PRELIMINARY SUSTAINABILITY ASSESSMENT FOR FISHING EFFECTS (SAFE) OF PELAGIC LONGLINE FISHERIES ON PORBEAGLE SHARKS AND IDENTIFICATION OF F-BASED BIOLOGICAL REFERENCE POINTS

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PRELIMINARY SUSTAINABILITY ASSESSMENT FOR FISHING EFFECTS (SAFE) OF PELAGIC LONGLINE FISHERIES ON PORBEAGLE SHARKS AND IDENTIFICATION OF F-BASED BIOLOGICAL REFERENCE POINTS

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SUMMARY

A Sustainability Assessment for Fishing Effects (SAFE) was conducted for the porbeagle shark in the North and South Atlantic oceans. The SAFE approach is a quantitative assessment that computes a proxy for fishing mortality rate as the product of four susceptibility components: availability of the species to the fleets, encounterability of the gear given the species vertical distribution, gear selectivity, and post-capture mortality. The information used to compute the four components came from several sources: observer programs from several ICCAT fleets (capture location, size, status, and disposition of observed animals, vertical distribution of the gear), archival tags from various ongoing projects (distribution, vertical habitat use, and post-release mortality), and ICCAT catch and effort data. The product of these four components was used to compute a harvest rate that can be expressed as F (instantaneous fishing mortality rate) and compared to a value of F_{MSY} obtained based on productivity values derived exclusively from life history data. Results suggest that the porbeagle in the North and South Atlantic are not undergoing overfishing.

RÉSUMÉ

Une évaluation de la durabilité des effets de la pêche (SAFE) a été réalisée pour le requin-taupe commun dans les océans Atlantique Nord et Sud. L'approche SAFE est une évaluation quantitative qui calcule une approximation du taux de mortalité par pêche comme le produit de quatre composantes de sensibilité : la disponibilité de l'espèce pour les flottilles, la possibilité de rencontrer l'engin de pêche compte tenu de la distribution verticale de l'espèce, la sélectivité de l'engin de pêche et la mortalité après capture. Les informations utilisées pour calculer ces quatre composantes proviennent de plusieurs sources : programmes d'observateurs de plusieurs flottilles de l'ICCAT (lieu de capture, taille, état et disposition des animaux observés, distribution verticale de l'engin), marques archives de divers projets en cours (distribution, utilisation verticale de l'habitat et mortalité après la remise à l'eau) et données de prise et effort de l'ICCAT. Le produit de ces quatre composantes a été utilisé pour calculer un taux de capture qui peut être exprimé par F (taux de mortalité par pêche instantanée) et comparé à une valeur de FPME obtenue sur la base de valeurs de productivité dérivées exclusivement de données sur le cycle vital. Les résultats suggèrent que le requin-taupe commun dans l'Atlantique Nord et Sud ne fait pas l'objet d'une surpêche.

RESUMEN

Se realizó una evaluación de la sostenibilidad de los efectos de la pesca (SAFE) para el marrajo sardinero en los océanos Atlántico norte y sur. El enfoque SAFE es una evaluación cuantitativa que calcula una aproximación para la tasa de mortalidad por pesca como

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producto de cuatro componentes de susceptibilidad: la disponibilidad de la especie para las flotas, la posibilidad de encontrar el arte de pesca dada la distribución vertical de la especie, la selectividad del arte de pesca y la mortalidad posterior a la captura. La información utilizada para calcular los cuatro componentes procedía de varias fuentes: programas de observadores de varias flotas de ICCAT (ubicación de la captura, talla, estado y disposición de los animales observados, distribución vertical de los artes de pesca), marcas archivo de varios proyectos en curso (distribución, uso vertical del hábitat y mortalidad posterior a la liberación) y datos de captura y esfuerzo de ICCAT. El producto de estos cuatro componentes se utilizó para calcular una tasa de extracción que puede expresarse como F (tasa de mortalidad por pesca instantánea) y compararse con un valor de F_{RMS} obtenido sobre la base de valores de productividad derivados exclusivamente de datos del ciclo vital. Los resultados sugieren que los stocks de marrajo sardinero en el Atlántico norte y sur no están siendo objeto de sobrepesca

KEYWORDS

Ecological Risk Assessment, Biological reference points,
Pelagic fisheries, By-catch Sustainability Assessment for Fishing Effects,
Ecological Risk Assessment, Life history, Biological reference points,
Pelagic fisheries, Shark fisheries, By-catch, Porbeagle

1. Introduction

The SAFE (Sustainability Assessment for Fishing Effects) approach has been previously used to attempt to determine the overfishing status of pelagic and other sharks (Zhou *et al.* 2009, 2011; Zhou and Griffiths 2008), more recently for elasmobranchs in the Pacific Ocean (Zhou *et al.* 2019). An analogous approach was used to determine the overfishing status of porbeagle in the Southern Hemisphere (Hoyle *et al.* 2017). Briefly, the SAFE is a data-limited approach that computes quantitatively—not qualitatively or semi-quantitatively—the *susceptibility* component of a traditional Ecological Risk Assessment (ERA; Hobday *et al.* 2007) or Productivity and Susceptibility Analysis (PSAs). This susceptibility is a proxy for harvest rate, which can in turn be expressed as an instantaneous rate of fishing mortality *(F*) and compared to an *F*-based reference point.

Previous ERAs for a suite of pelagic sharks conducted by ICCAT's Shark Species Group in 2008 (Cortés et al. 2010) and 2012 (Cortés *et al.* 2015) included this quantitative susceptibility component, but only in the context of vulnerability (the combination of susceptibility to fisheries and stock productivity) to assess the relative risk of multiple species to pelagic longline fisheries in the Atlantic. Here, we used the susceptibility component, which is calculated as the product of availability (horizontal overlap between the stock and fleets), encounterability (vertical overlap between the fishing gear and stock distribution at depth), selectivity (the probability of the animal being caught if it encounters the gear), and post-capture mortality (the overall mortality associated with capture, including that occurring if animals are released alive) to compute a proxy for harvest rate. This harvest rate can be expressed as an instantaneous rate of fishing mortality (*F*), which can then be compared to an *F*-based reference point (e.g. F_{MSY}). Here, we derived F_{MSY} values based on externally computed productivity estimates (Cortés and Semba 2020) using only life history data and compared them to the *F* values obtained in the SAFE approach to determine whether overfishing is occurring.

Since the porbeagle became prohibited by several CPCs towards the end of 2010 and was listed in CITES Appendix II in 2014, catch rates, size compositions, and treatment of animals caught by the different fleets has likely been affected. Based on this, we opted to limit the analysis to 2010-2018.

2. Materials and methods

We computed susceptibility quantitatively based on the SAFE approach as the product of four conditional probabilities (availability, encounterability, selectivity and post-capture mortality). Availability is the probability that the fleet will interact with the stock on the horizontal plane; encounterability is the probability that one unit of fishing effort will encounter the available stock; selectivity is the probability that the encountered population will actually be captured by the fishing gear; and post-capture mortality is the probability that the captured population will die.

The analysis included the fleets for which information from observer programs was made available. For the North Atlantic we used data from Canada, Japan, Portugal, and USA; and for the South Atlantic, information from Japan, Namibia, South Africa, and Uruguay. We limited the analysis to 2010-2018 because of the likely influence of management changes on catch rates, size compositions, and treatment and disposition of the catch.

Availability was calculated as the proportion of the spatial distribution of the pelagic longline fleet that overlaps that of the stock as has traditionally been done in previous ERAs. Spatial effort distribution was aggregated for all years to calculate a single availability at a 5º x 5º resolution (see Bowlby *et al.* 2020 for more details on computation of availability). Species distributions were obtained by supplementing IUCN (Global Marine Species Assessment) distribution maps with information from observer records, catch records, and archival (satellite) tag positive locations and also aggregated at a 5º x 5º resolution to allow comparison with the effort distribution (Bowlby *et al.* 2020).

Encounterability was estimated as the degree of overlap between the depth distribution of the stock and that of the longline gear. To that end, we described the approximate depth distribution of the gear from each of the fleets included in the analysis. We then collated information on depth preference of porbeagle sharks tagged with archival satellite tags from several sources, including activities from the Shark Research and Data Collection Program (SRDCP), summarized as histograms of time at depth in 5 m bins during the day and night. Information was available from four sharks tagged in the Northeast Atlantic (latitude ~ 47° N, longitude ~ 7° W; two females: 195 cm FL each; two males: 181-203 cm FL), from 18 sharks tagged in the Northwest Atlantic (latitude ~ 42 to 44° N, longitude ~ -48 to -70° W; 13 females: 88-209 cm FL; three males: 95-127 cm FL; 2 sex unknown: 110-152 cm FL), and 1 animal tagged in the Southwest Atlantic (latitude: -36.191, longitude:-52.850, tagged 7/3/2016, 181 cm FL mature male, 28 days with complete depth information at a sampling rate of 10 minutes). We combined the satellite tagging data from the Northwest and Northeast Atlantic to construct the porbeagle depth distribution histograms for the North Atlantic and data from the single, but detailed, Southwest Atlantic shark for the South Atlantic. The final step was to calculate the overlap between the species distribution and that of the gear at night and during the day (day and night were defined with an algorithm that takes into account time, data, latitude, longitude, and nautical dusk and dawn in the specific region) and average them to obtain the daily probability of being encountered. For the Uruguayan fleet, encounterability was calculated as the mean of the values for the shallow and deep water components. Overall encounterability was calculated as the mean of values for each individual fleet weighted by the proportional effort exerted by each fleet to the total effort by all fleets (from EFFDIS for 2010-2018).

