Predictive bycatch hotspots modelling (species distribution vs. fishing effort)

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Context

In the UK, the ecosystem objective of the Fisheries Act (2020) and Joint Fisheries Statement (Defra, 2022a) sets out the government's ambition that 'incidental catches of sensitive species are minimised and, where possible, eliminated'. The UK Bycatch Mitigation Initiative (BMI) outlines how the fisheries policy authorities will achieve this ambition, including the specific policy objective to "*identify 'hotspot' or high-risk areas*" (Defra, 2022a; Defra, 2022b).

Clean Catch (www.cleancatchuk.com/) is a Defra funded project and forms part of the BMI. Clean Catch is contributing to the above objective by conducting a systematic review of the literature and predictive modelling to identify sensitive species bycatch hotspots within the UK exclusive economic zone (EEZ) by overlapping species distribution and fishing effort data. These exercises are led by ZSL. Both exercises contribute to work packages in the 'Regional Bycatch Prioritisation Framework Project'

The 'Regional Bycatch Prioritisation Framework Project' is a further Defra funded research project as part of the BMI. Among its research activities, the project will conduct spatially explicit productivity and susceptibility analyses (PSA) for 124 sensitive species of marine mammal, seabird and elasmobranch (in so far as data allow). A PSA is a semi-quantitative approach to access the likely impacts of fisheries on bycaught species. For potential bycatch species in a fishery, vulnerability is assessed on two axes: i) productivity, the "*capacity of a species to recover after the population is depleted*" defined by life-history characteristics; and ii) susceptibility, the propensity "*of a species to capture and mortality*", a product of how the fishing practices and gear interact with that species. Multiple criteria (or attributes) are selected to determine the productivity (e.g. age at maturity, reproductive strategy) and susceptibility (e.g. mortality rate when captured). Incorporation of spatial (and temporal) information, relating to the distribution of the fishery and species of interest, supports a spatially explicit PSA, mapping vulnerability and identifying risk hotspots.

The species models (existing models and new ensemble models) produced and collated by ZSL, will be an input to the PSA delivered by the wider 'Regional Bycatch Prioritisation Framework Project'. The following provides further detail on the predictive bycatch hotspots modelling work being delivered by ZSL. It is intended to serve as a starting point for a discussion around the use of the species distribution models as inputs to the PSA exercise.

Objectives

Predictively map sensitive species bycatch risk, in time and space. In so far as data allow, this will be achieved by overlapping distribution data and fishing effort for 124 sensitive species:

- 20 species of marine mammal;
- 59 species of elasmobranch; and
- 45 species of seabird.

Methods

Species distribution

We have obtained existing distribution models for:

- 12 cetacean species from Waggitt et al. (2020); and
- 34 seabirds species from (Bradbury et al., 2017).

For the remaining species, we have produced ensemble species distribution models (SDM). Distribution maps obtained and produced will be seasonal: winter (October to March) and summer (April to September), as defined in Bradbury et al. (2017).

Species observations were downloaded from the Ocean Biodiversity Information System (OBIS) using the R package Robis (Provoost and Bosch, 2022). Appendix 1 shows the species names used for searching along with the number of observations found. The Robis search package employs data quality filters to exclude observations based on characteristics of the data such as completeness of different metadata. Exclusions were made for properties 2,3,4,5,6,7,18,19 (see https://www.rdocumentation.org/packages/robis/versions/1.0.0/topics/qcflags). Observations were limited to the area bounded by the latitudinal limits of 40-70°N and 45°W – 15°E representing the North Atlantic.

Environmental data used for modelling Predictive environmental variables will be obtained from Bio-ORACLE (Assis et al., 2018). These data were specifically developed to support modelling the distribution of marine biodiversity. The layers are an average of the 20 years (2000-2020) at 0.05 decimal degree resolution for the parameters depth, slope, salinity, sea surface temperature (SST), oxygen saturation (O2), primary productivity (PP), photosynthetically available radiation (PAR) and current speed with separate layers of minimum and maximum values of each parameter used to account for seasonality (excluding static variables of depth and slope).

Seasonal species distribution modelling was performed using the Biomod2 R package to produce an ensemble model (Thuiller W et al., 2025). Seasons were defined as Winter (October – Mar) and

Summer (April – September) to align with the definitions of Bradbury et al. (2017). Background / pseudoabsence data were generated using the “disk” strategy selected with a 10km minimum distance and 100km maximum distance from presence points. A presence:background ratio of 1:1 was used where more than 1,000 presence observations were available, and a ratio of 1:5 was used where fewer than 1,000 presences were available. A random selection of 10% of observations were held back for model evaluation. Ensemble models were created using modelling algorithms “ANN”, “RF”, “GBM” and “Maxnet” with the “block” cross validation strategy, “bigboss” optimisation and True Skill Statistic (TSS) model selection threshold of 0.5. Models were evaluated using the Relative Operating Characteristic (ROC) metric. Variable contribution to each model was assessed using the variable_importance function, which assigns a 0 (low) to 1 (high) value to each variable.

Models were performed where 50 or more seasonal observations were available. Models with ROC evaluation less than 0.7 were rejected for as poor quality.

Fishing effort

Cefas have provided processed VMS data (2015-2021, inclusive) aggregated by 0.05 degree C-squares, month, year, vessel length, category and metier level 3 and include the effort and landings variables (mean speed, effort in kwh, effort in hours, weight and value). The dataset consists of the following Level 3 metiers: Bottom Trawl, Gillnets and entangling nets, Harvesting machines, Longlines, Pelagic trawls, Seines, Surrounding nets, Traps.

These have been processed to produce cumulative annual and seasonal (winter/summer, as above) rasters for each metier. 2015-2021 inclusive. See example below (Figure 1).

