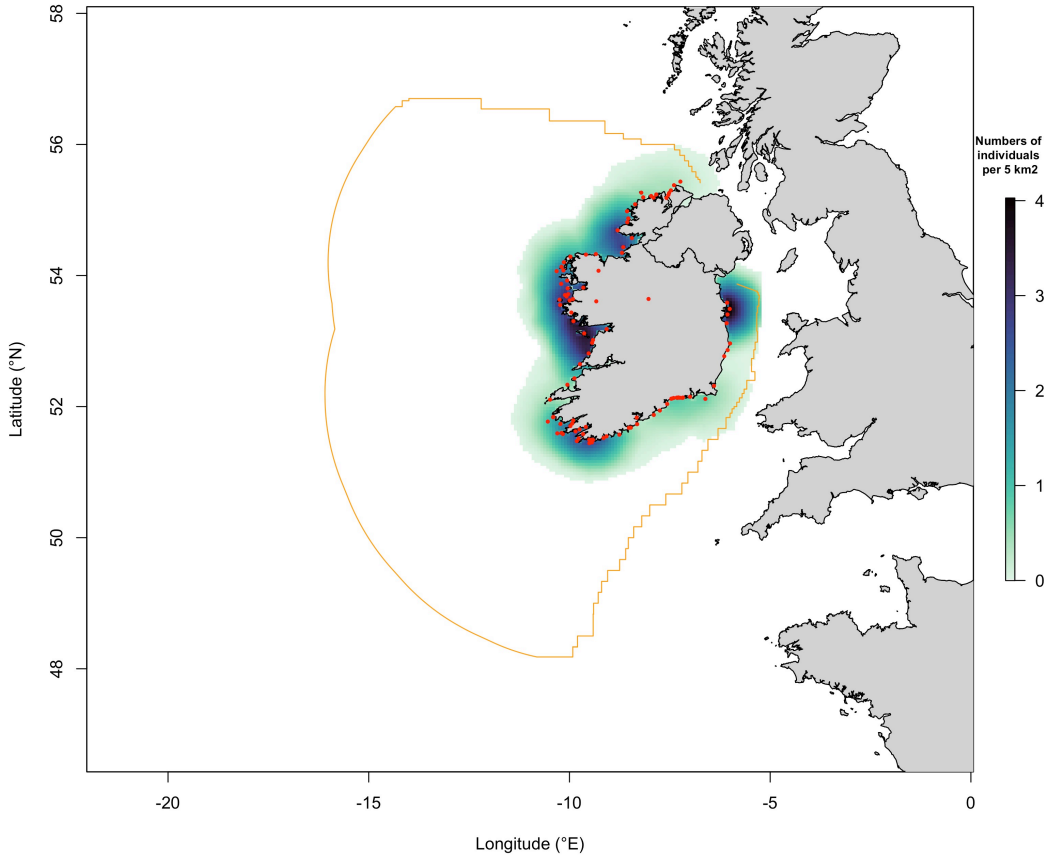
Common gull



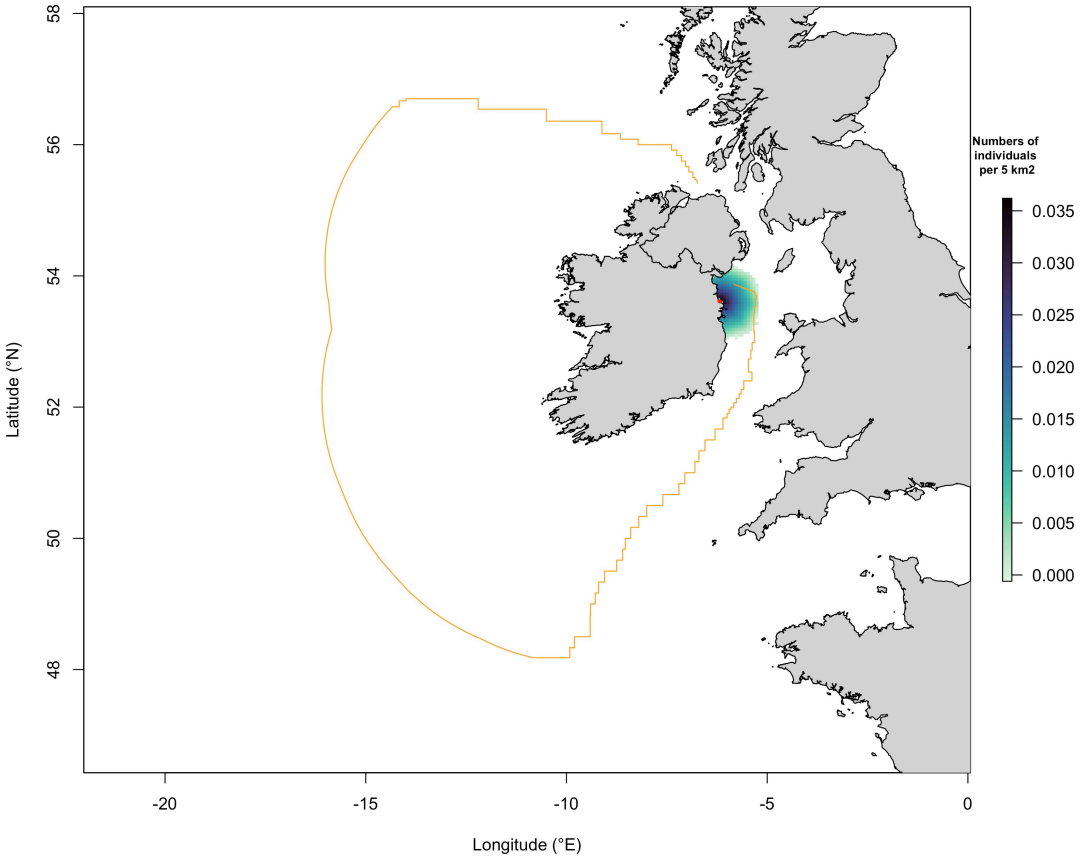

Herring gull
Latitude (°N)
58
56
54
52
50
48
-20
-15
-10
-5
0
Longitude (°E)
Numbers of individuals per 5 km2
20
15
10
5
0


Urban herring gull
Latitude (°N)
58
56
54
52
50
48
-20
-15
-10
-5
0
Longitude (°E)
Numbers of individuals per 5 km2
7
6
5
4
3
2
1
0