Selectivity is size-dependent by definition and thus any attempt to produce a single value for a stock should be regarded as a crude approximation. Here, we estimated a “contact selectivity” (proportion of fish encountering the gear that are caught; Griffiths *et al.* 2018) by 1) obtaining a stable age distribution from a life table/Leslie matrix approach (Cortés and Semba 2020) and transforming it into a “stable length” distribution through the von Bertalanffy growth function for females and males separately (because the stable age/length distribution from the life table/Leslie matrix is only available for females, the female stable age distribution was assumed for males); 2) computing length-frequency distributions for females and males from observer program data for 2010-2018; 3) using these observed length-frequency distributions to estimate selectivity by eye assuming a dome-shaped selectivity function; 4) computing a value of selectivity for each fleet as the sum of the products of the stable length distribution and the proportion selected at each length bin (doing this separately for females and males); 5) computing the overall selectivity for each fleet as the mean of the selectivity values for females and males (assuming females and males are equally abundant); and 6) computing a single value of selectivity for all fleets combined as the mean of selectivities for the individual fleets weighted by the proportional total catch of each fleet to the total catch of all fleets during 2010-2018 obtained from Task 1 (**Table 1**). In equation form selectivity for each fleet f for females is:

$$Sel_{f,females} = \sum_{l=min}^{l=max} p_l \times s_{l=females}$$

and for males:

$$Sel_{f,males} = \sum_{l=min}^{l=max} p_l \times s_{l=males}$$

where p_l is the proportion of the population in each length interval from minimum to maximum length (equal for females and males), and $s_{l=females}$ and $s_{l=males}$ are the proportions in each length interval selected according to the selectivity curve fit to the observed data for females and males, respectively. The selectivity for each fleet is then computed as the average of $Sel_{f,females}$ and $Sel_{f,males}$.

For all fleets combined, selectivity was expressed as:

$$Sel_{all\ fleets} = \frac{\sum_{f=1}^{f=n} Sel_f \times C_f}{\sum_{f=1}^{f=n} C_f}$$

where C_f is the total catch of fleet f during 2010-2018.

Post-capture mortality was estimated based on information on the fate (action taken) of animals collected in scientific observer programs. Total post-capture mortality (PCM) was calculated as the sum of animals kept (K) and discarded dead (DD) relative to the total number of animals observed. We also accounted for cryptic mortality by applying post-release mortality; p_D) to the sum of animals lost (L) and whose fate was unknown (U). Mortality of animals released alive (RA) was also estimated by applying the same post-release mortality estimate. The post-release mortality value used (13.6%) was the average of two estimates: 27.2% from Campana *et al.* (2016) and 0% from Anderson *et al*. (In press). The equation was thus:

$$PCM = \frac{K + DD + (L + U)p_D + RAp_D}{K + DD + L + U + RA}$$

Post-capture mortality for all fleets combined was calculated as the mean of PCM values for the individual fleets weighted by the proportional total catch of each fleet to the total catch by all fleets during 2010-2018 from Task 1 (**Table 1**).

The fraction of the populations lost to fishing (Zhou and Griffiths 2008), which is the exploitation rate (U) was approximated as the product of the four components: availability, encounterability, selectivity, and post-capture mortality, such that:

$$U \approx \frac{\sum a_f}{A} \times \frac{D_f}{D} \times Sel \times P\,CM$$

where a_f is the spatial distribution of the fleet, A is the spatial distribution of the stock, D_f is the depth distribution of the gear, D is the depth distribution of the stock, Sel is selectivity, and PCM is post-capture mortality.

The value of U is the fraction of the population lost due to fishing and the corresponding instantaneous fishing mortality rate is:

$$F = 1 - \ln(1 - U)$$

This *F* can then be compared to an *F*-based reference point such as F_{MSY} derived based on life history (Cortés and Brooks 2018).

Status determination

We used values of $\hat{\alpha}$ **,** the maximum number of female spawners that can be produced by a female spawner throughout her life, from Cortés and Semba (2020) to determine the productivity level (low, medium, high) reported in Cortés and Brooks (2018). The derived productivity levels can then be linked to a specific F_{MSY}/M ratio that takes into account when animals are selected (i.e., immature, mature) and the type of fishery selectivity. The resulting value of F_{MSY} can then be compared to the *F* value obtained in the SAFE analysis to determine whether overfishing is occurring.

3. Results

Availability

The spatial effort distribution (5º x 5º squares) of the fleets included in the analysis overlaid on the spatial distribution of porbeagle is shown in **Figures 1-7**. The spatial distribution from the IUCN maps was significantly augmented by data from mostly satellite tags in the Northwest Atlantic. In the Southern Hemisphere porbeagles have a circumpolar distribution.

Availability for the North Atlantic ranged from 0.07 for Canada to 0.29 for Japan and the USA; for the South Atlantic, availability ranged from 0.01 for Namibia to 0.09 for Japan (**Table 2**). Overall availability for all fleets combined was 0.53 for the North Atlantic and 0.11 for the South Atlantic (**Table 2**).

Encounterability

The approximate depth distribution of the pelagic longline gear is shown in **Figure 8**. The Japanese fleet fishes in waters generally ranging from approximately 70 to 135 m in both the North and South Atlantic, the Uruguayan fleet fished both shallow (30 to 100 m) and deep waters (100-200 m), as does the Namibian fleet (7-45 m and 145-180 m), whereas the four remaining fleets (Canada, Portugal, South Africa, and USA) fish mostly shallow waters <100m.

Figures 9 and **10** show the time at depth of porbeagle during the day and night in the North Atlantic and South Atlantic. In the North Atlantic, porbeagle spend about 52% of the time during the day and 64% of the time at night above 40 m (**Figure 9**), whereas in the South Atlantic, the single shark tagged spent only 10% of the time during the day and 45% of the time at night above 40 m (**Figure 10**).

Encounterability ranged from 17% for the Japanese fleet to 68% for the USA fleet in the North Atlantic, and from 8% for the South African fleet to 31% for the Namibian fleet in the South Atlantic. Encounterability for the combined fleets in the North Atlantic was 31% and 25% for the South Atlantic (**Table 2**).

Selectivity

Selectivity curves fit by eye to the observed female and male length distributions available for each fleet are shown in **Appendix 1**. The observed length distributions for females and males are similar for most fleets, with the majority of fleets catching predominantly small, immature animals. Selectivity ranged from 19% for the USA fleet to 66% for the Canadian fleet in the North Atlantic, and from 20% for the Japanese fleet to 47% for the Namibian fleet in the South Atlantic. Selectivity for the combined fleets in the North Atlantic was 38% and 26% for the South Atlantic (**Table 2**).

Post-capture mortality

Post-capture mortality ranged from 39% for the Canadian fleet to 56% for the Japanese fleet in the North Atlantic (for the Portuguese fleet it was set to the mean of the three other fleets), and from 65% for the Japanese fleet to 74% for the Uruguayan fleet in the South Atlantic (for the Namibian and South African fleets it was set to the mean of the Japanese and Uruguayan fleets). Post-capture mortality for the combined fleets in the North Atlantic was 48% and 68% for the South Atlantic (**Table 2**).

Fishing mortality, F-based reference points, and status

Table 2 summarizes and **Figure 11** shows the four components of the proxy for U by fleet and stock. More eccentric values in **Figure 11** reflect higher susceptibility. Availability is low for all fleets because of their limited overlap with the porbeagle distribution in the North and South Atlantic. Encounterability is higher for the USA and Canada because the gear fishes a wide range of shallow depths (down to ca. 100 m). Selectivity was highest for the Canadian fleet because of the widest range of lengths represented. Post-capture mortality tended to be high for most fleets and lowest for Canada.

The estimated value of F for the North Atlantic was 0.031 and 0.005 for the South Atlantic (**Table 3**).

Cortés and Semba (2020) report values of the maximum lifetime reproductive rate ($\hat{\alpha}$) of 3.22 for a 1.5 year reproductive cycle in the North Atlantic and 3.25 for an annual reproductive cycle in the South Atlantic, which were deemed the most likely scenarios in both areas. These values correspond to medium productivity (defined as $\hat{\alpha}$ values ranging from 2.67 to 6.0) in Cortés and Brooks (2018). These authors reported (their Table 5) that $F_{MSY}/M = 0.60$ for medium productivity shark stocks when immature animals are selected by the fishery and the selectivity is dome shaped. Using the average value of M for adults in Cortés and Semba (2020) (0.082 for the North and 0.103 for the South) yields a value of $F_{MSY} = 0.049$ for the North Atlantic and $F_{MSY} = 0.062$ for the South Atlantic. Using the values of F derived above this would indicate that overfishing is not occurring in the North Atlantic ($0.031 < 0.049$) or in the South Atlantic ($0.005 < 0.062$) (**Table 3**).

If a logistic, instead of a dome-shaped, selectivity was assumed, F_{MSY} becomes 0.036 for the North Atlantic and 0.045 for the South Atlantic; if both logistic and dome-shaped selectivities are assumed, $F_{MSY} = 0.042$ and 0.053 for the North and South Atlantic, respectively, for stocks of medium productivity when immature animals are selected (Cortés and Brooks 2018). In both cases the conclusion that there is no overfishing would still hold ($F = 0.031 < 0.036$ or 0.042 for the North Atlantic; $F = 0.005 < 0.042$ or 0.053 for the South Atlantic; **Table 3**).

4. Discussion

Unlike previous ERAs for Atlantic pelagic sharks that only addressed the relative propensity of stocks to capture by the different fleets, this was a quantitative analysis that estimated a proxy of F. However, results must be interpreted cautiously.