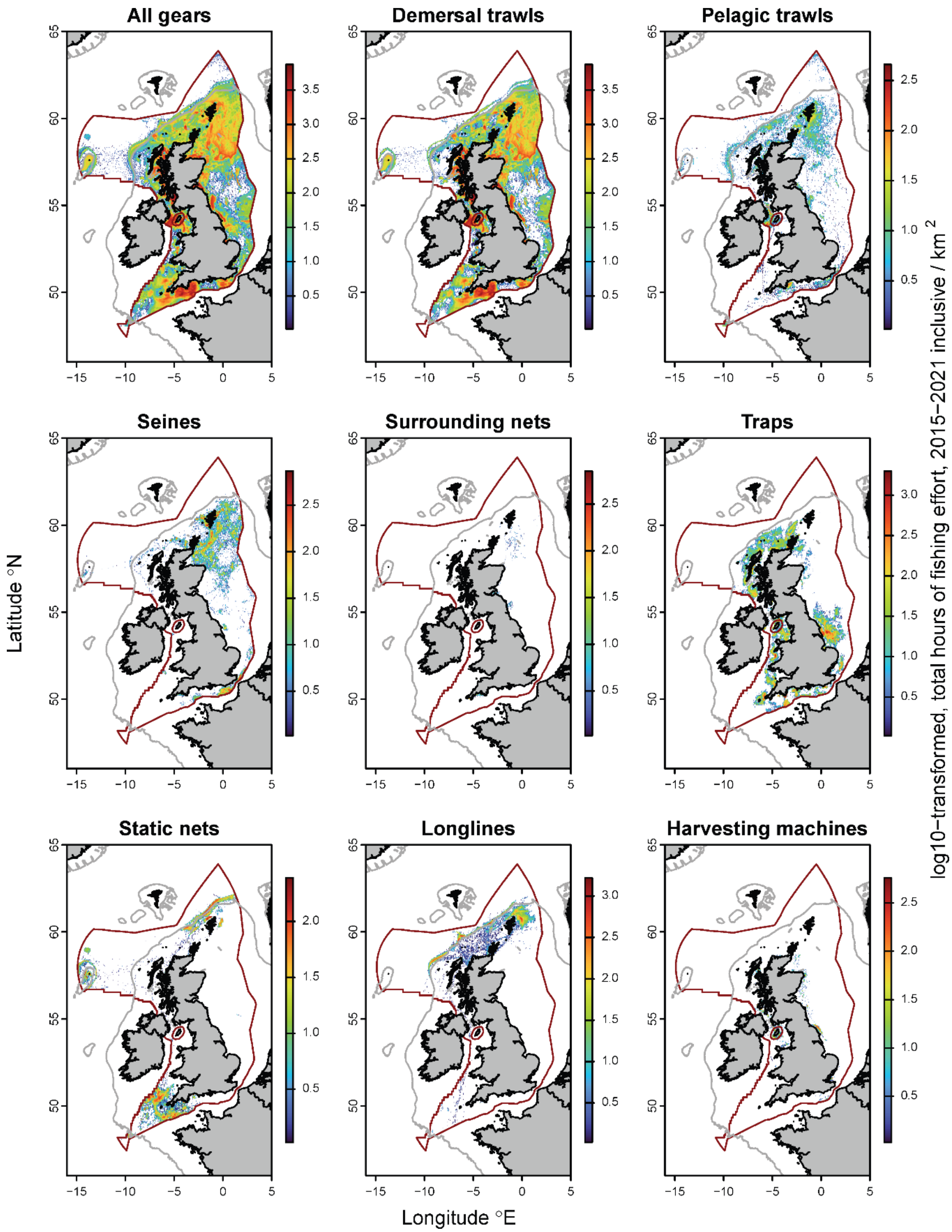

Figure 1: Total hours of fishing effort, 2015-2021 inclusive, by gear type. For graphical clarity effort is log10-transformed. The 200m depth contour is indicated (grey line). The UK EEZ is drawn (dark red line). Data: fishing effort, Cefas; depth contour, EmodNet; maritime boundaries, UKHO; countries, ESRI.

Risk mapping

The susceptibility of each species to each metier will be considered by an expert panel (drawn from the Regional Bycatch Prioritisation Framework Project working group), based on available evidence in the literature.

For each combination of species and gear to which they are susceptible a risk map will be produced as follows. Effort rasters (cumulative hours of effort) will be log-transformed and scaled to an index (0-1), distribution maps based on abundance will be log-transformed and scaled to a 0-1 index, while habitat suitability indices will just be linearly scaled to a 0-1 index. The risk index will be a simple multiplication of the fishing effort and distribution maps, producing a further 0-1 index, where 0 = low fishing and / or low distribution and 1 = highest fishing and highest distribution. Individual species outputs will also be combined to produce outputs for groups of taxa (e.g. all elasmobranchs).

Results

OBIS observation data comes from a wide range of sources. Examples are provided in Appendix 0. Using 4 representative species (Thornback Ray, Arctic Skua, Grey Seal and Common Dolphin) we see that typically data comes from 20+ sources for each species, including “Irish Ground Fish Survey”, Marine Recorder, various datasets from JNCC, ICES as well as taxon specific datasets such as cetacean strandings database and GPS telemetry.

Species distribution models (SDMs) were attempted for all elasmobranchs and all mammals except the 12 covered by Waggitt et al. (2020), while no bird SDMs were conducted with the exception of several tests for comparison with Waggitt et al. (2020) and Bradbury et al. (2017) maps.

Outputs have been obtained or produced for:

- 19/20 Mammals (95%) - 12 from Waggit et al (2017) and 7 novel SDMs
- 34/45 Seabirds (76%) - all based on Bradbury et al. (2017)
- 30/59 Elasmobranchs (51%) - all novel SDMs

Appendix 1a&b contains tables showing model statistics for each novel SDM (note includes hyperlinks to plots of output). Examples of SDM outputs in comparison to Waggitt et al. (2020) and Bradbury et al. (2017) are presented below (Figure 2 to Figure 8).

