QUANTIFYING HORIZONTAL OVERLAP BETWEEN LONGLINE FLEETS AND PORBEAGLE DISTRIBUTION FOR ECOLOGICAL RISK ASSESSMENT

Nathan G. Taylor
International Commission for the Conservation of Atlantic Tunas

SCRS/2020/100 Collect. Vol. Sci. Pap. ICCAT, 77(6): 169-179 (2020)

QUANTIFYING HORIZONTAL OVERLAP BETWEEN LONGLINE FLEETS AND PORBEAGLE DISTRIBUTION FOR ECOLOGICAL RISK ASSESSMENT

Heather D. Bowlby[1], Nathan Taylor[2], John Carlson[3]

SUMMARY

*The Sustainability Assessment for Fishing Effects (SAFE) ecological risk assessment was updated by the Sharks Working group for the 2020 assessment of porbeagle shark (*Lamna nasus*). This paper describes how distribution information for the Northern and Southern stocks was evaluated relative to fishing effort to determine the extent of geographical overlap (i.e. availability) of porbeagle to commercial fishing activity. Availability was calculated as the amount of the porbeagle distribution (5x5 degree resolution) used by the fishery divided by the total area of the porbeagle distribution in the North or South Atlantic. For comparison, the proportion of fishing effort that overlaps with porbeagle relative to the total amount of fishing effort was also calculated in the North and South Atlantic*.

RÉSUMÉ

*L'évaluation des risques écologiques SAFE (« Sustainability Assessment for Fishing Effects », évaluation de la durabilité des effets de la pêche) a été mise à jour par le Groupe d'espèces sur les requins pour l'évaluation du requin-taupe commun (*Lamna nasus*) de 2020. Ce document décrit la façon dont les informations sur la distribution des stocks du Nord et du Sud ont été évaluées par rapport à l'effort de pêche afin de déterminer l'étendue du chevauchement géographique (c'est-à-dire la disponibilité) du requin-taupe commun avec l'activité de pêche commerciale. La disponibilité a été calculée comme étant la quantité de la distribution du requin-taupe commun (résolution de 5x5 degrés) utilisée par la pêcherie divisée par la surface totale de la distribution du requin-taupe commun dans l'Atlantique Nord ou Sud. À titre de comparaison, la proportion de l'effort de pêche qui chevauche le requin-taupe commun par rapport à la quantité totale de l'effort de pêche a également été calculée dans l'Atlantique Nord et Sud.*

RESUMEN

*El grupo de trabajo sobre tiburones actualizó la evaluación de los riesgos ecológicos de la evaluación de la sostenibilidad de los efectos de la pesca (SAFE) para la evaluación del marrajo sardinero (*Lamna nasus*) en 2020. En este documento se describe cómo se evaluó la información sobre la distribución de los stocks septentrionales y meridionales en relación con el esfuerzo pesquero para determinar el grado de superposición geográfica (es decir, la disponibilidad) del marrajo sardinero a la actividad pesquera comercial. La disponibilidad se calculó como la cantidad de la distribución del marrajo sardinero (resolución de 5x5 grados) utilizada por la pesquería dividida por el área total de la distribución del marrajo sardinero en el Atlántico norte o sur. A efectos de comparación, también se calculó la proporción del esfuerzo de pesca que se superpone con el marrajo sardinero en relación con la cantidad total de esfuerzo de pesca en el atlántico norte y sur*

KEYWORDS

SAFE, Ecological Risk Assessment, Availability, Porbeagle Shark

[1] Fisheries & Oceans Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, CANADA. E-mail address of lead author: heather.bowlby@dfo-mpo.gc.ca.
[2] International Commission for the Conservation of Atlantic Tunas, Calle Corazon de Maria 6-8, 28002, Madrid, Spain.
[3] NOAA Fisheries Service, Southeast Fisheries Science Center, Panama City, FL, USA