The current analysis included the entire North Atlantic, but some European fleets operating in the Northeast Atlantic were not included, albeit catches are expected to be minimal since the retention prohibition in 2010 by the EU and the inclusion of porbeagle in CITES Appendix II in 2014. The analysis for the South Atlantic was based mostly on two fleets, Japan and Uruguay, and very little information was available from the Southeast Atlantic. There are additional positive and negative aspects of the current analysis. Positive aspects include that: 1) multiple sources were used to characterize the distribution of porbeagle (satellite tags, observer reports, catch records) to supplement the existing IUCN distribution maps, 2) the computation of encounterability used information on depth use by porbeagle derived from satellite tags, 3) the computation of selectivity explicitly used observed length frequencies by fleet, and 4) the computation of post-capture mortality used information from two studies on post-release survival (also based on satellite tags). In contrast, some shortcomings include for example the computation of encounterability, which was based on the approximate maximum range of the gear depth distribution by fleet, which is a coarse approximation and likely overestimates this component because the gear operates most of the time at depths between the minimum and maximum depths.

It is also important to note that the fishing mortality values estimated in this analysis can be influenced by data availability, e.g. information on the fate of the animals used to compute post-capture mortality and particularly length information from observer programs.

In terms of the validity of the F-based reference points used, the assumption that mostly immature individuals are selected is supported by the observed length distributions. The prediction of overfishing status was also robust to the assumed selectivity pattern.

The results of this analysis for the South Atlantic agree with those from Hoyle at al. (2017), who also found that there was a very low risk of overfishing for porbeagle in the Southern Hemisphere. These authors found that for all the regions they examined combined (Eastern Atlantic Ocean to Western Pacific Ocean) fishing mortality was less than 9% of their reference point in all years assessed (1992-2014) and decreased to half that level in more recent years, with at most a 4% probability of exceeding the reference point in 2010-2014. For comparison, the values of F we estimated in the current analysis ranged from 8 to 11% of our F-based reference point in the South Atlantic. For the North Atlantic, our results seem consistent with the low recent catches recorded in the area (mean of 67 mt during 2010-2018, Task 1 data).

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Table 1. Task 1 catch (t whole weight) by year and total effort (estimated number of hooks) of porbeagle in the North Atlantic by fleet, 2010-2018.

	Catch										Effort
	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total	Total
USA	3	11	4	29	13	42	6	17	5	130	55,619,845
Portugal	7	0	0					0	0	8	43,919,299
Japan North	11	13	48	98						170	223,576,191
Canada	83	30	33	19	10	6	5	4	4	194	19,042,210
Japan South	8	7	25	15	13	4	1	0		73	275,138,555
Uruguay	6	12	12							30	1,313,285
Namibia											30,420,484
South Africa											9,350,429

Table 2. Values of the four components of susceptibility (availability, encounterability, selectivity, and post-capture mortality) used to calculate the harvested proportion of the population (U) and the corresponding *F* proxy by fleet and for the North and South Atlantic areas combined.

Fleet	Availability	Encounterability	Selectivity	Post-capture mortality	U	F
Canada	0.07	0.62	0.66	0.39	0.0120	0.0121
Portugal	0.13	0.41	0.46	0.49	0.0123	0.0123
Japan North	0.29	0.17	0.20	0.56	0.0057	0.0057
USA	0.29	0.68	0.19	0.52	0.0193	0.0195
Japan South	0.09	0.24	0.20	0.65	0.0030	0.0030
Namibia	0.01	0.31	0.47	0.69	0.0013	0.0013
South Africa	0.02	0.08	0.29	0.69	0.0003	0.0003
Uruguay	0.02	0.26	0.40	0.74	0.0016	0.0016
North Atlantic	0.53	0.31	0.38	0.48	0.0305	0.0310
South Atlantic	0.11	0.25	0.26	0.68	0.0046	0.0046

Table 3. Instantaneous fishing mortality rate (*F*) and F_{MSY} values for the North and South Atlantic obtained with different assumptions about selectivity.

	F	F_{MSY}		
Area		Dome-shaped	Logistic	Both
North	0.031	0.049	0.036	0.042
South	0.005	0.062	0.045	0.053

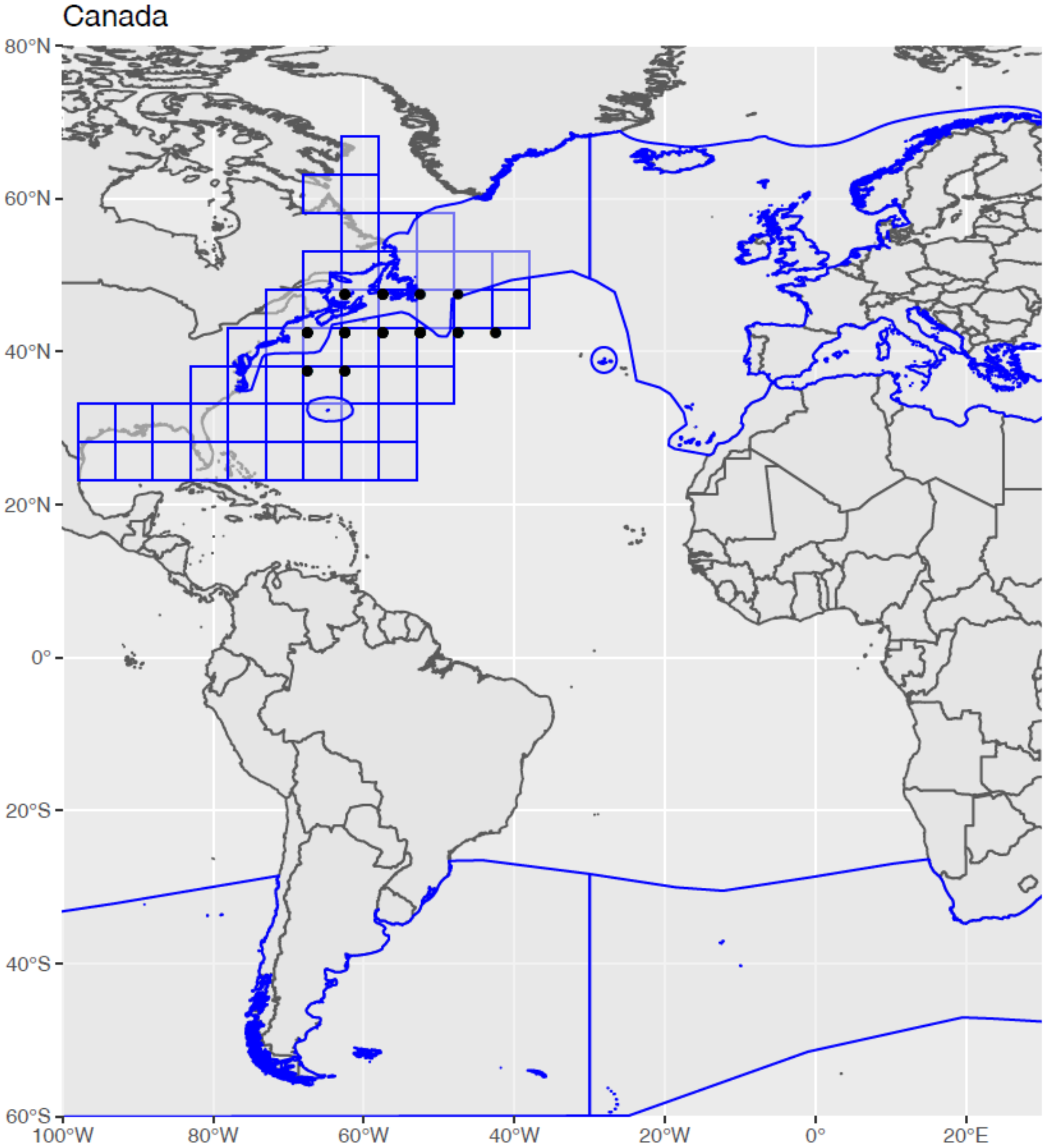


Figure 1. Effort distribution (number of hooks shown as presence/absence in 5º x 5º squares; black dots) of pelagic longline fleet for Canada, 2010-2018. Porbeagle distribution is shown as blue contours (IUCN) augmented by 5x5 degree squares obtained from other sources (e.g. satellite tag data).