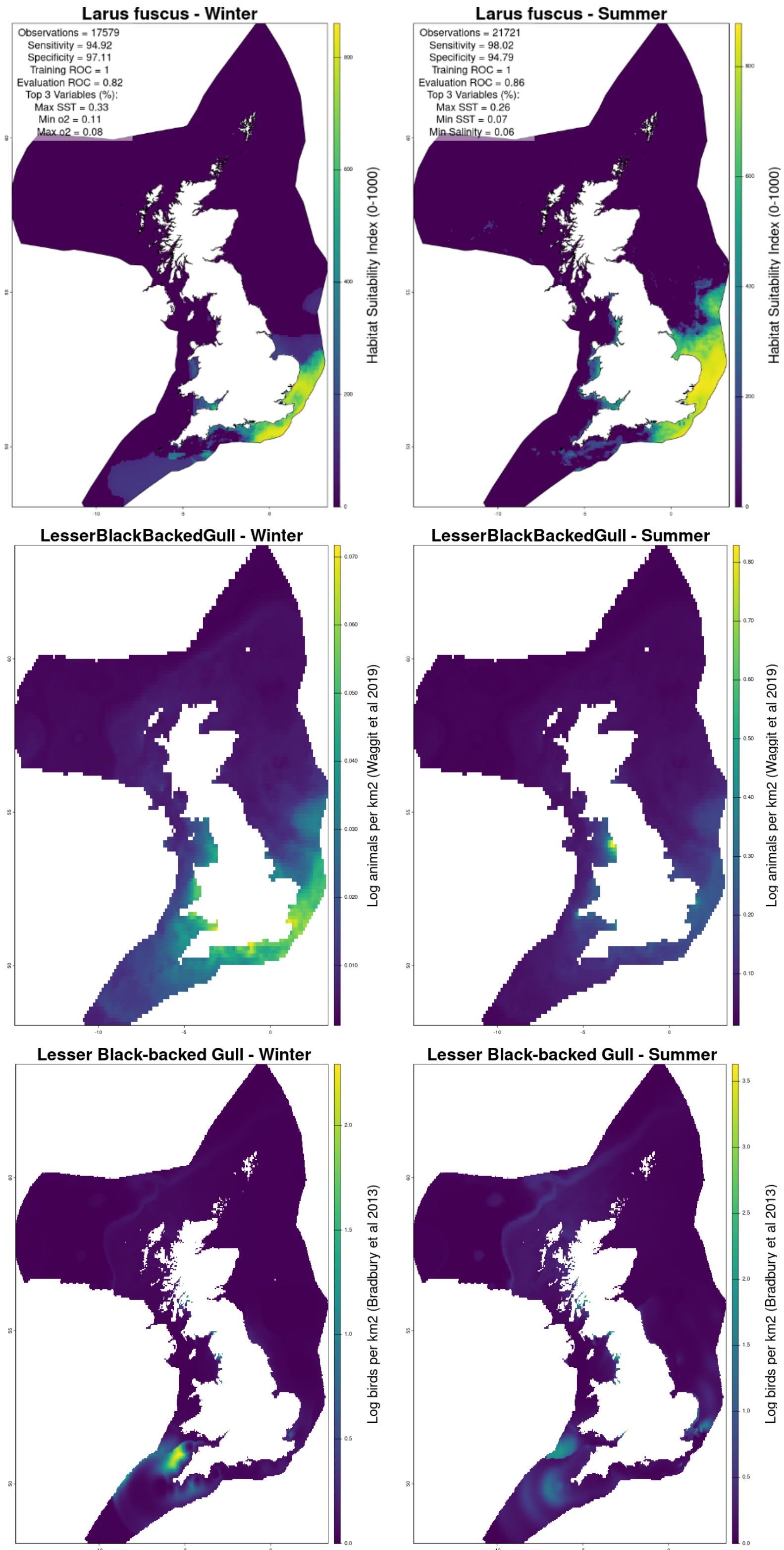

Figure 2: comparison of Lesser Black-backed Gull (*Larus fuscus*) based on (top) new species distribution model, (middle) abundance estimates from Bradbury et al (2019) and (bottom) abundance from Waggit et al (2013).