1. Introduction

Sustainability Assessment for Fishing Effects (SAFE) is a quantitative ecological risk assessment method that can be used to help determine status in data-poor scenarios (Zhou & Griffiths 2008). A version of the SAFE model was used in the 2012 Ecological Risk Assessment (ERA) conducted by ICCAT (Anon 2010) and will be updated in the 2020 porbeagle assessment. One of the required inputs to the SAFE model is an estimate of the overlap between the distribution of porbeagle and the various longline fleets that it interacts with. This overlap can be in a horizontal plane, representing the geographical extent over which each fleet may come in contact with porbeagle (called availability). Or it can be in the vertical plane, representing the proportion of time that the species is available to the fishing gear given depth preferences and diel diving behavior (called encounterability). This paper focuses on the horizontal plane and uses information on porbeagle distribution and ICCAT Task 2 longline fishing effort in the North Atlantic to calculate the proportional overlap by fleet for input into the SAFE model (Cortes *et al*. 2020).

2. Methods

2.1 Porbeagle Distribution: North and South Atlantic

Distributional data for the North and South Atlantic were available as a shapefile from the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (NatureServe and IUCN 2019). This was the information used in the previous ERA to characterize distribution (Anon 2010). For the South Atlantic, additional observational data had been compiled and compared with the IUCN data prior to the 2009 assessment, and there were no differences in distribution when observational data were added. Although there was new information presented at the 2020 assessment that showed an expanded distribution for porbeagle in the South Atlantic (Mejuto *et al.* 2020), the group felt that it should be investigated further prior to incorporating it into the availability calculations. Thus for this assessment, the distribution of the combined Southern stock was characterized from the IUCN data only.

The distribution of the combined Northern stock was characterized from new spatial data in the Northwest Atlantic combined with the IUCN information. Several data sources were amalgamated and included: Canadian at-sea observer reports (1370 records; 1978-2018) and commercial fisheries captures (3699 records; 2003 – 2018), the Canadian pelagic shark surveys (47 locations; 2007, 2009, 2017), US observer data (243 records; 1992-2018), and satellite tagging (24 individuals; 2001-2013). For the satellite tagging data specifically, locations for 17 individuals were estimated from light level readings (and associated depth and temperature) using the GPE3 state-space model (Wildlife Computers). For the other 7 tags, GPE3 output was not available so the estimated locations from ARGOS were used. Only positional estimates with a quality code of 2 or 3 were included, representing positions with error estimates of < 250 m and 250-500 m, respectively

The original intention was to use these data to characterize relative density when describing porbeagle distribution in the Northwest Atlantic (i.e. to identify areas of high/low density). However, this was not feasible for several reasons: (1) it was difficult to determine how much weight to give the satellite tagging data. For example, metrics based on the number of observations were not informative: fishery-dependent data represented single point locations of porbeagle captures (varying numbers of individuals), while the satellite tagging data represented 14,844 location observations from only 24 individuals. (2) the available data on distribution spanned a large number of years with the majority being collected prior to the previous ICCAT assessment of porbeagle (Anon 2010). Even grouping observations by blocks of years led to inappropriately large changes in distribution over time, particularly in the most recent 10 years. (3) Using only the fishery-dependent data or fishery-independent data in isolation, or grouping all data sources into time blocks, suggested that porbeagle distribution was discontinuous along the continental shelf. Although porbeagle are highly mobile and would be expected to be found in different locations seasonally (Campana *et al.* 2015), it is not biologically reasonable to suggest that individuals in (for example) the Gulf of Maine are not connected with individuals along the Atlantic Bight, or individuals off Northern Newfoundland. Even though every effort was made to amalgamate the available data on distribution, it was still too sparse to be used to characterize relative density in recent years.

Furthermore, the ERA would be applied to combined Northern (NE and NW) and combined Southern (SE and SW) stocks in the 2020 porbeagle assessment (Cortés *et al*. 2020). A data set for the NE that was equivalent to the one from the NW (i.e. one that amalgamated several sources of capture data, plus fishery-independent and satellite tagging data) could not be developed in time for this assessment. Therefore, the new information on spatial distribution in the NW was combined with the IUCN polygon for the NE when describing distribution for the Northern stock.