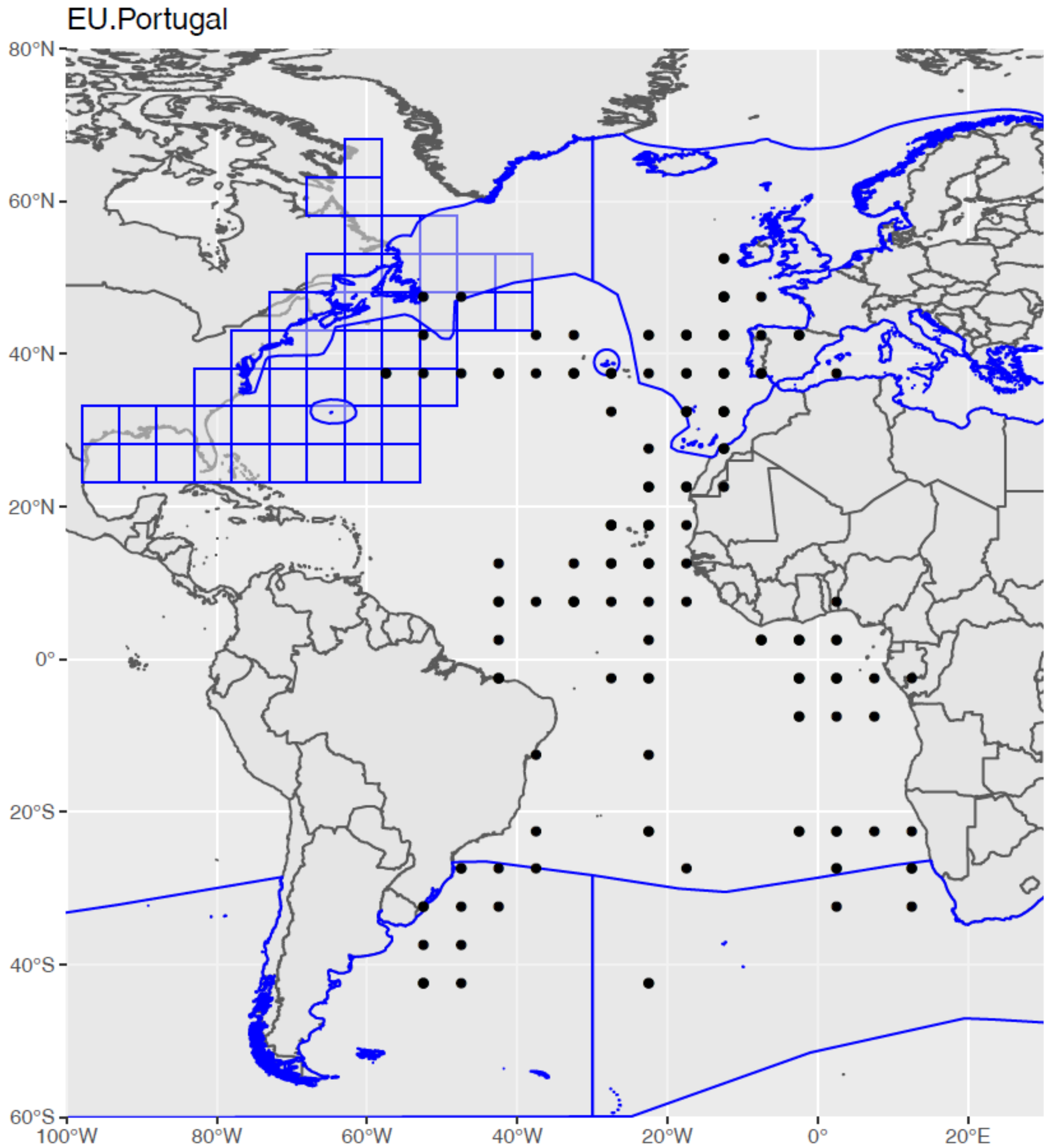


Figure 2. Effort distribution (number of hooks shown as presence/absence in 5º x 5º squares; black dots) of pelagic longline fleet for Portugal, 2010-2018. Porbeagle distribution is shown as blue contours (IUCN) augmented by 5x5 degree squares obtained from other sources (e.g. satellite tag data).

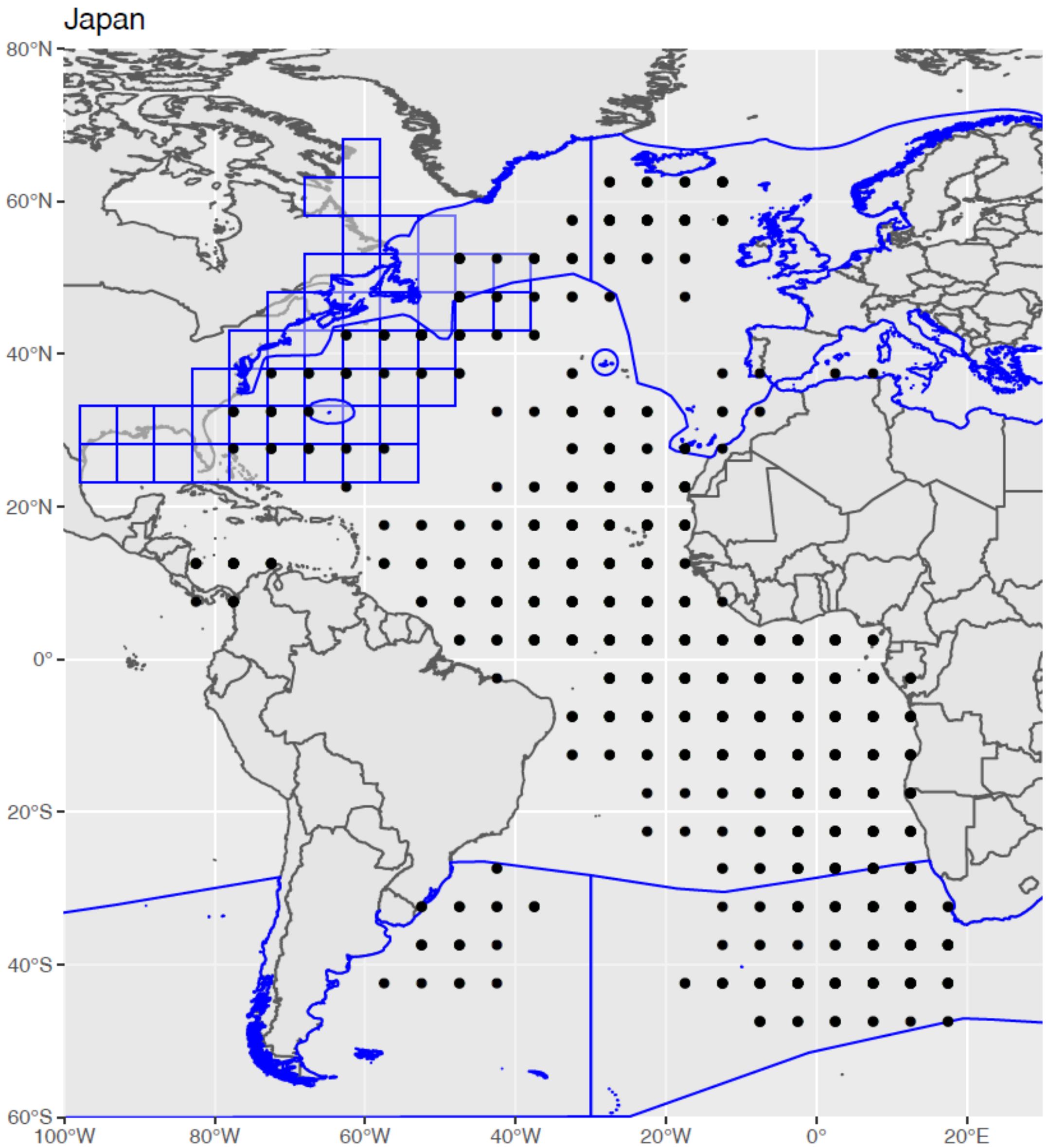


Figure 3. Effort distribution (number of hooks shown as presence/absence in 5º x 5º squares; black dots) of pelagic longline fleet for Japan, 2010-2018. Porbeagle distribution is shown as blue contours (IUCN) augmented by 5x5 degree squares obtained from other sources (e.g. satellite tag data).