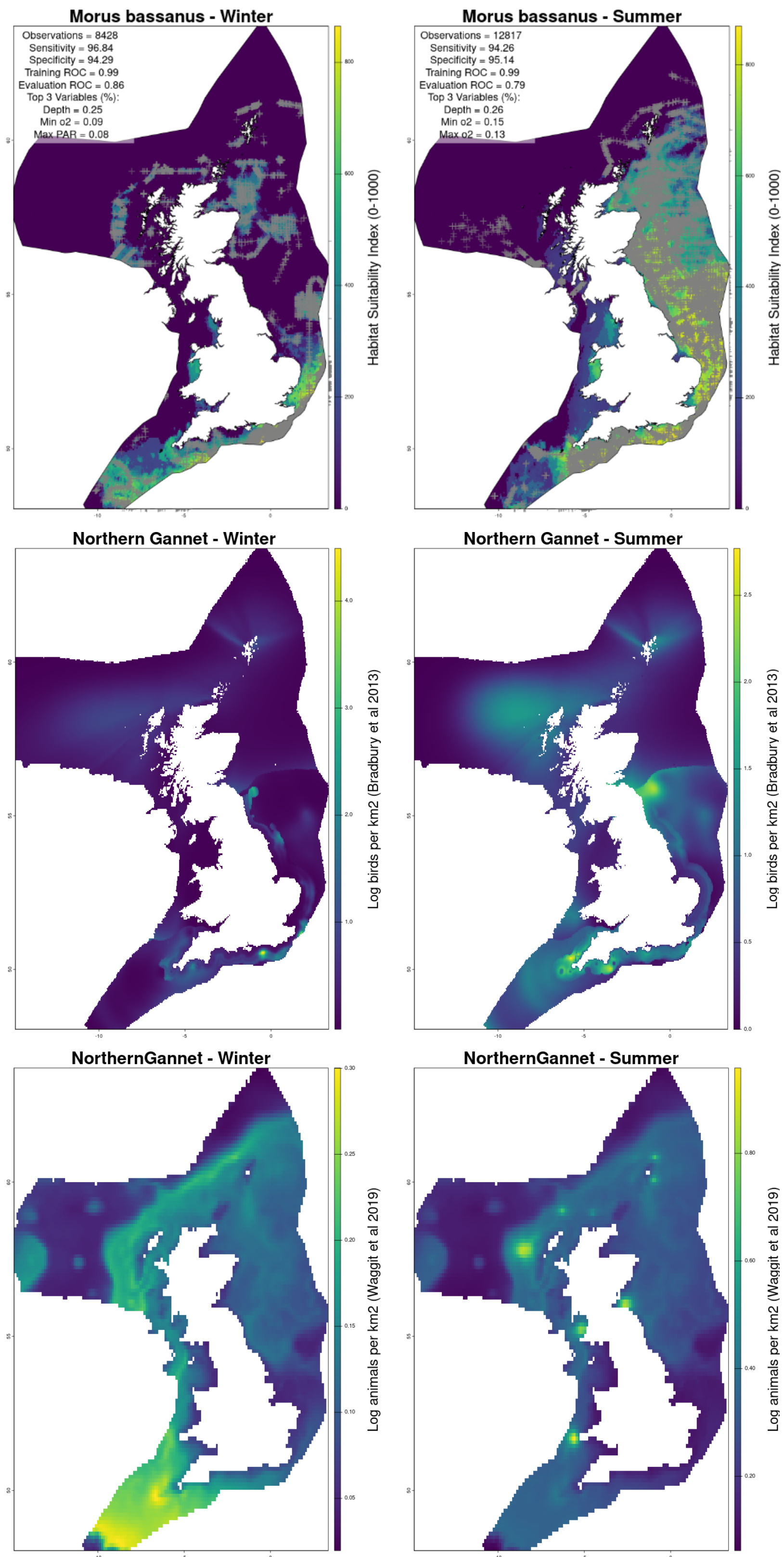

Figure 3: comparison of Northern Gannet (*Morus bassanus*) based on (top) new species distribution model, (middle) abundance estimates from Bradbury et al (2019) and (bottom) abundance from Waggit et al (2013).

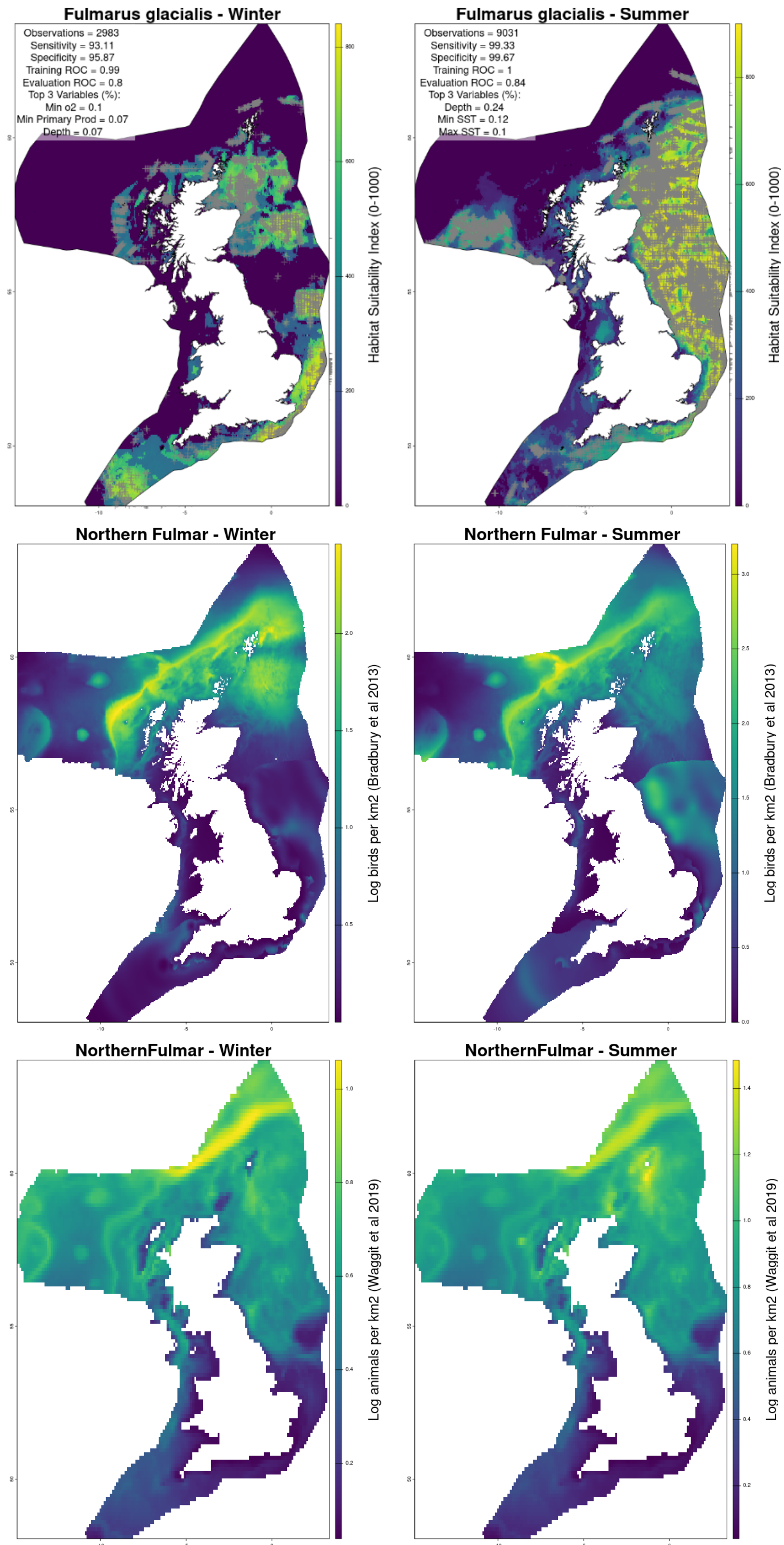

Figure 4: comparison of Northern Fulmar (*Fulmarus glacialis*) based on (top) new species distribution model, (middle) abundance estimates from Bradbury et al (2019) and (bottom) abundance from Waggit et al (2013).