2.2 Fishing Effort: Data Processing and Analyses

Updated catch and effort data (T2CE) were used to characterize longline fishing effort. It is named "T2CE" to reference the information related to Task 2 Catch and Effort statistics. T2CE are basically data obtained from sampling a portion of the individual fishing operations of a given fishery in a specified period of time. In its general form, T2CE is defined as: the catch in weight (kg) or in number of fishes obtained by a given amount of effort in a given stratum. ICCAT's Standing Committee on Research and Statistics (SCRS) requires that T2CE data be submitted every year by fleet and gear, at monthly time steps. Minimum resolution is 1x1 degree squares for all surface gears and 5x5 degree squares for longline gears.

However, longline records exist at a variety of spatial and temporal resolutions that require standardization. The coarsest resolution for spatial data is 5x5 degrees, but some data is provided at finer resolutions (e.g. 1x1 degrees). Because records across all fleets and time steps do not exist at resolution higher than 5x5, finer resolution data are aggregated into 5x5 resolution prior to archival. T2CE data were queried from the ICCAT database system on April 7th, 2020. The extracted data consisted of longline effort aggregated by quarterly time step and at 5x5 spatial resolution.

Additional data processing was required because reported effort data are known to be incomplete for some CPCs and time periods. Effort reconstruction of the historical time series was needed in order to ensure that the magnitude of fishing mortality in each spatial cell was scaled appropriately to reflect the best estimate of total effort. Although there was a previous attempt to reconstruct the effort time series (referred to as EFFDIS developed by Palma and Gallego 2008, DeBruyn *et al.* 2015, Beare *et al*. 2016), a review of the methods showed that EFFDIS estimations using the Beare *et al*. (2016) method were directly contrary to expectations: this method estimated that effort was lower than reported before the year 2000 (where the expectation was that the estimated effort would be higher than reported) and higher than reported after 2000 (where coverage was more complete and estimates should have been similar to what was reported). A different method of effort reconstruction was needed.

We used the Taylor *et al.* 2020 method to generate a new EFFDIS. This methodology raises reported effort using the coverage ratio (CovRatio) statistic reported by CPCs in their annual submissions. The CovRatio statistic is a quantity that reflects a CPC's own estimate of the degree of completeness of their T2CE coverage. Reported effort is scaled directly from the CovRatio, because the value represents an annual constant that applies to all fishing locations:

$$\hat{E}_{y,f} = \frac{E_{y,f}}{R_{y,f}}$$

where $R_{y,f}$ is the coverage ratio, $E_{y,f}$ is the reported effort, and $\hat{E}_{y,f}$ is the total estimated effort for year y, and flag f. For instances in which the CovRatio statistic was not provided, missing values were imputed hierarchically using the most detailed data by year, and fleet resolution at the coarsest resolution to coverage ratios averaged across years and CPCs (Taylor *et al.* 2020).

2.3 Quantifying overlap

For the new spatial data in the Northwest Atlantic, point locations were aggregated in a 5x5 degree raster grid to ensure a spatial scale consistent with the effort data. This aggregation generated a simple presence-absence map, identifying all of the 5-degree grid squares that contained porbeagle observations, regardless of the total number of observations (**Figure 1**). The IUCN spatial data was brought into R as a shapefile, and the multiploygon object was disaggregated into individual polygons and split into the Northern and Southern components. In order to combine the new data from the Northwest with the IUCN data, the raster grid for the Northwest Atlantic was transformed into small polygon objects. These individual small polygons (raster plus IUCN polygons) were dissolved into a single large polygon representing the whole distribution of porbeagle in the entire North Atlantic. This union prevented any duplication that may have resulted from effort points being distributed in multiple overlapping polygons (**Figure 1**). Combining all spatial data from the North resulted in a larger distribution for the combined Northern porbeagle stock as compared to the previous assessment (Anon 2010). Notably, the distribution now extends into the middle of the Atlantic and down to the Gulf of Mexico.

Distribution information for the combined Southern stock came entirely from the IUCN data and was the same as that used in the 2009 ERA (Anon 2010). Similar to the North, the two polygons representing the circumpolar Southern distribution were dissolved into a single polygon prior to intersection with the effort data.

Availability represents the proportion of the porbeagle stock that is accessible to the fishery. It is calculated as the sum of the fished area that overlaps with the porbeagle distribution relative to the total area of the porbeagle distribution. In this assessment, it was a presence-absence type of calculation because the density of porbeagle in different locations could not be taken into consideration. Being able to quantify relative density in different areas would improve estimates of availability (Zhou & Griffiths 2008) and could be an area of future research. Any effort that occurred during 2010-2018 was used in the availability calculations.