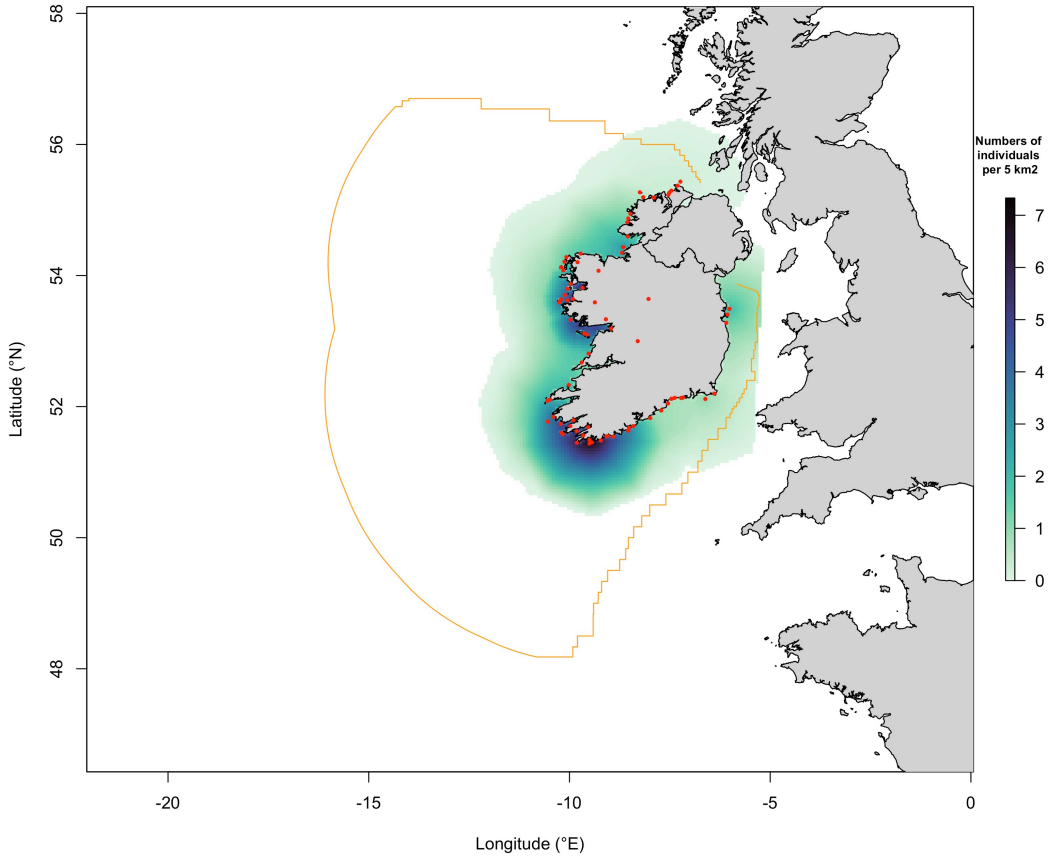
Great black-backed gull



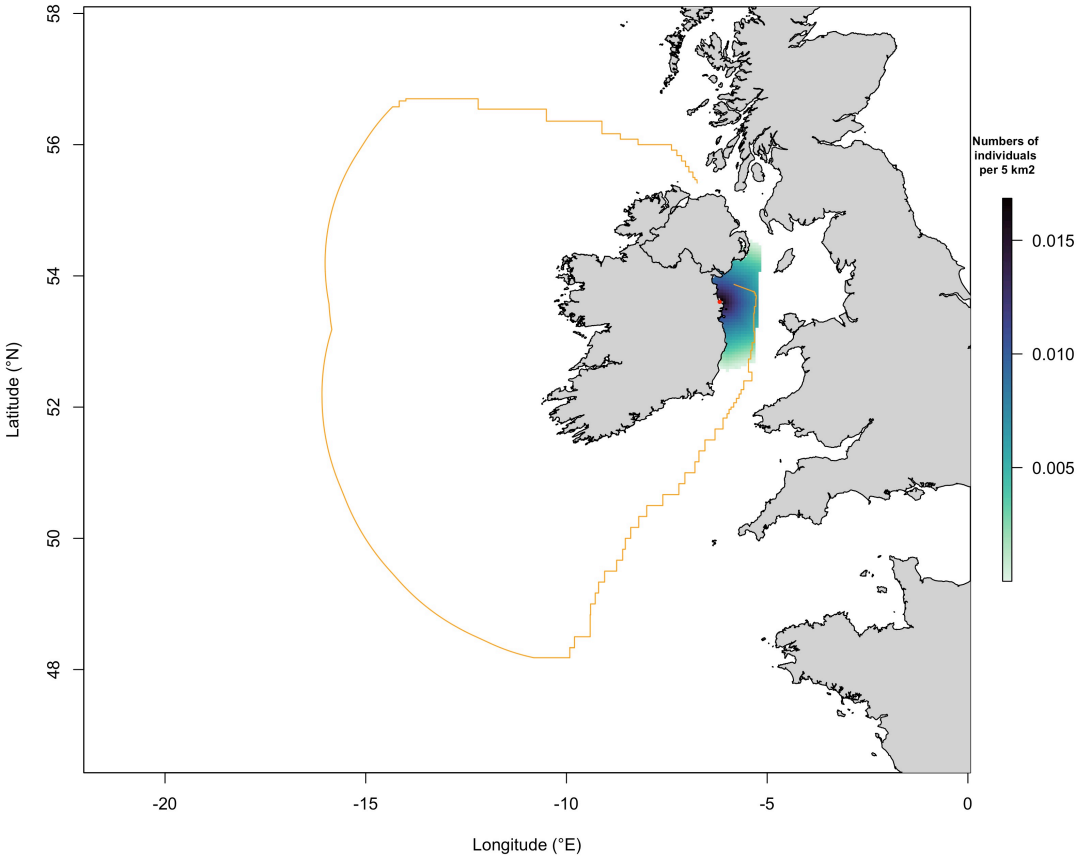
Urban great black-backed gull