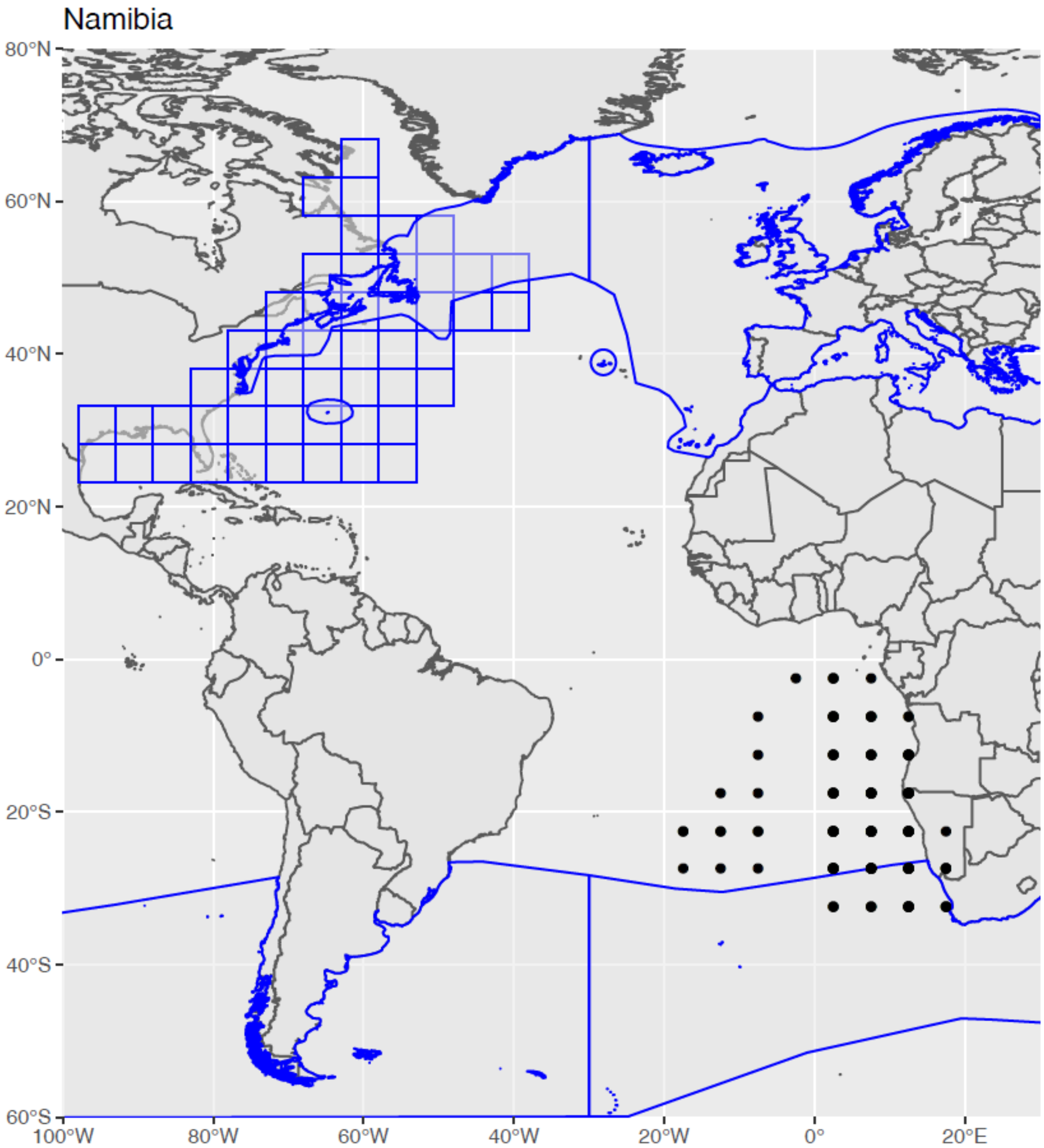


Figure 4. Effort distribution (number of hooks shown as presence/absence in 5º x 5º squares; black dots) of pelagic longline fleet for Namibia, 2010-2018. Porbeagle distribution is shown as blue contours (IUCN) augmented by 5x5 degree squares obtained from other sources (e.g. satellite tag data).

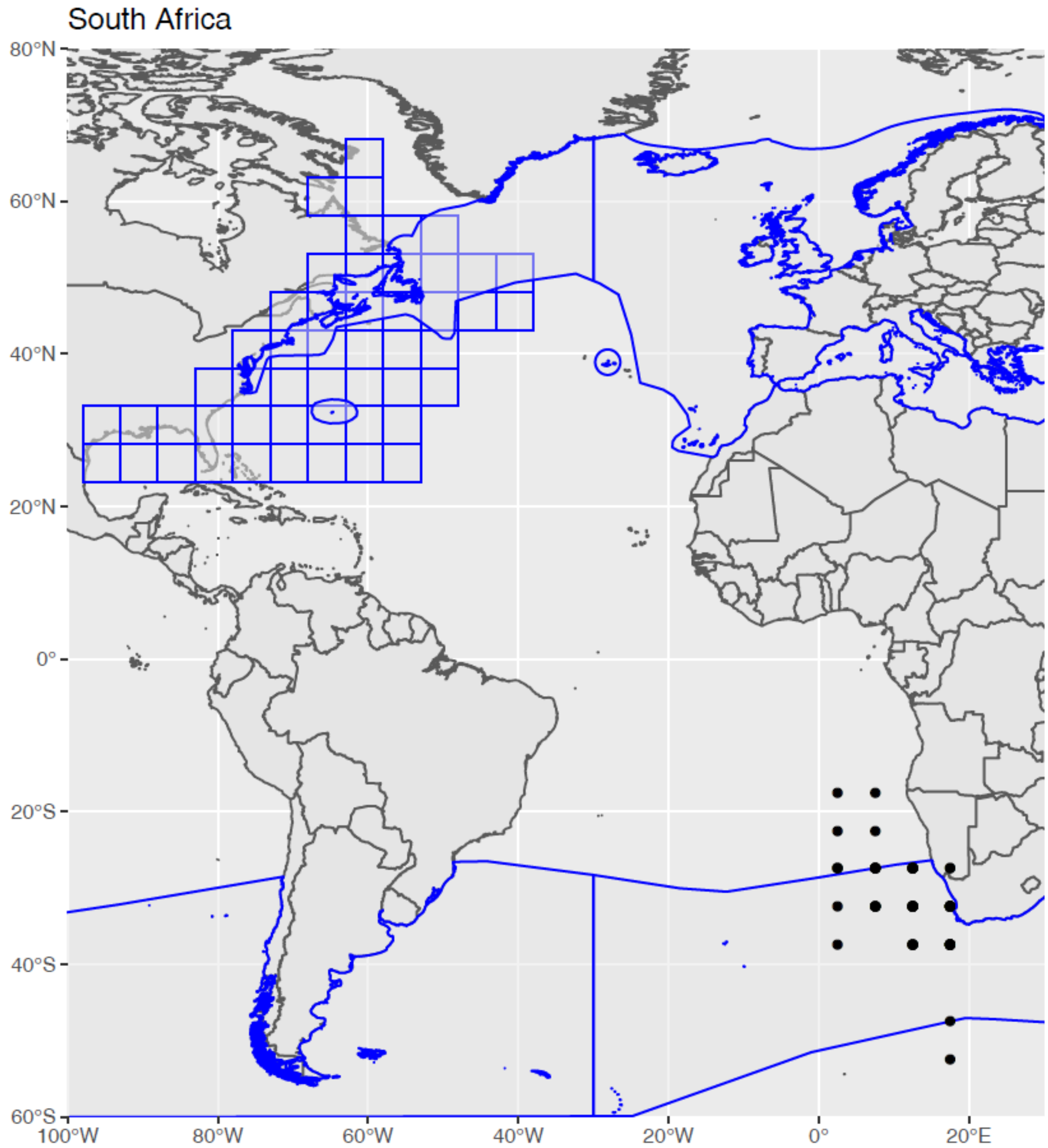


Figure 5. Effort distribution (number of hooks shown as presence/absence in 5º x 5º squares; black dots) of pelagic longline fleet for South Africa, 2010-2018. Porbeagle distribution is shown as blue contours (IUCN) augmented by 5x5 degree squares obtained from other sources (e.g. satellite tag data).

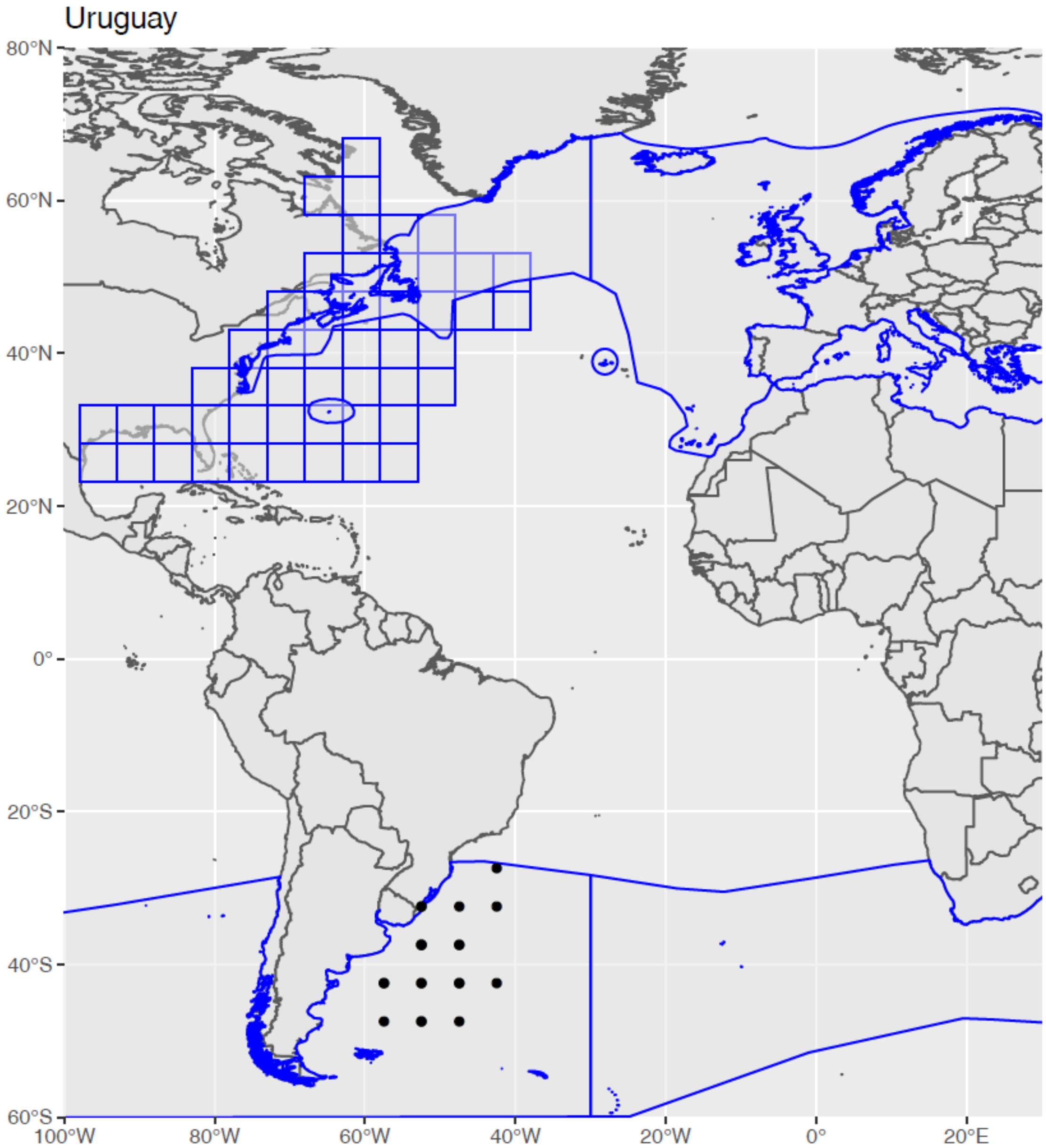


Figure 6. Effort distribution (number of hooks shown as presence/absence in 5º x 5º squares; black dots) of pelagic longline fleet for Uruguay, 2010-2018. Porbeagle distribution is shown as blue contours (IUCN) augmented by 5x5 degree squares obtained from other sources (e.g. satellite tag data).