Beyond calculating availability, effort data overlapping with the porbeagle stock was compared with the total amount of effort expended in the North or South Atlantic, respectively. This represented the proportion of longline effort that had the potential to interact with porbeagle. In this case, effort can be considered as presence-absence, or as a relative amount from T2CE or EFFDIS, expressed in terms of the number of hooks. The latter method of characterizing effort was preferred, because it gave proportionately less weight to regions that were uncommonly fished. Furthermore, the EFFDIS estimates account for any gaps in reporting and are considered a better representation of total fishing effort. From T2CE or EFFDIS, the total number of hooks at each point location was summed for all years from 2010 to 2018, consistent with the calculation of availability for the ERA (Cortés *et al.* 2020).

There were four types of overlap calculated in this document: Availability based on presence-absence data (Type 1) or effort overlap based on presence-absence, the relative magnitude of reported (T2CE), or the relative magnitude of estimated (EFFDIS) effort (Type 2).

Initially, the four types of estimates were done by individual fleet (i.e. by flag) to facilitate quality control for data from individual CPCs. However, the SAFE model requires a single availability value in the North as well as in the South to quantify horizontal overlap (Cortes *et al*. 2020). The fleets that provided data for the ERA of the Northern stock were: Japan (North), Canada, Portugal and the USA. For the Southern stock: South Africa, Namibia, Japan (South) and Uruguay (Cortes *et al.* 2020). Therefore, effort data from these specific fleets were summed to generate the availability estimate for the combined Northern and Southern stocks of porbeagle. Effort from the Japanese fleet north of 5 degrees latitude was considered Japan (North) and south of 5 degrees latitude was considered Japan (South). For consistency, the Portuguese data were similarly split at the equator and only the effort in the North was considered in these analyses, because other types of Portuguese data only contributed to the Northern component of the ERA (Cortes *et al.* 2020). Note that the combined North and South availability estimates are not merely the sum of estimates for individual countries, but were calculated directly from a combined data set.

All positional information was analyzed using spatial packages (‘sp’, ‘sf’, ‘raster’, ‘rnaturalearth’, and ‘stars’) in R. All positional information was in decimal degrees and was spatially referenced using the WGS84 datum for analyses and visualization. Note that the method used here to calculate availability relied on several functions in R that cannot deal well with small rasters. CPCs that reported effort in less than 10 individual 5x5 degree grid cells were excluded from the calculation. This limitation of the analyses can be remedied in future work if the overlap calculations based on spatial area are desired for individual fleets in the future. Note that this limitation did not affect the combined analyses for the Northern and Southern fleets.

3. Results and Discussion

In the years since the last porbeagle assessment (i.e. 2010-2018), fishing effort from 18 fleets has overlapped with the distribution of porbeagle in the North Atlantic (NE and NW combined). Fishing effort from 14 fleets has overlapped in the South Atlantic (SE and SW combined; **Table 1**). The estimates of overlap for individual fleets could change quite substantially depending on the method used in the calculation (e.g. Canada in the North; **Table 1**). Availability estimates based on presence-absence and the extent of overlap in spatial area (Type 1) tended to be quite divergent from the estimates based on the magnitude of effort (e.g. Type 2 EFFDIS). If one was high, the other tended to be low and vice versa (**Table 1**). However, when accounting for the magnitude of effort from T2CE or EFFDIS, there was extremely little difference to the estimates of availability for individual CPCs (**Table 1**). This is because the CovRatio values are relatively high in recent years, making estimated effort very similar to reported effort.

For input into the ERA, we show the availability metric calculated from the overlap in geographical area between porbeagle distribution and fishing effort (presence-absence; type 1; **Table 2**). For comparison, we show the three metrics for the proportion of effort that overlaps geographically with porbeagle in the North and South Atlantic (Type 2; **Table 2**) To aid in interpretability, maps of porbeagle distribution overlaid with presence-absence data (**Figure 2**) as well as T2CE or EFFDIS effort data (**Figure 3**) are provided. For the North, it is important to note that the spatial distribution of porbeagle that was used to calculate availability was much larger than in the previous ERA, primarily due to the inclusion of satellite tagging data from the NW Atlantic. For the South, it is important to note that availability is so low because of the portion of the Southern distribution in the Pacific, where there is no effort by the fleets considered in this assessment.