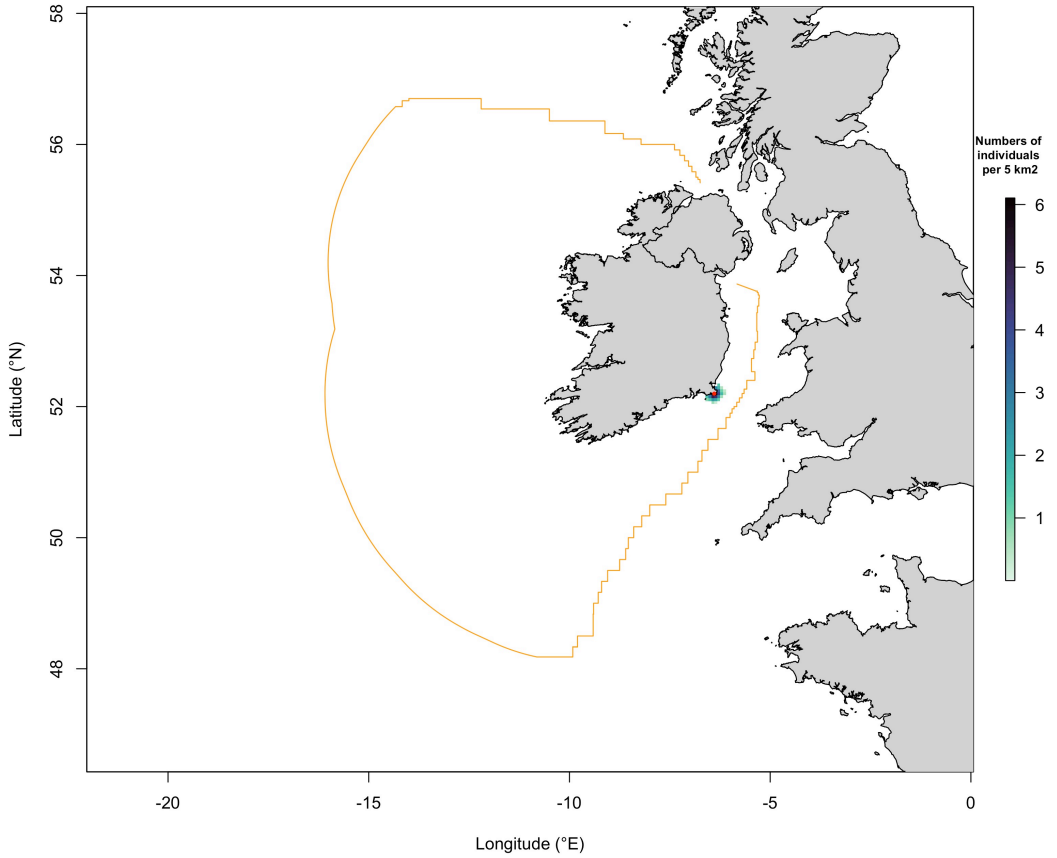
Lesser black-backed gull



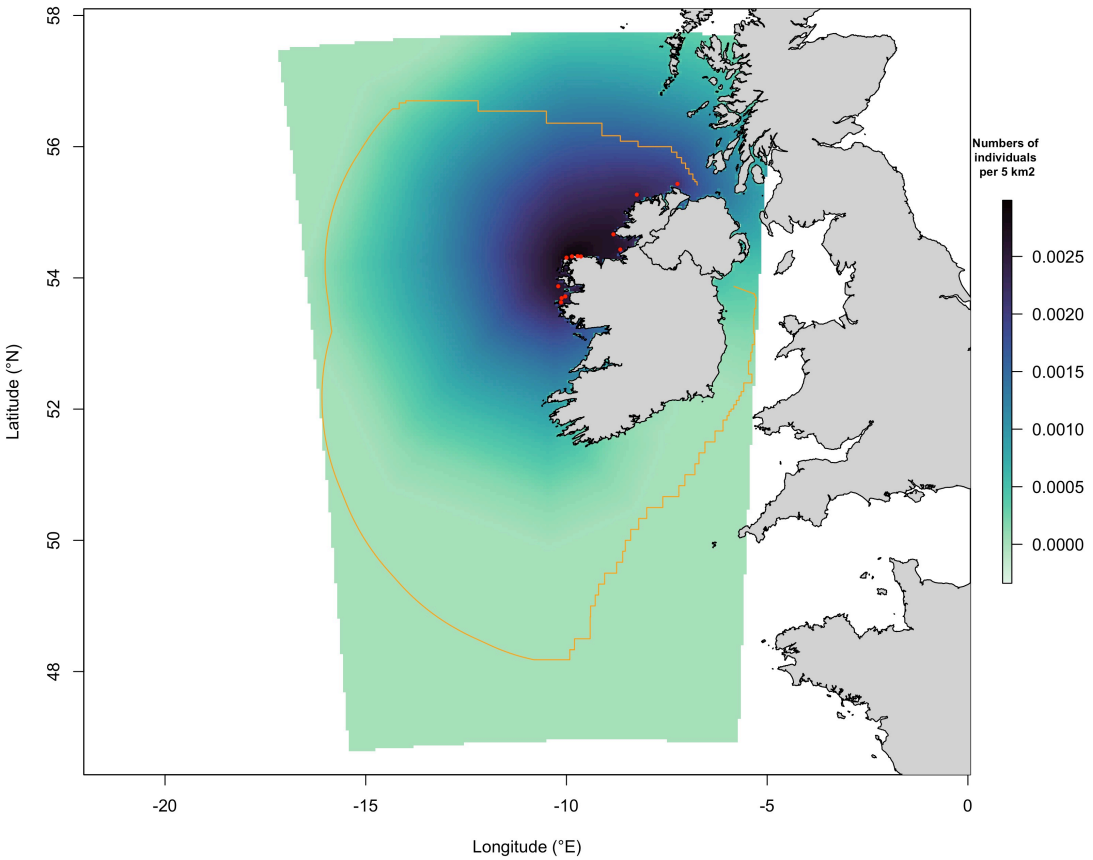
Urban lesser black-backed gull



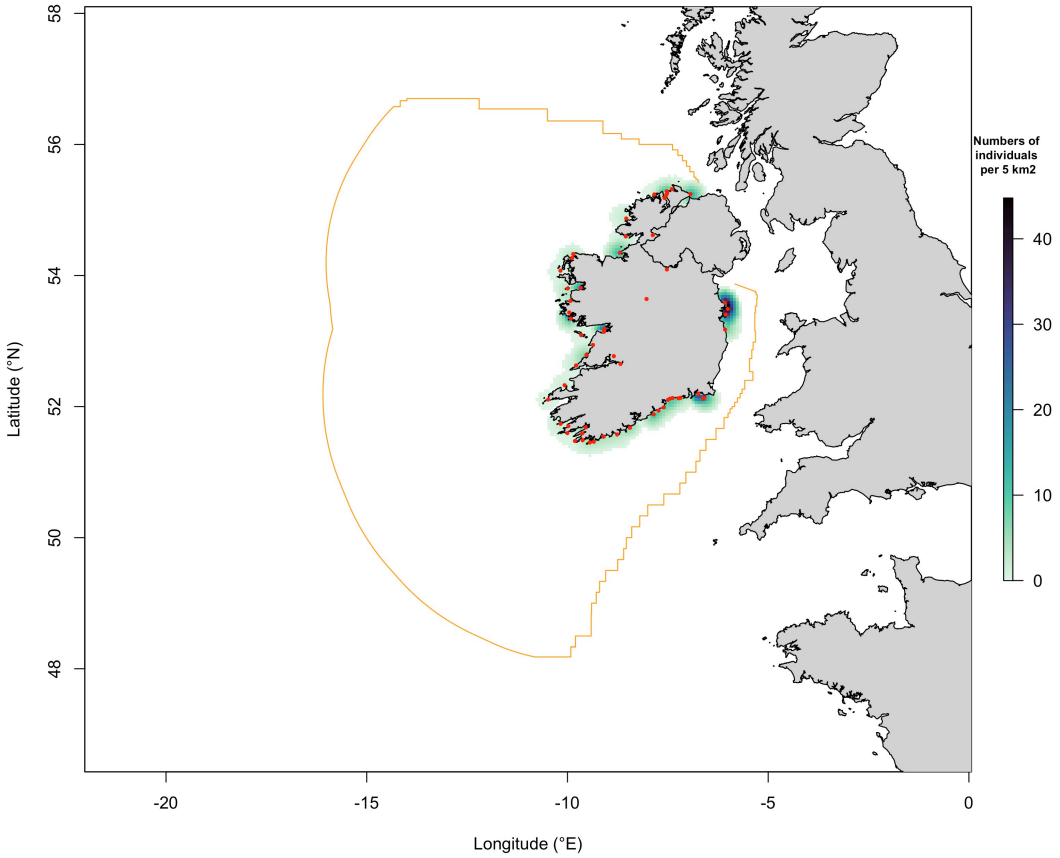