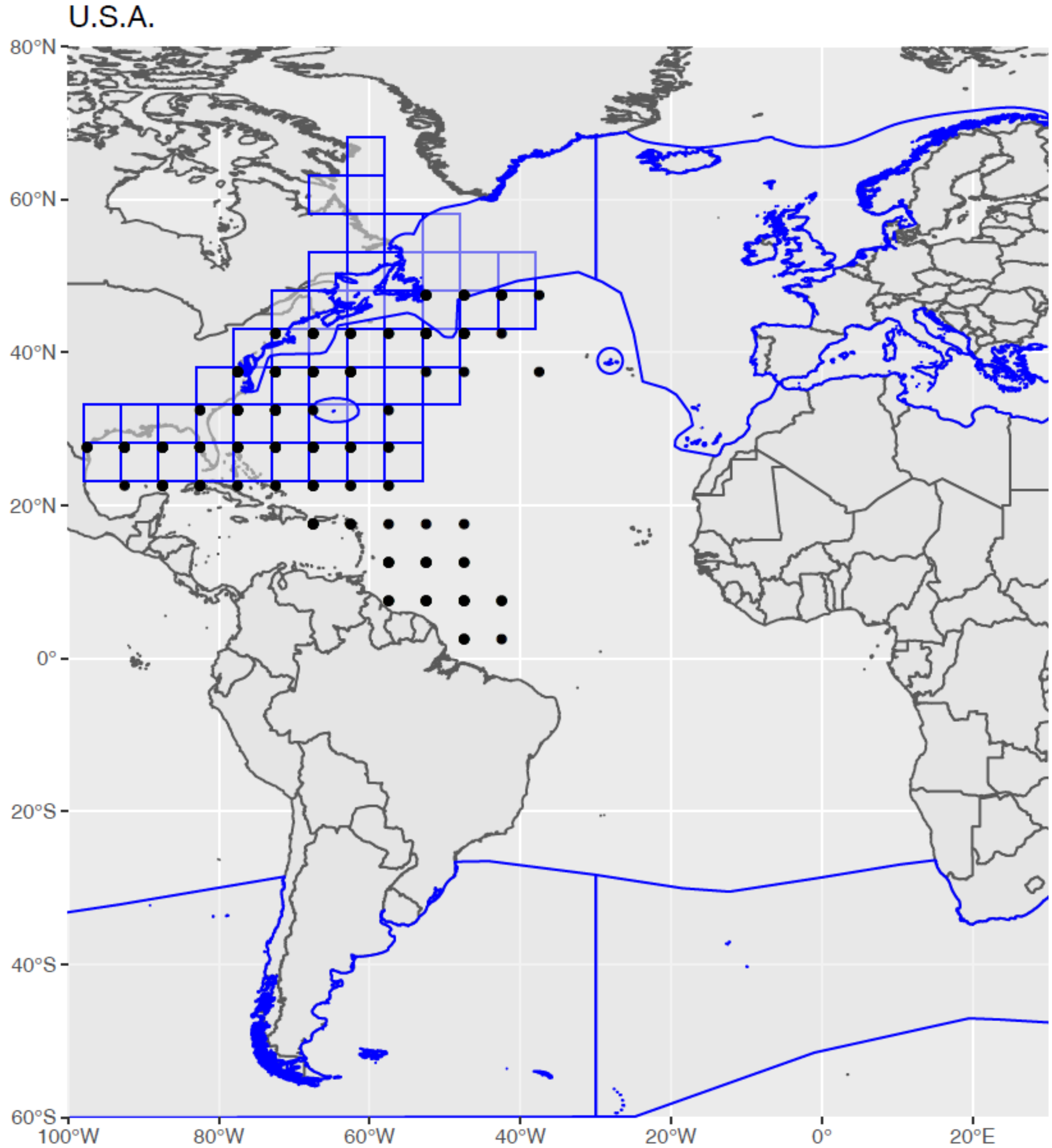
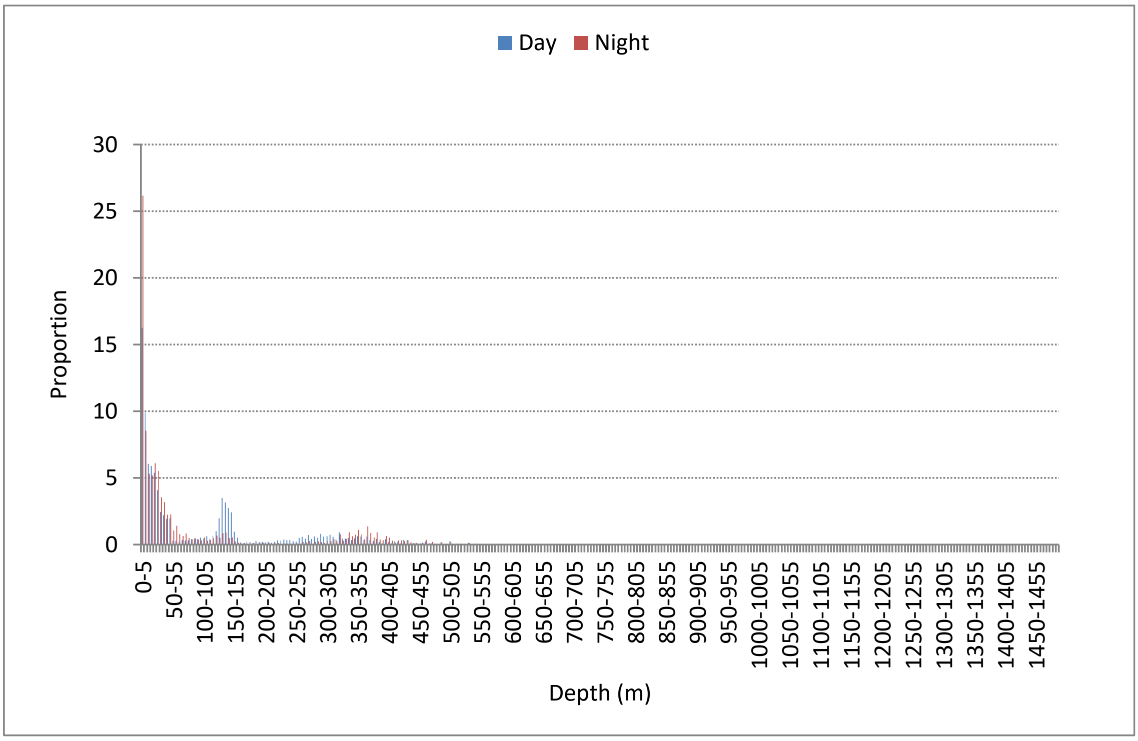


Figure 7. Effort distribution (number of hooks shown as presence/absence in 5º x 5º squares; black dots) of pelagic longline fleet for USA, 2010-2018. Porbeagle distribution is shown as blue contours (IUCN) augmented by 5x5 degree squares obtained from other sources (e.g. satellite tag data).

								30-100	
	Range	15-100	70-135	70-135	7-45; 145-180	20-50	40-50; 80-100	100-200	2-97
Depth	Fleet	CANADA	JAPAN N	JAPAN S	NAMIBIA	PORTUGAL	S. AFRICA	URUGUAY	USA
0									
5									TUN, SWO
10					BSH, SMA,				
15		SWO			SWO				
20									
25									
30									
35									
40							SWO		
45									
50									
55									
60									
65									
70									
75									
80							TUN		
85									
90									
95									
100									
105								JAP	
110									
115									
120									
125									
130									
135									
140									
145					TUN				
150									
155									
160									
165									
170									
175									
180									
185									
190									
195									
200									

Figure 8. Approximate depth distribution of pelagic longline gear by fleet. Capital letters indicate targeted species.



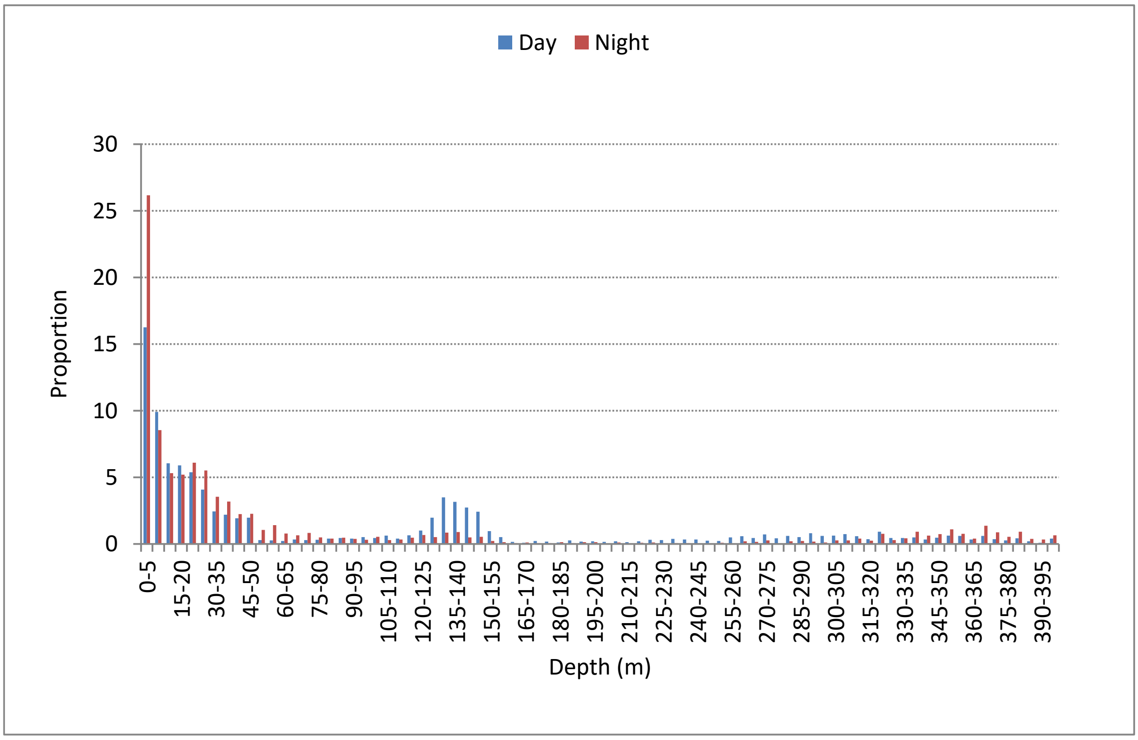


Figure 9. Histogram of time at depth of porbeagle during the day and night for the North Atlantic. The bottom panel shows time at depth down to 400 m (>95% of all occurrences) for clarity.