In the previous ERA, substantial work was done to separate the fleets into shallow and deep set components when calculating availability, particularly for the South (Anon 2010). A similar analysis was not possible for the current assessment due to time constraints.

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Table 1. A comparison of availability estimates (Type 1) and three metrics of effort overlap (Type 2) for individual fleets affecting porbeagle in the North and South Atlantic.

Country	North Type 1 Availability	North Type 2 pres-abs	North Type 2 T2CE	North Type 2 EFFDIS	South Type 1 Availability	South Type 2 pres-abs	South Type 2 T2CE	South Type 2 EFFDIS
Barbados	NA	0	0	0	NA	0	0	0
Belize	0.14331	0.08055	0.11231	0.11231	0.06643	0.10413	0.07192	0.07192
Brazil	0	0	0	0	0.10266	0.24819	0.23656	0.2279
Canada	0.07443	0.95172	0.99918	0.9992	0	0	0	0
China PR	0.06185	0.03373	0.00625	0.00625	0.01068	0.0119	0.00403	0.00403
Chinese Taipei	0.16999	0.05007	0.01373	0.01358	0.10432	0.22926	0.19759	0.19828
EU.Cyprus	NA	0.8	0.98159	0.98159	NA	0	0	0
EU.España	0.27772	0.17503	0.24488	0.24639	0.08568	0.10854	0.06901	0.06856
EU.Italy	NA	0.74247	0.79555	0.7934	NA	0	0	0
EU.Malta	NA	0.16327	0.03446	0.0315	NA	0	0	0
EU.Portugal	0.1331	0.27273	0.18927	0.19506	0.03532	0.14182	0.04341	0.0432
Japan.N	0.28651	0.1816	0.09896	0.09898	0	0	0	0
Japan.S	0	0	0	0	0.09218	0.20652	0.14113	0.13684
Korea Rep.	0.08384	0.02475	0.0048	0.00441	0.04014	0.08251	0.24259	0.22411
Maroc	NA	0.51613	0.72442	0.32995	NA	0	0	0
Mexico	NA	0.28111	0.09091	0.09091	NA	0	0	0
Namibia	0	0	0	0	0.01291	0.23269	0.21361	0.20669
Philippines	0	0	0	0	0.02323	0.14595	0.12818	0.12818
South Africa	0	0	0	0	0.0192	0.95495	0.98205	0.98165
St. Vincent and Grenadines	0.16999	0.16428	0.31847	0.31847	1.00E-05	0.00221	0.00017	0.00017
Trinidad and Tobago	0	0	0	0	0	0	0	0
U.S.A.	0.28678	0.70484	0.94249	0.94286	0	0	0	0
UK.Bermuda	NA	1	1	1	NA	0	0	0
Vanuatu	0.11636	0.16386	0.15269	0.15474	0.02154	0.03373	0.02095	0.01949
Venezuela	0	0	0	0	0	0	0	0
Uruguay	0	0	0	0	0.02032	0.83721	0.92837	0.92837
Iceland	NA	0.8	0.58926	0.58926	NA	0	0	0
Panama	0	0	0	0	0	0	0	0
UK.British Virgin Islands	NA	0	0	0	NA	0	0	0
UK.Turks and Caicos	NA	1	1	1	NA	0	0	0
Angola	NA	0	0	0	NA	0	0	0
EU.United Kingdom	0.05208	0.66667	0.85538	0.85538	0	0	0	0
Côte d'Ivoire	NA	0	0	0	NA	0	0	0

Table 2. A comparison of availability estimates (Type 1) and three metrics of effort overlap (Type 2) for combined fleets affecting porbeagle in the North and South Atlantic. The fleets that provided data for the ERA of the Northern stock were: Japan (North), Canada, Portugal and the USA. For the Southern stock: South Africa, Namibia, Japan (South) and Uruguay.