Mediterranean gull



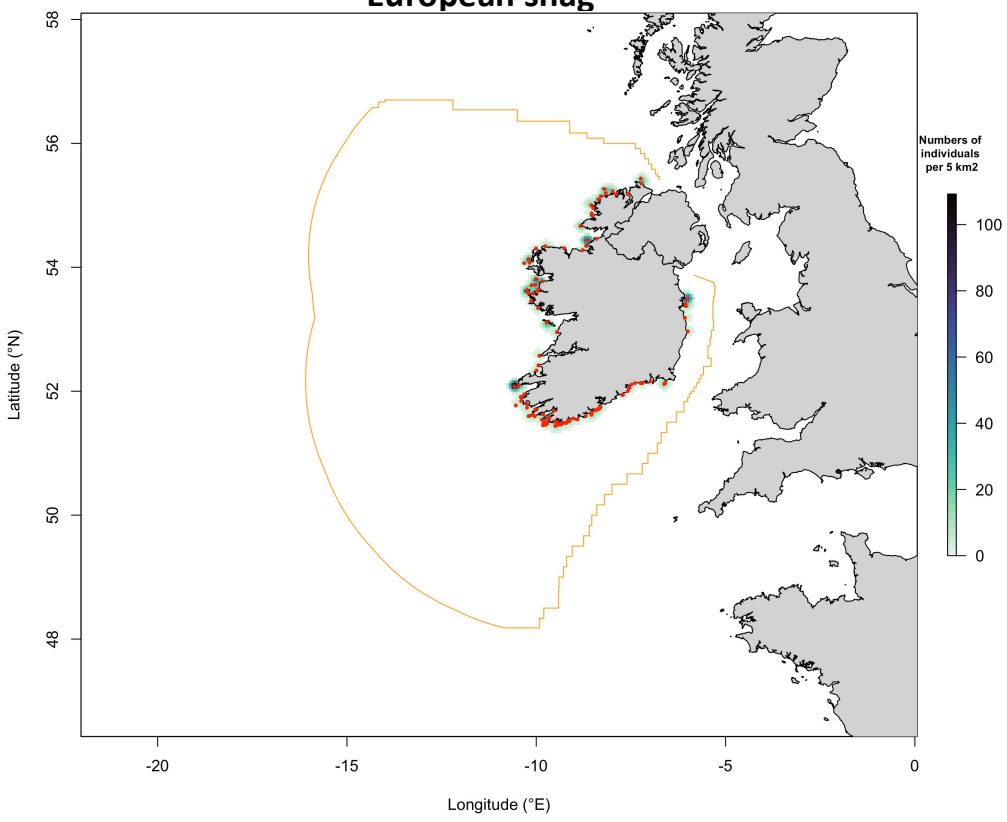
Great skua



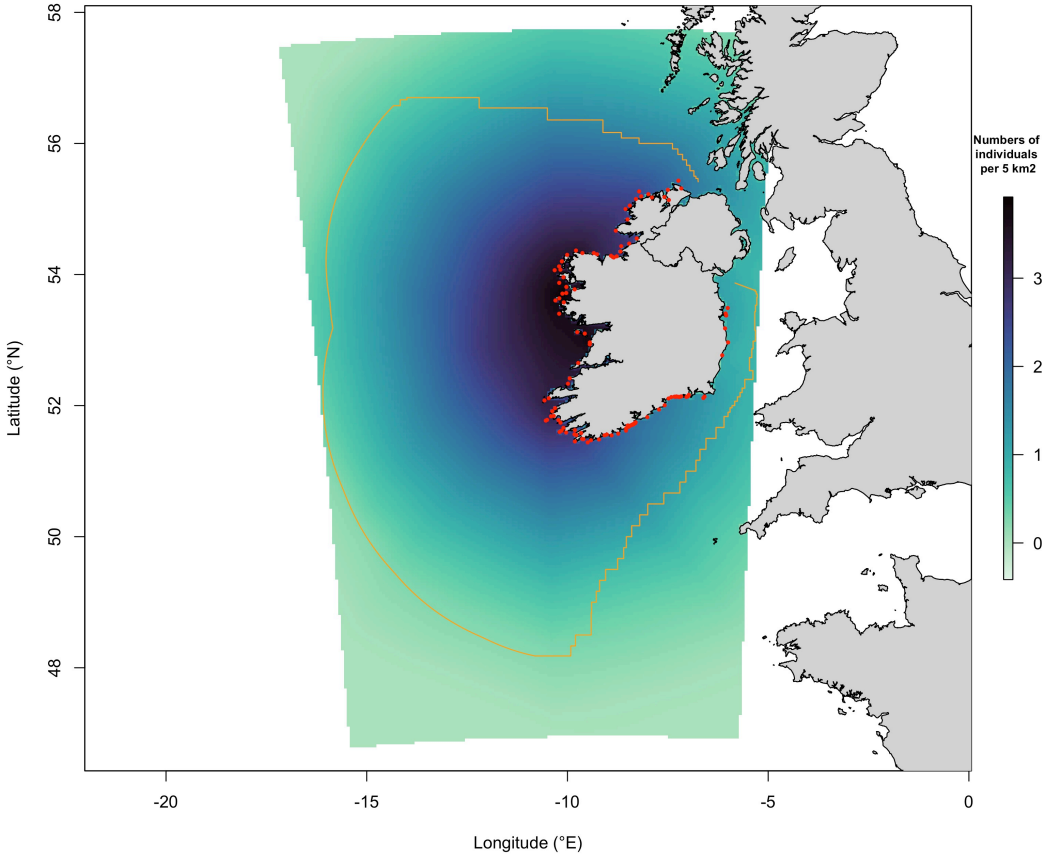
Cormorant