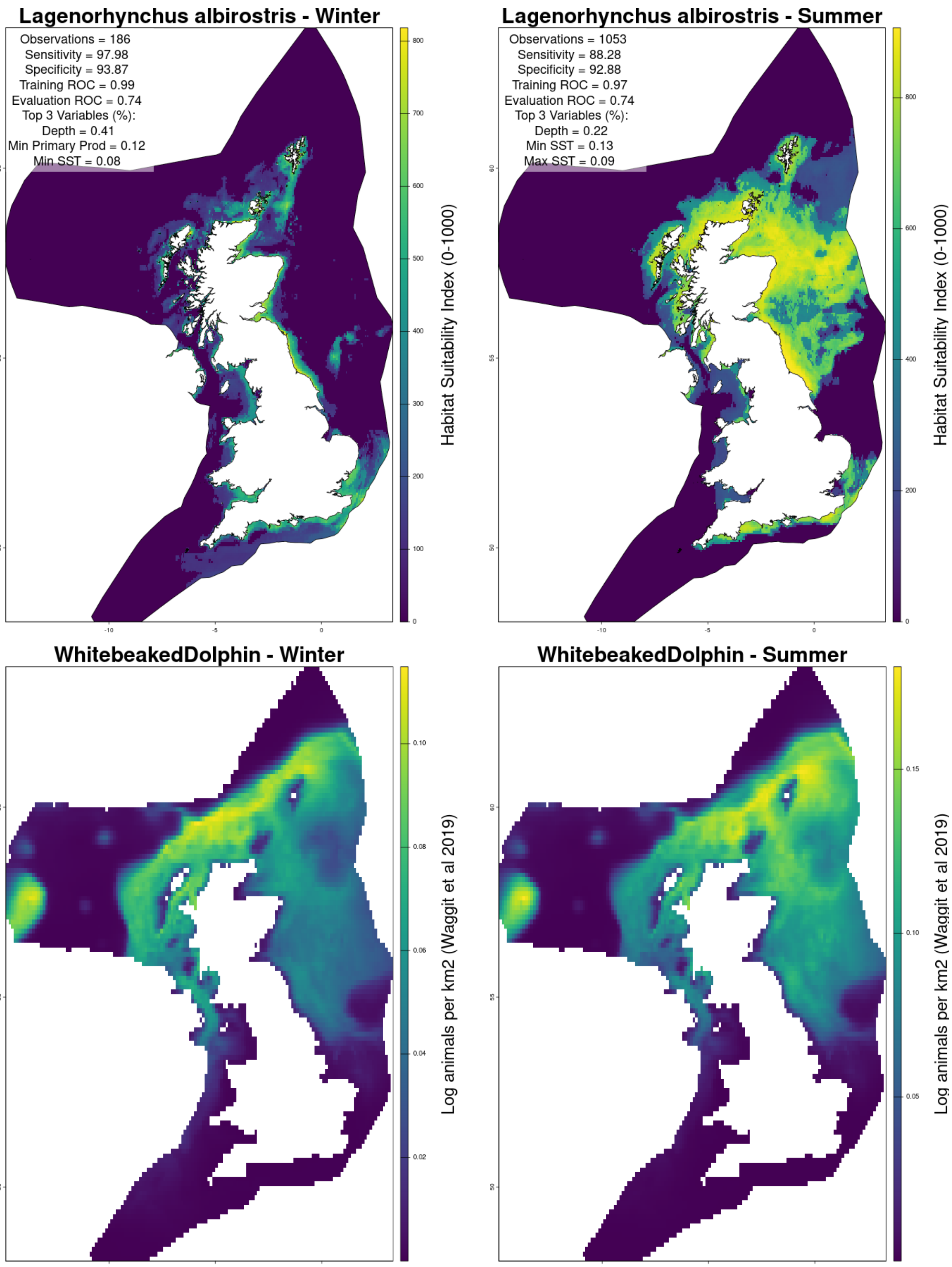

Figure 5: Comparison for White-Beaked Dolphin (*Lagenorhynchus albirostris*) based on (top) new species distribution model and (bottom) abundance from Waggit et al (2019).