	Presence-absence			
Stock	**Type 1 Availability**	**Type 2 pres-abs**	**Type 2 T2CE**	**Type 2 EFFDIS**
North	0.52979	0.45132	0.32065	0.31790
South	0.10573	0.30758	0.17970	0.17473

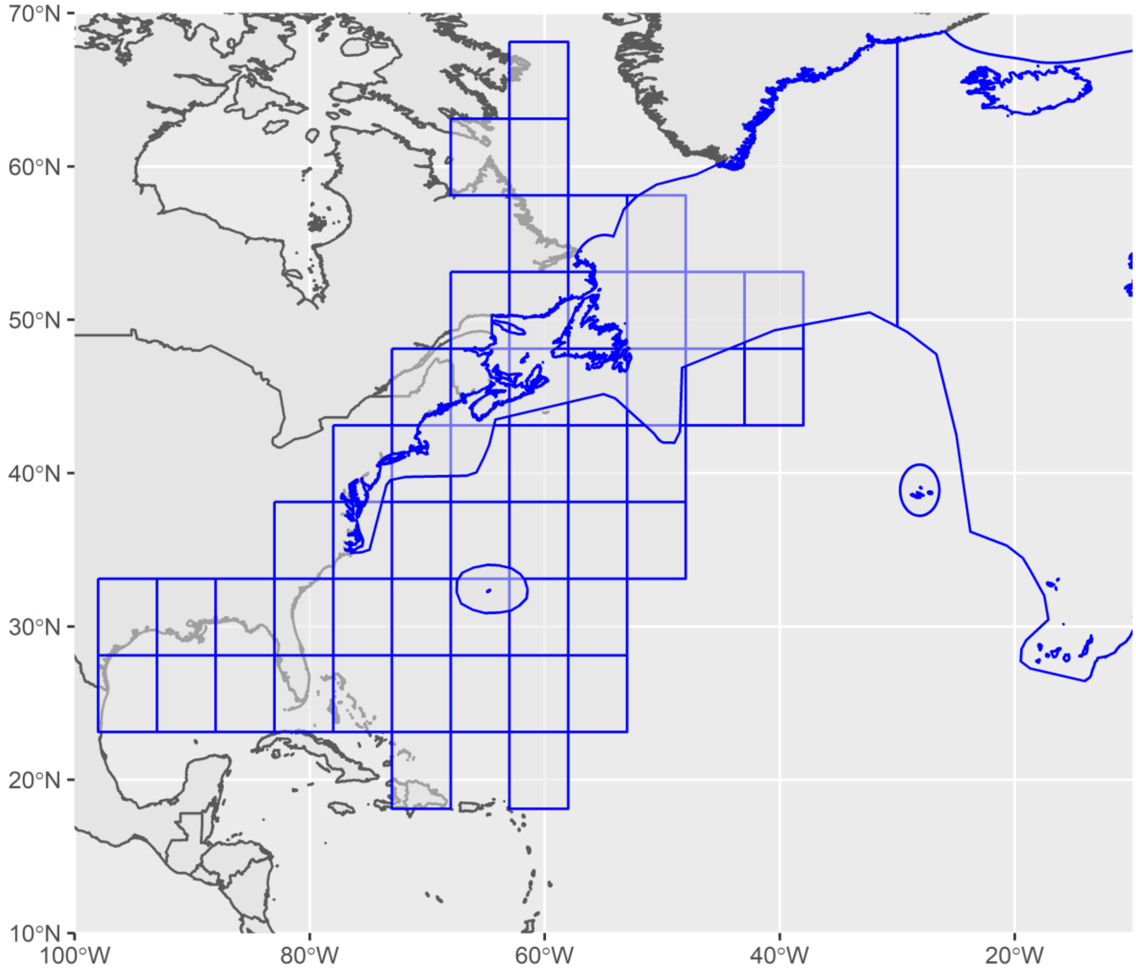

Figure 1. An overlay of the newly developed raster data layer of porbeagle distribution in the Northwest Atlantic (blue boxes) with the IUCN shapefile (blue lines) that was used in the previous ERA. Note the large increase in occupied area, with the raster layer extending into the middle of the Atlantic and Gulf of Mexico as compared to the northern, coastal distribution of the IUCN data.