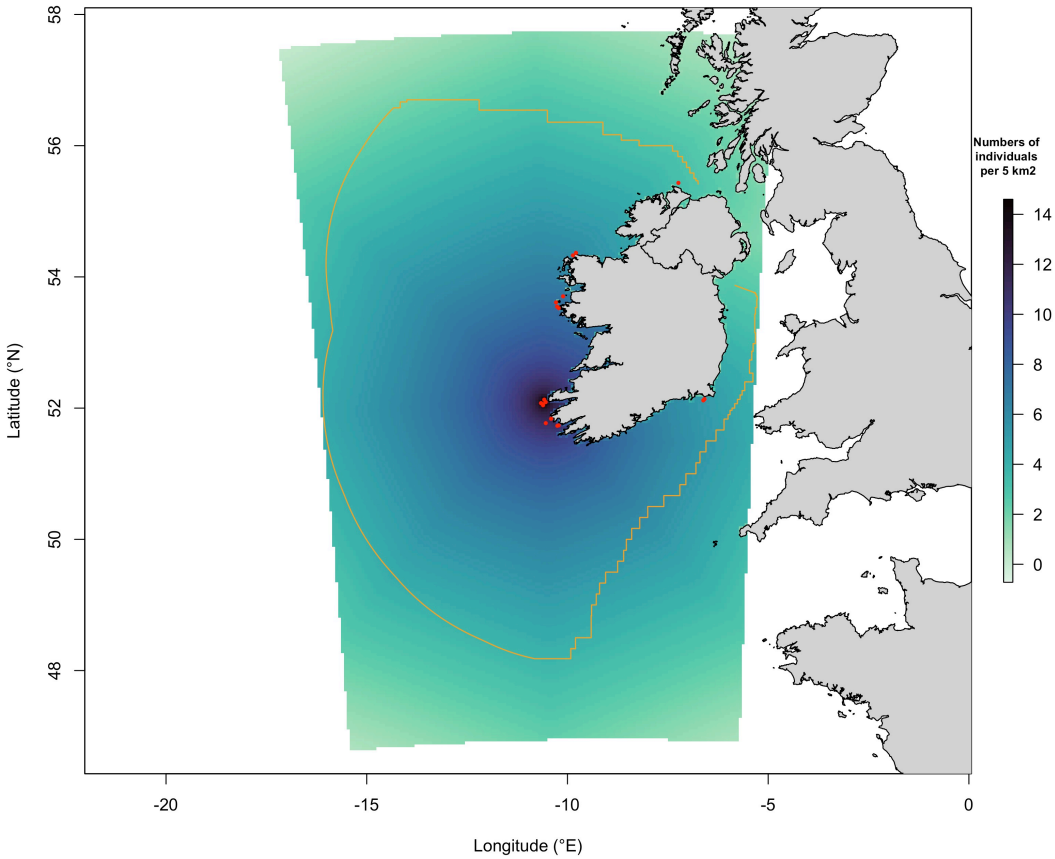
European shag



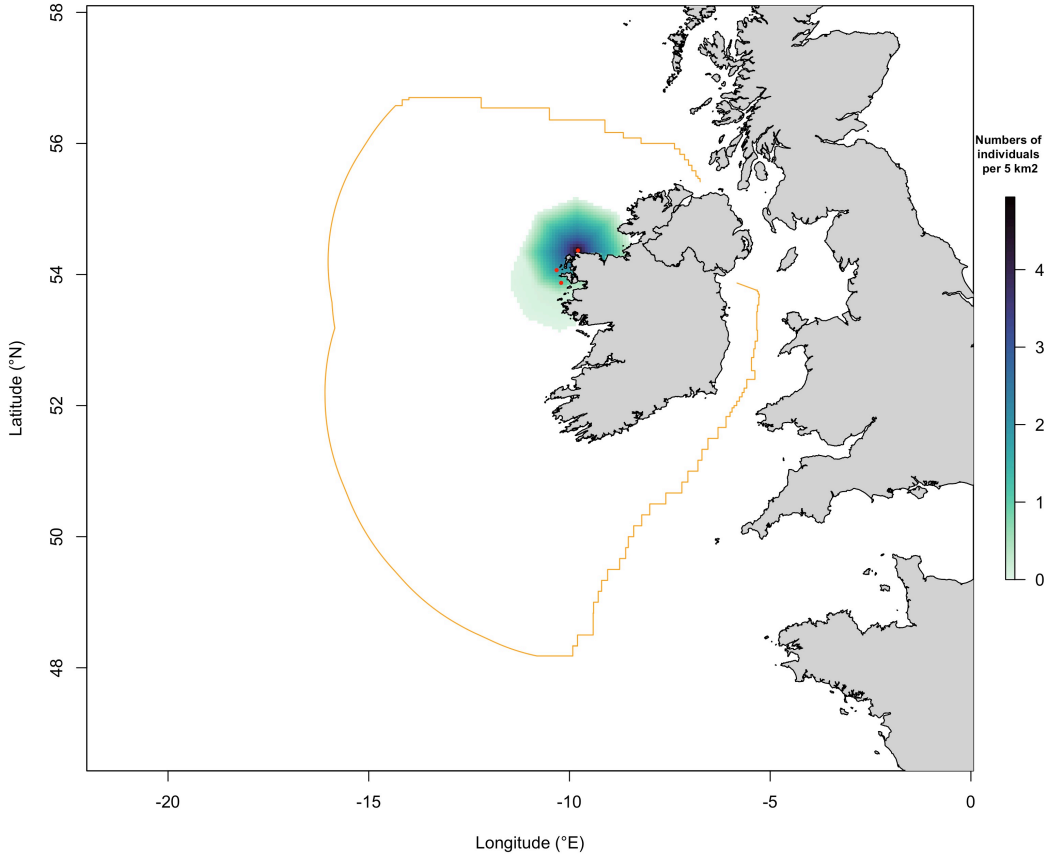
Northern fulmar



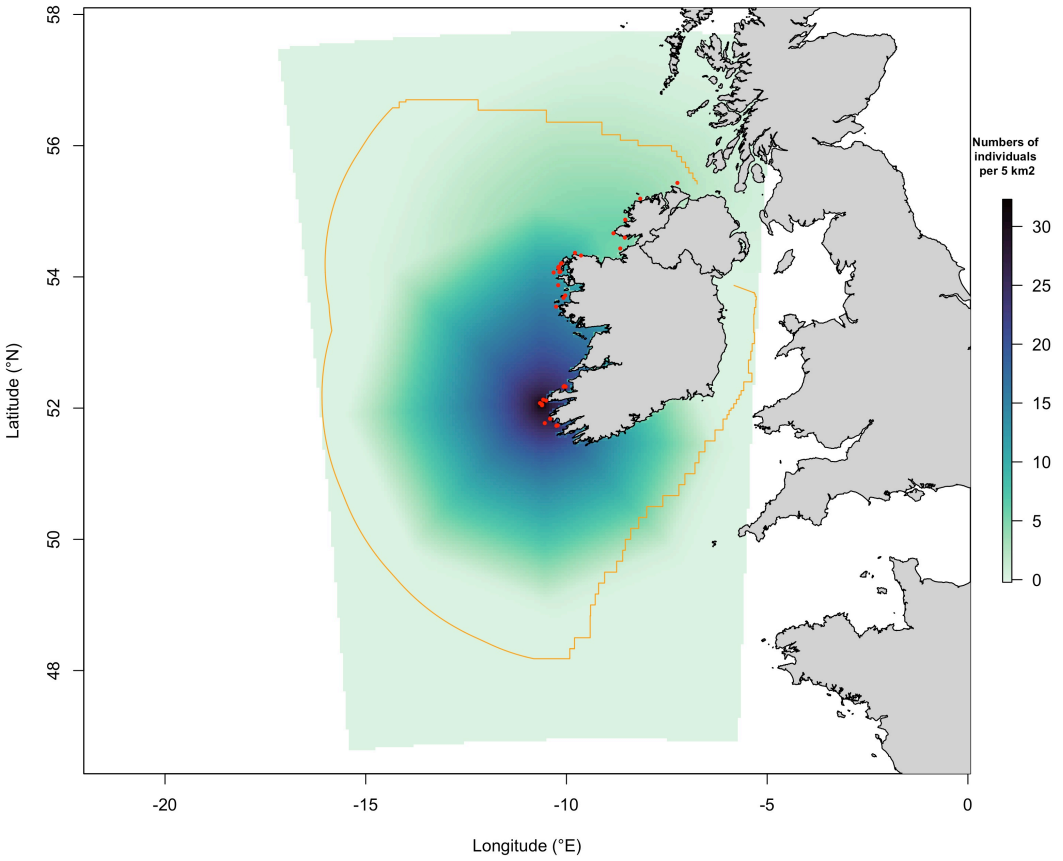