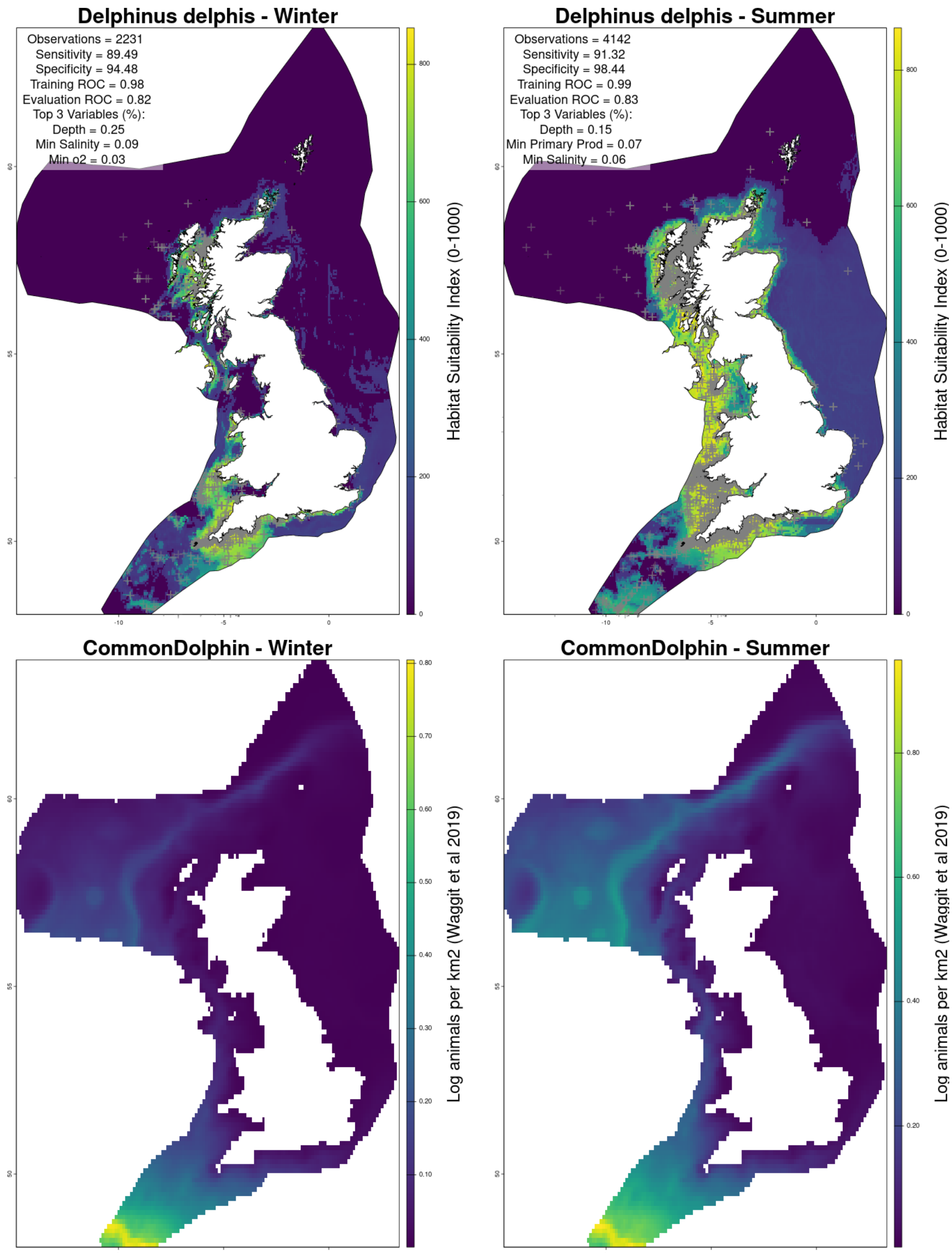

Figure 6: Comparison for Common Dolphin (*Delphinus delphis*) based on (top) new species distribution model and (bottom) abundance from Waggit et al (2019).

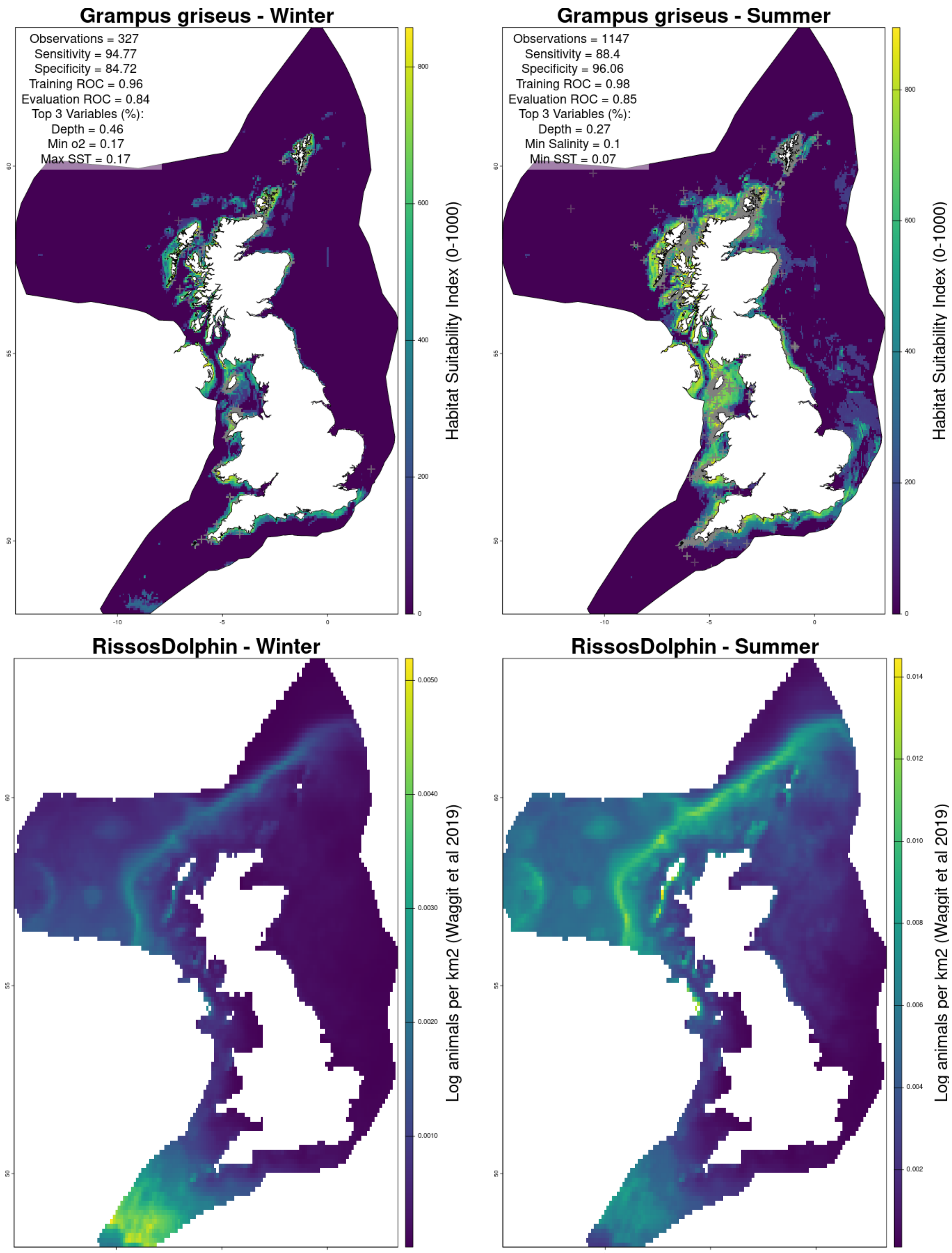

Figure 7: Comparison for Risso's dolphin (*Grampus griseus*) based on (top) new species distribution model and (bottom) abundance from Waggit et al (2019).