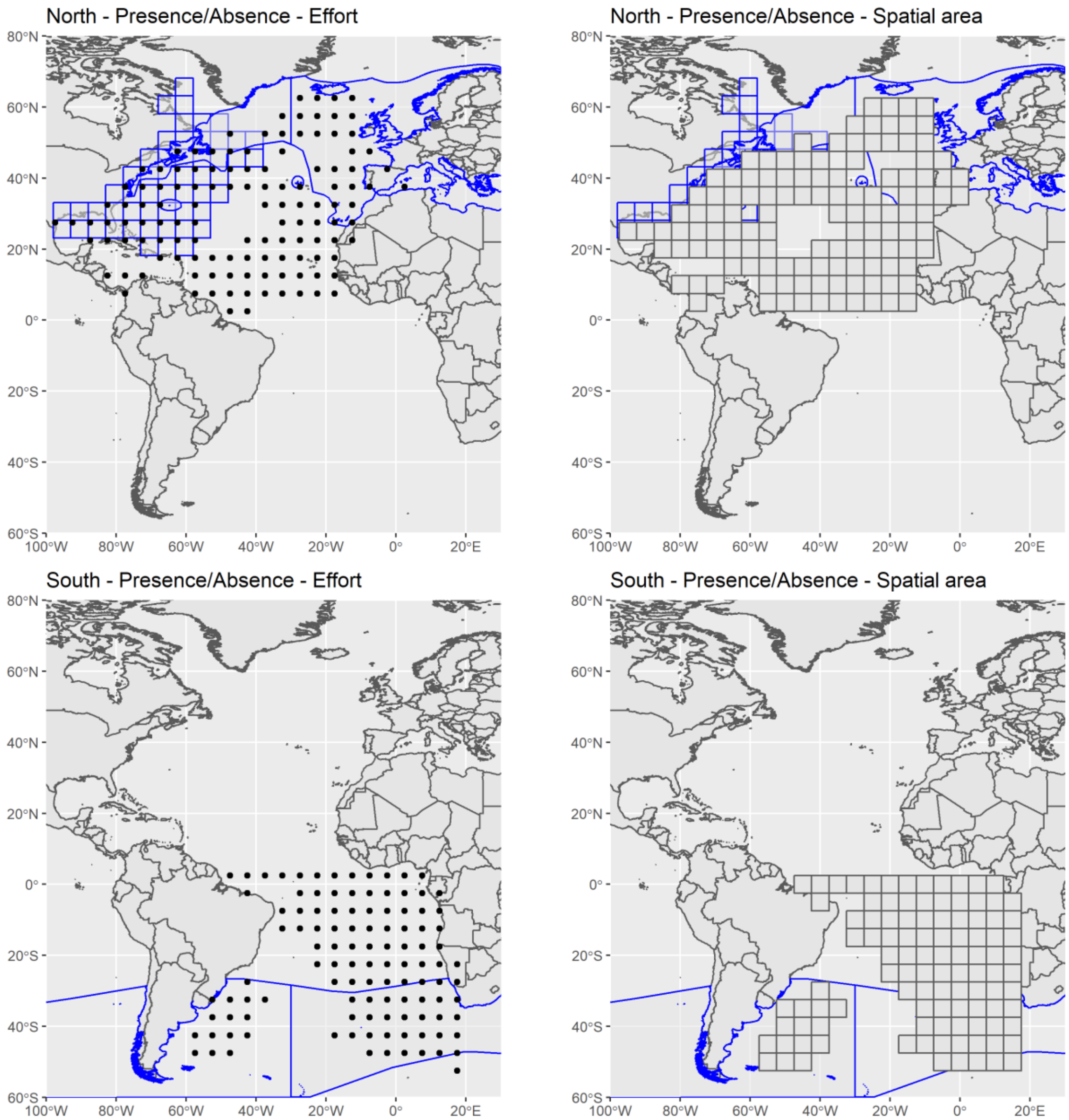

Figure 2. The spatial distribution of porbeagle (polygons outlined in blue) relative to the combined longline effort (presence/absence) in the North and South Atlantic. The data used to calculate availability (i.e. based on spatial area) are shown in the right-hand plots (grey squares). The left-hand plots show presence-absence effort data as point objects (black dots).