Manx shearwater



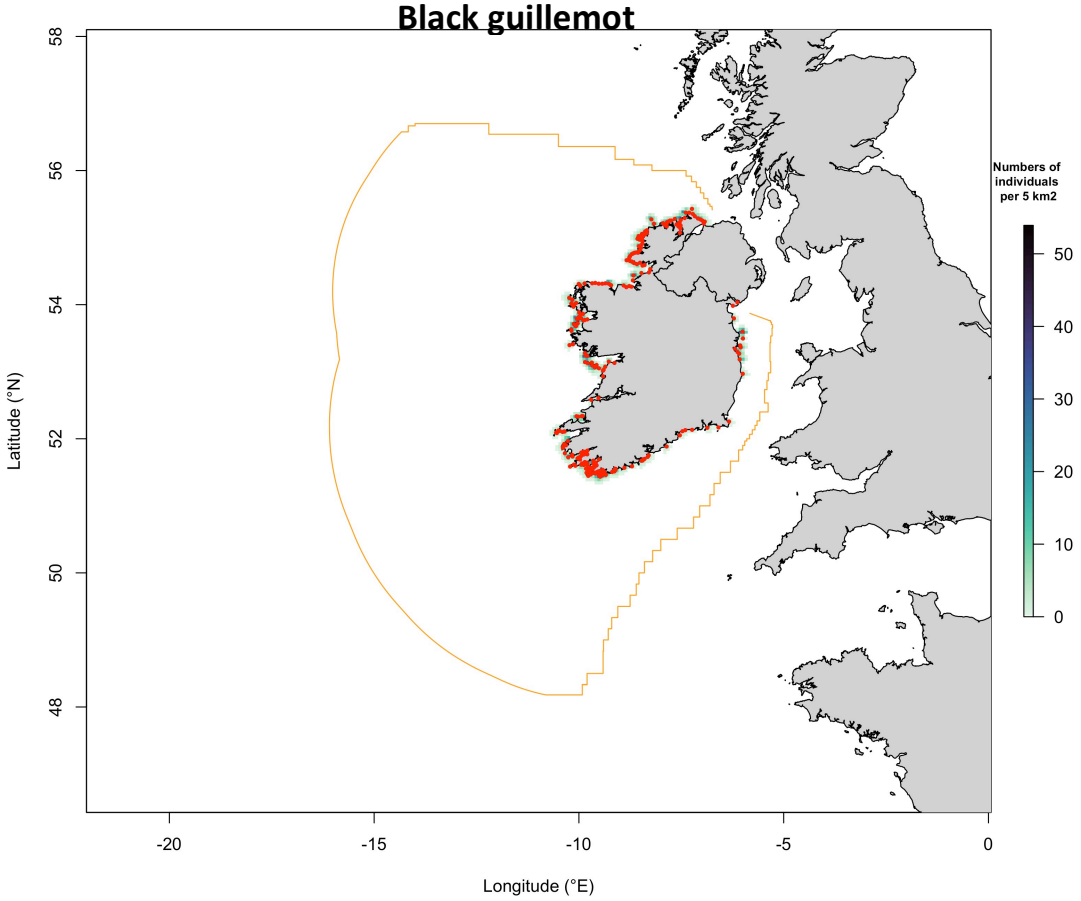
Leach's storm petrel



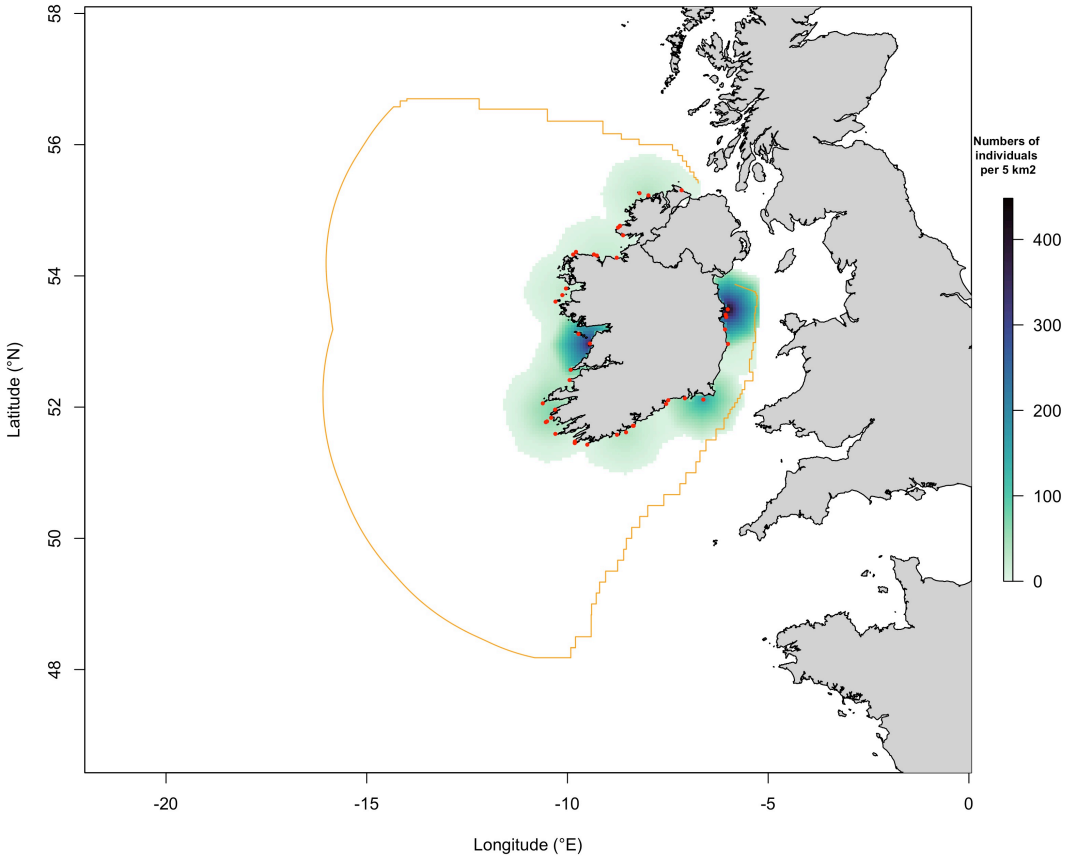
European storm petrel