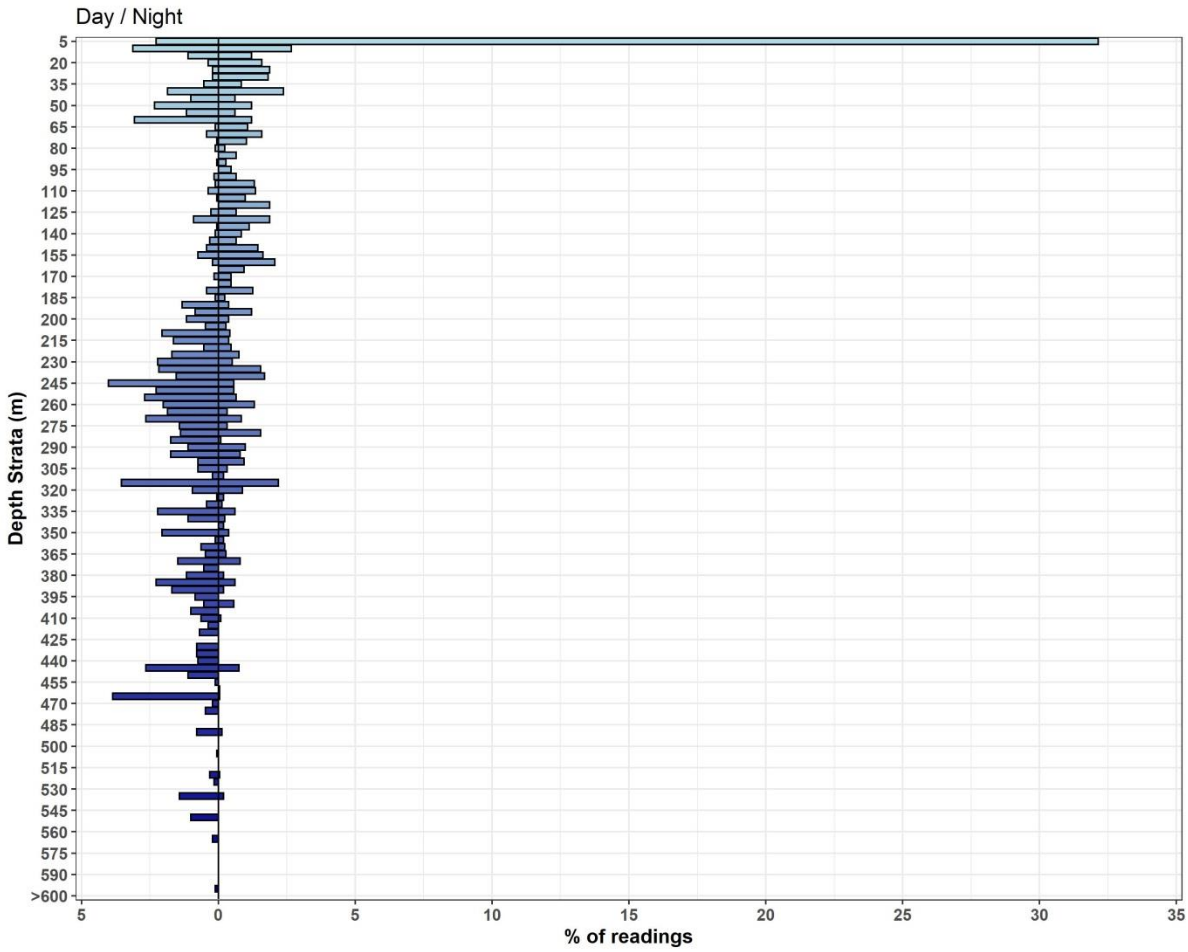


Figure 10. Histogram of time at depth of porbeagle during the day and night in the South Atlantic.

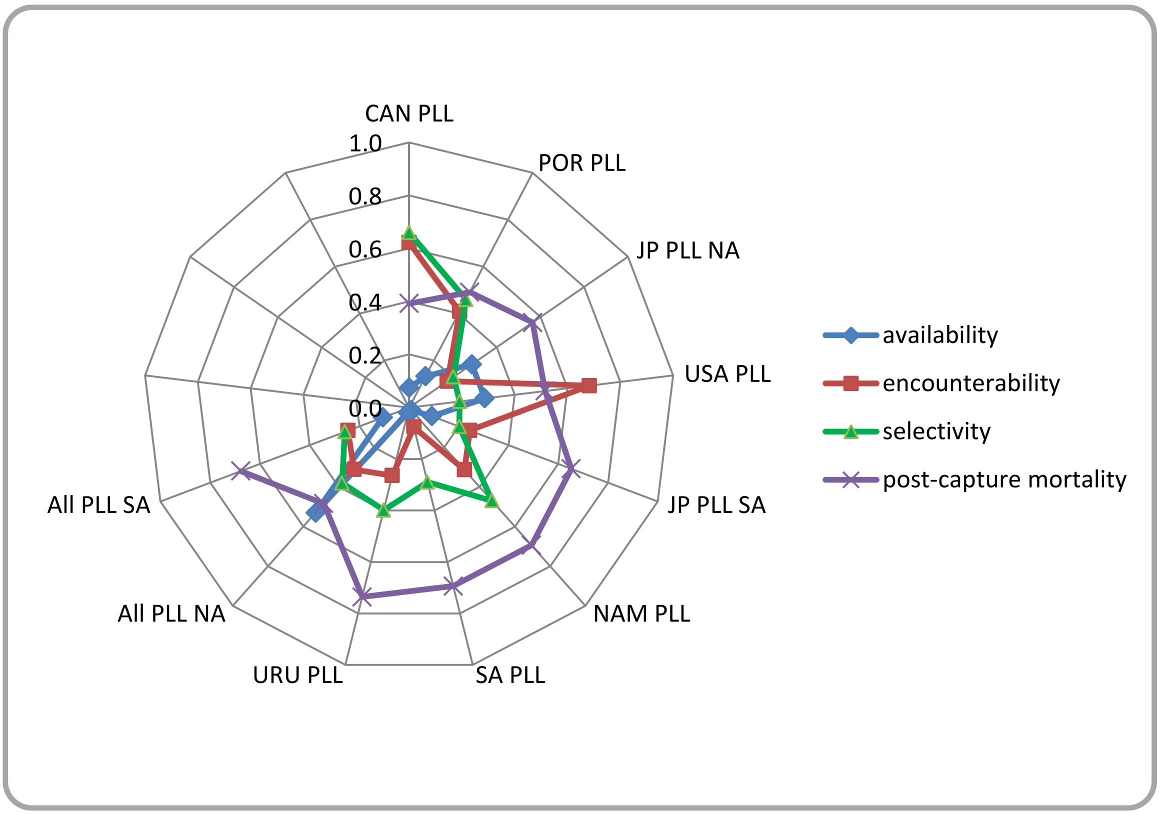
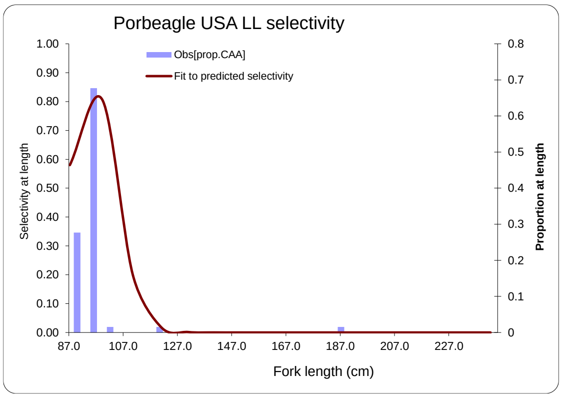
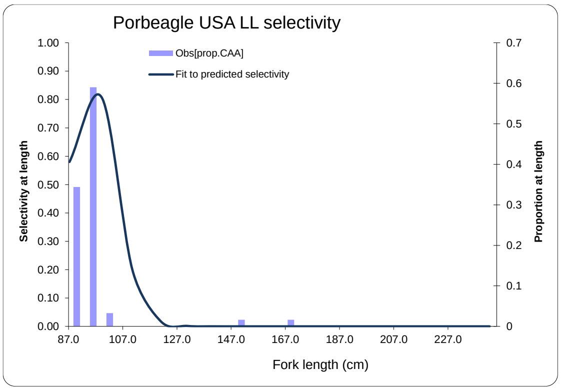


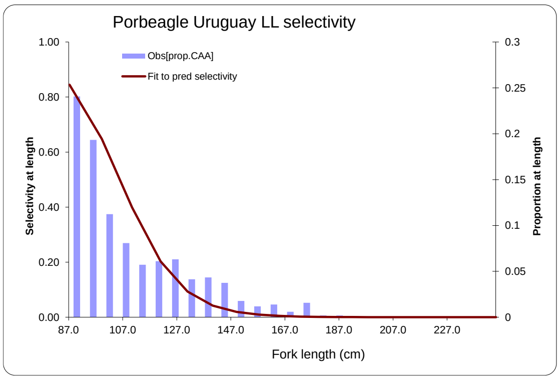
Figure 11. Radar plot of the four susceptibility attributes (availability, encounterability, selectivity, and post-capture mortality) by fleet.