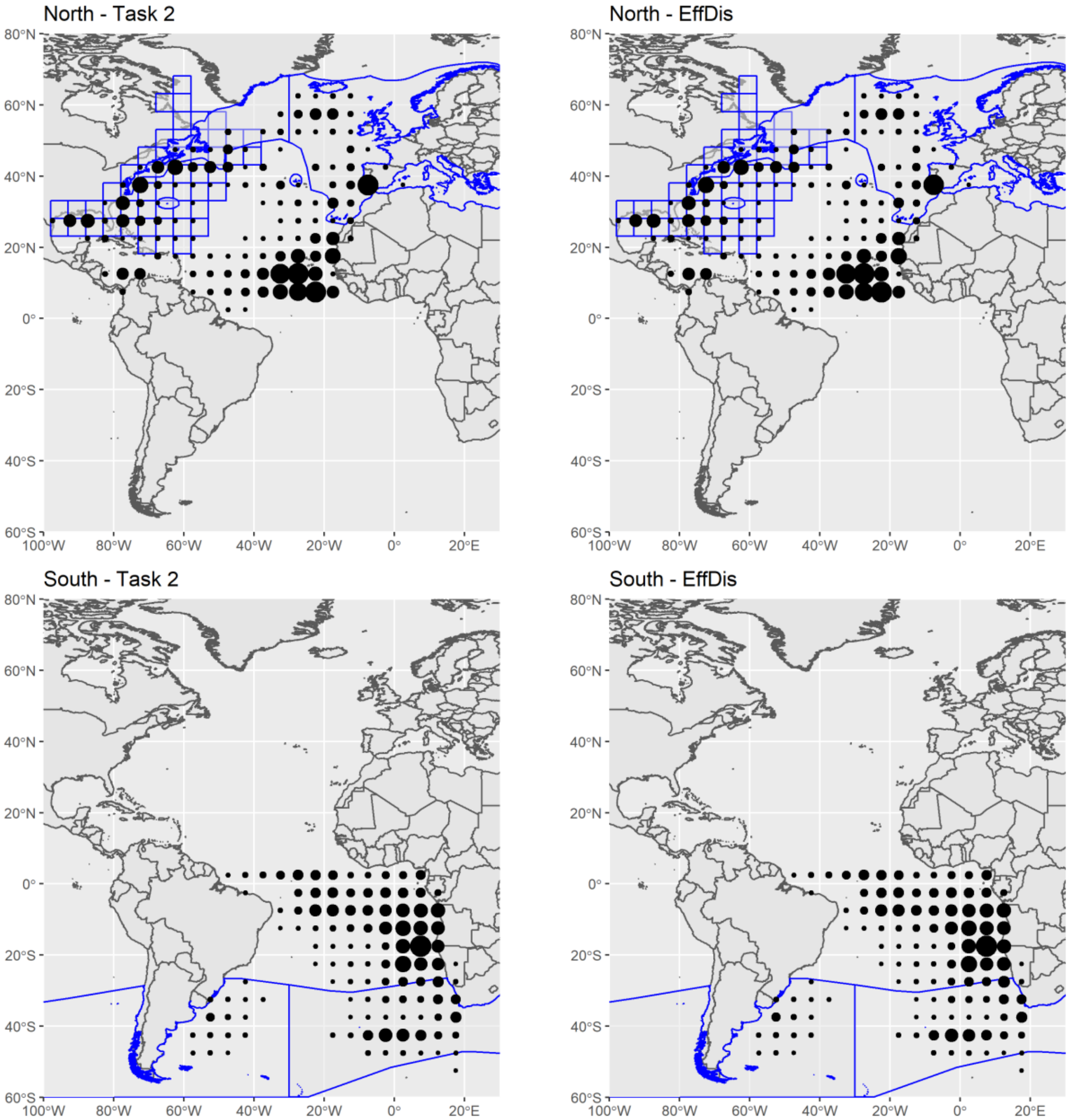

Figure 3. The spatial distribution of porbeagle (polygons outlined in blue) relative to the combined longline effort in the North and South Atlantic, where the relative magnitude of effort (sum of the number of hooks) is shown by the diameter of the points. The left-hand panels show the reported T2CE effort, while the left-hand panels show EFFDIS estimates of total effort.