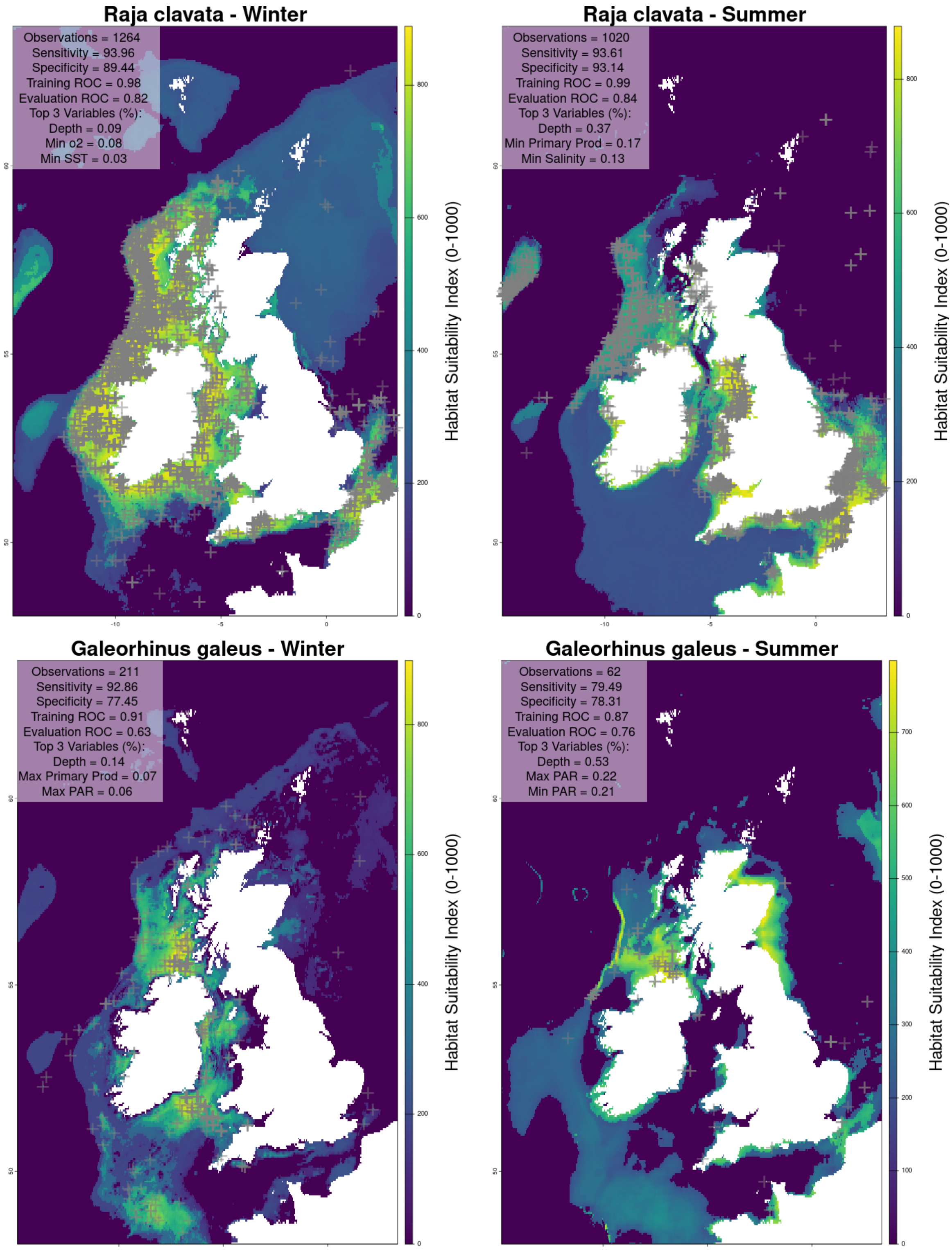

Figure 8: Example models for elasmobranch species (top) Thornback Ray (Raja clavata) and (bottom) Tope Shark (Galeorhinus galeus). Grey crosses show observations.

Risk maps will be produced for all required combinations of distribution and fishing effort pending determination of the susceptibility of each species to each metier (ongoing, delivered by the 'Regional Bycatch Prioritisation Framework Project'). See example risk map below (Figure 9).