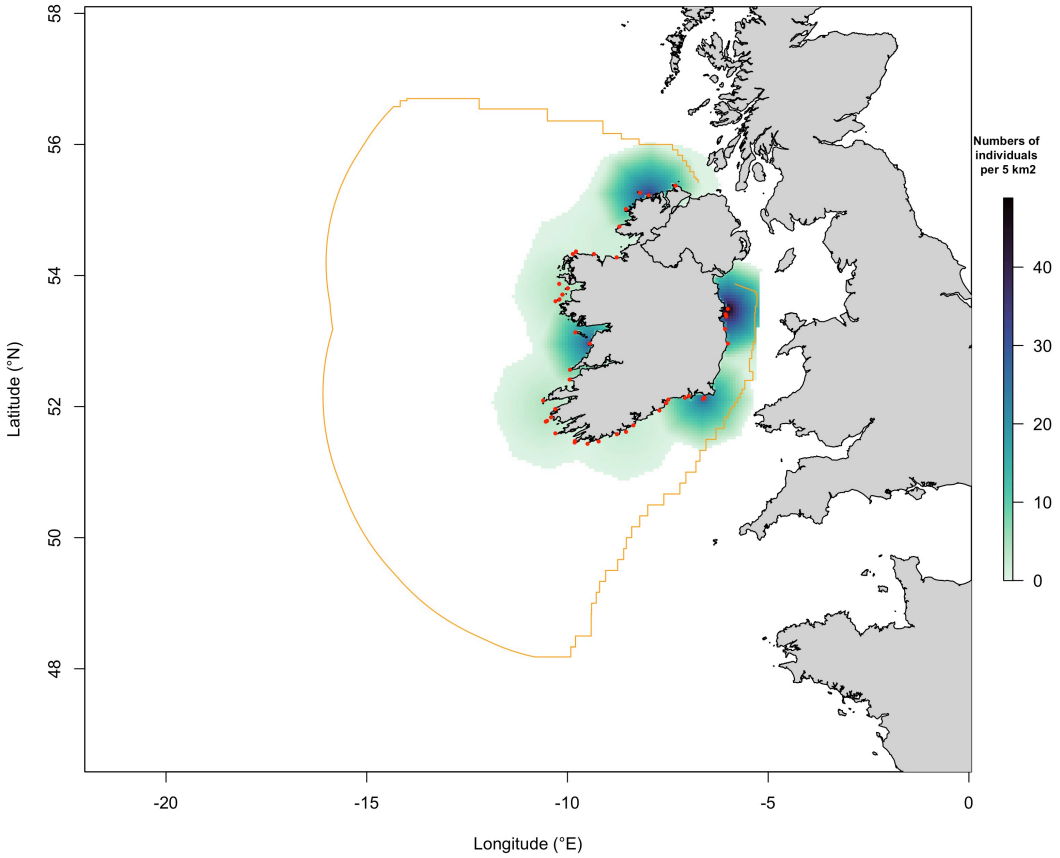
Black guillemot



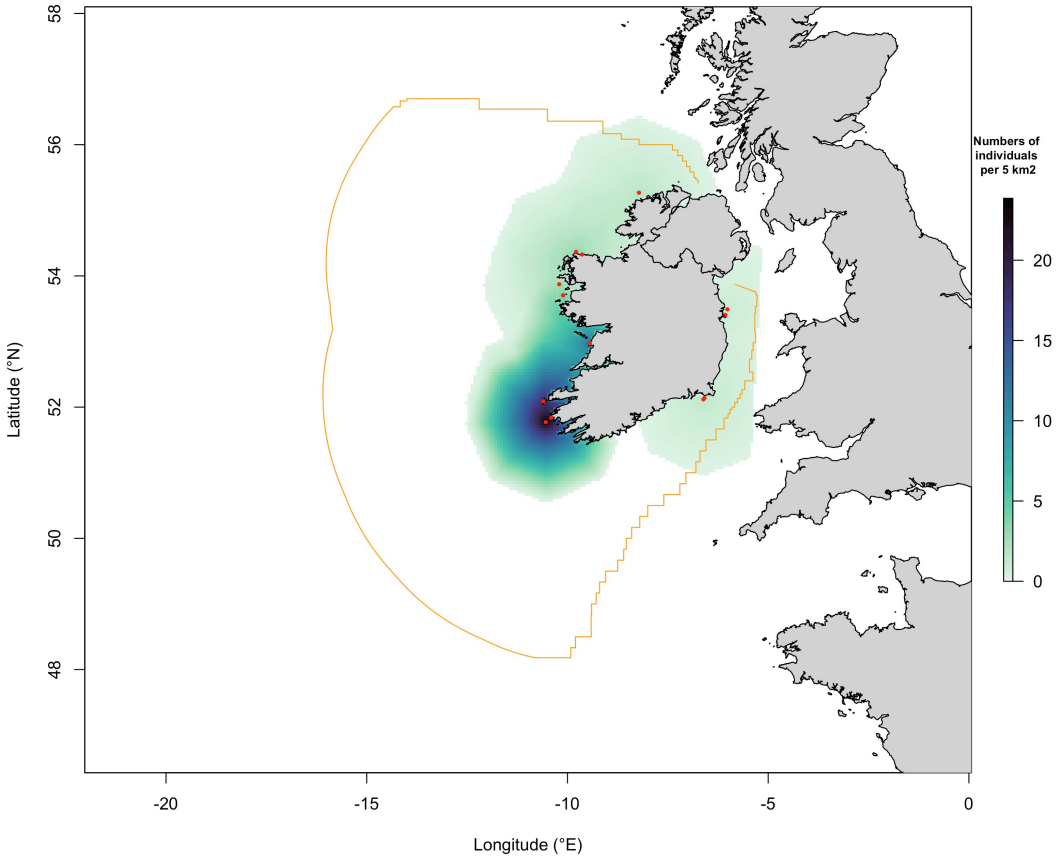
Common guillemot

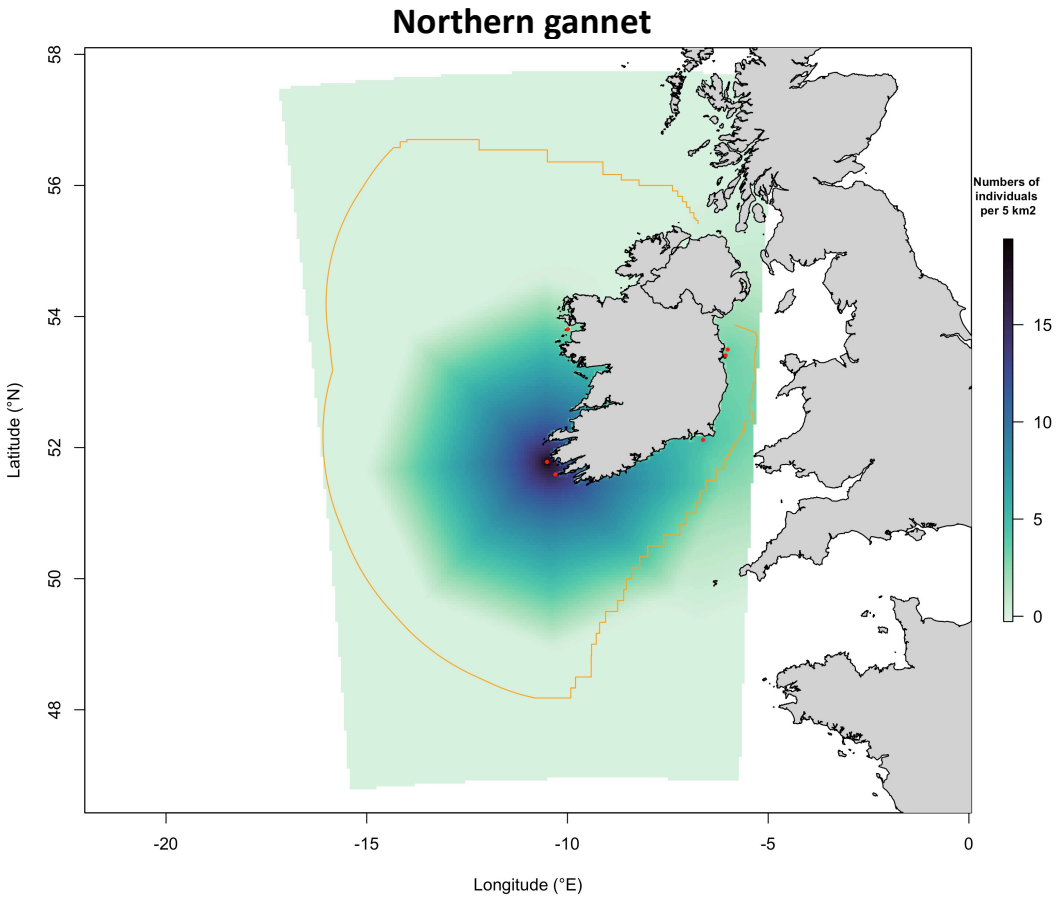


Razorbill



Atlantic puffin




Northern gannet
Latitude (°N)
58
56
54
52
50
48
-20
-15
-10
-5
0
Longitude (°E)
Numbers of individuals per 5 km2
15
10
5
0