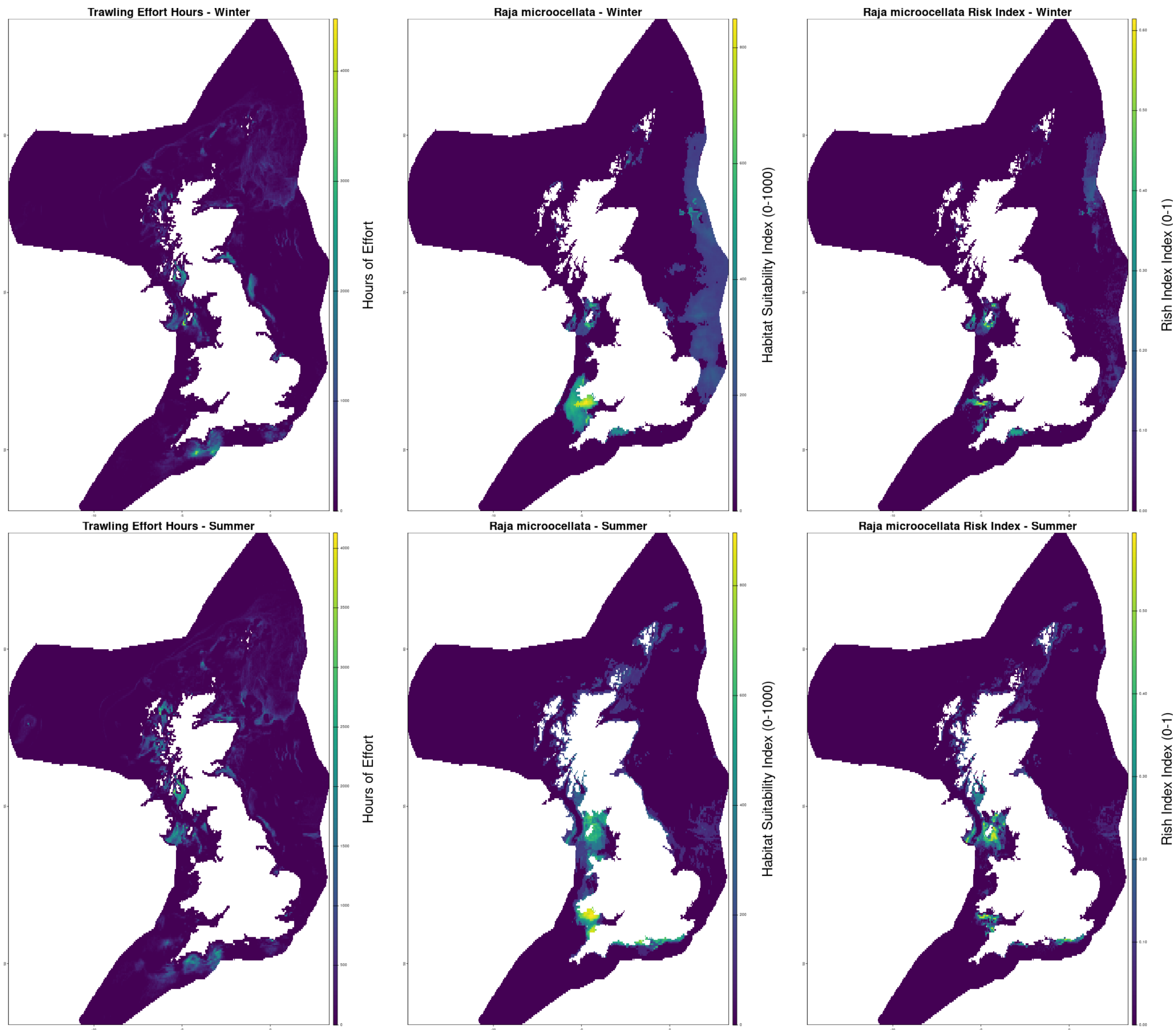

Figure 9: Example risk map for small-eyed ray (*Raja microocellata*). Left: trawl fishing effort. Centre: ensemble species distribution model. Right: Risk map, the areas of greatest risk (yellow) are where high fishing effort overlaps with high habitat suitability.

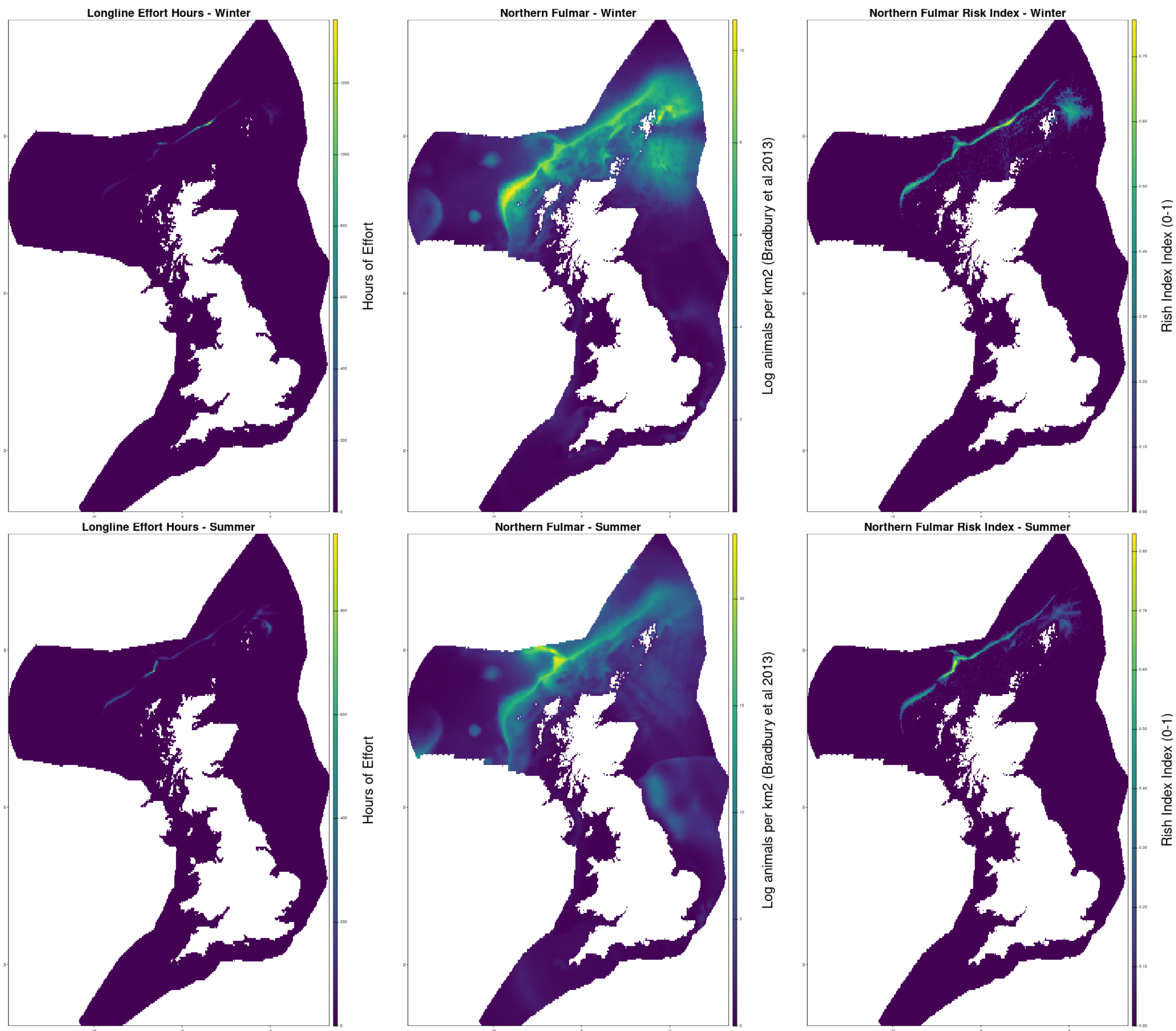

Figure 10: Example risk map for Northern Fulmar (*Fulmarus glacialis*). Left: Longline fishing effort. Centre: Abundance estimates from Bradbury et al (2013). Right: Risk map, the areas of greatest risk (yellow) are where high fishing effort overlaps with high abundance.

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