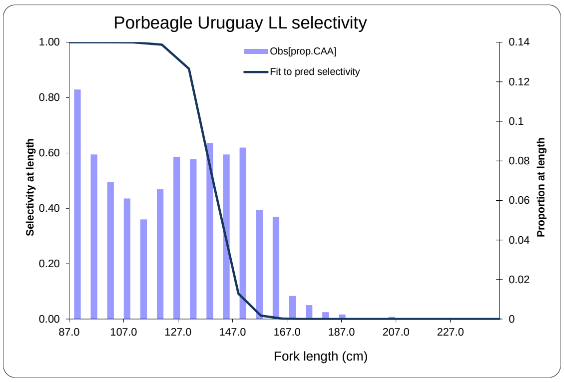
Appendix 1

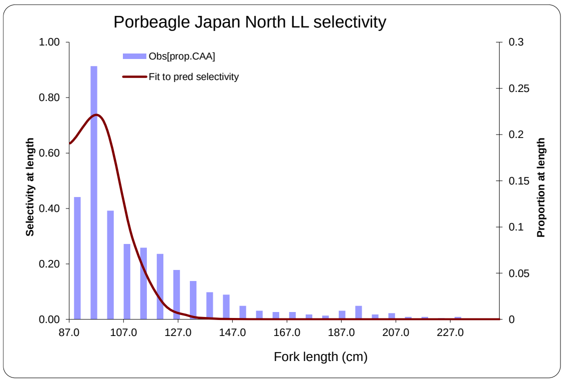
Fits (double logistic curve) to observed length distributions of females (left panels) and males (right panels) for each fleet.

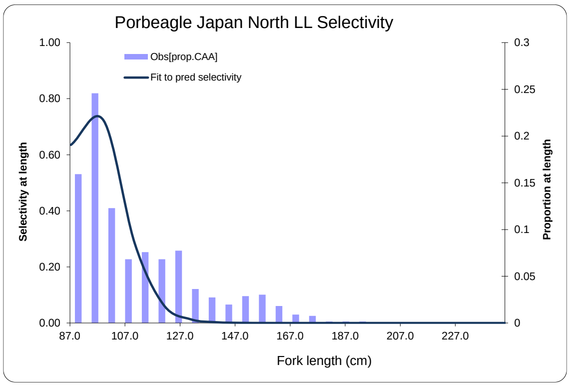


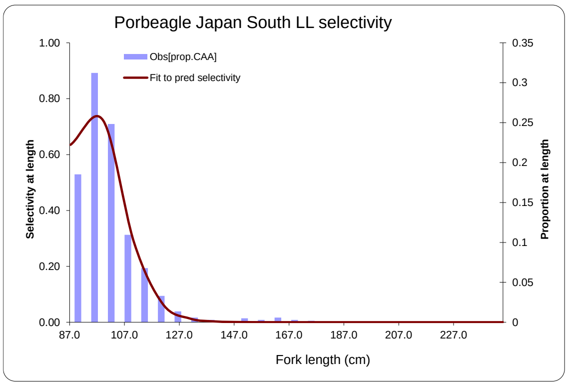


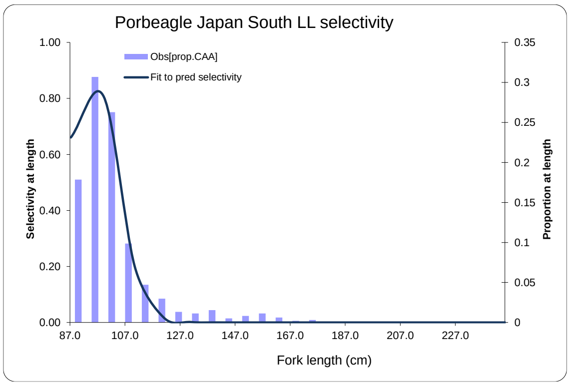


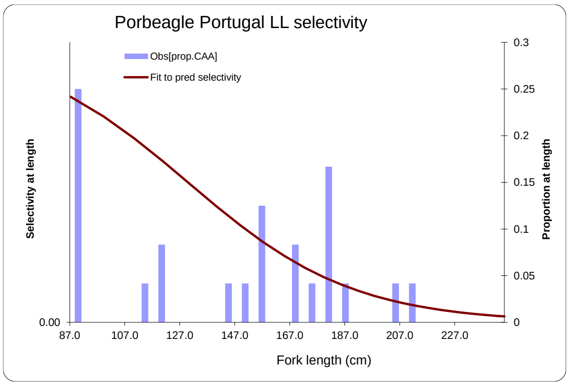


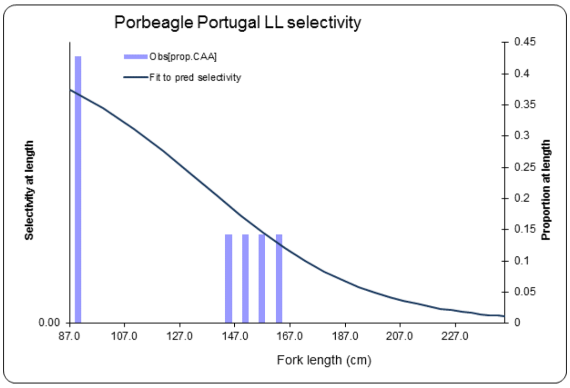


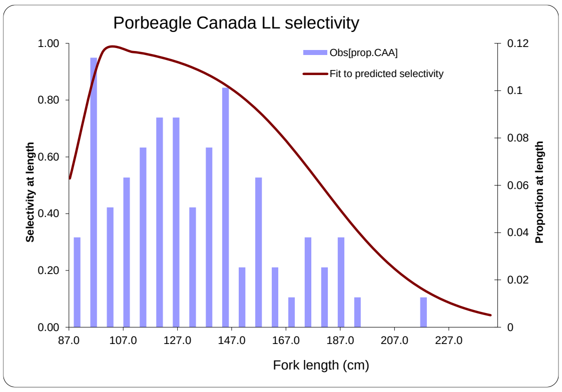


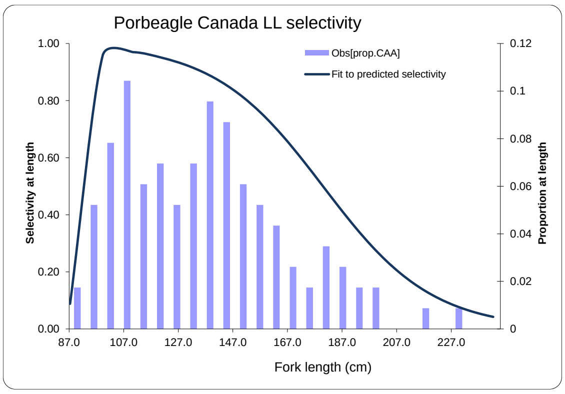


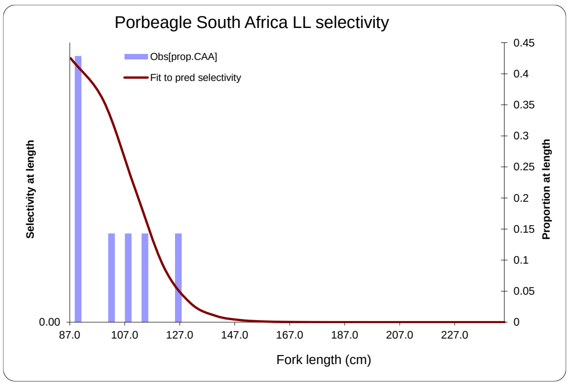


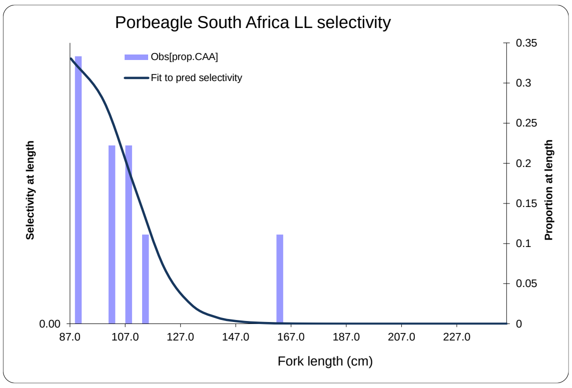

Porbeagle Portugal LL selectivity
Obs[prop.CAA]
Fit to pred selectivity
Selectivity at length
Proportion at length
0.00
0.3
0.25
0.2
0.15
0.1
0.05
0
87.0 107.0 127.0 147.0 167.0 187.0 207.0 227.0
Fork length (cm)

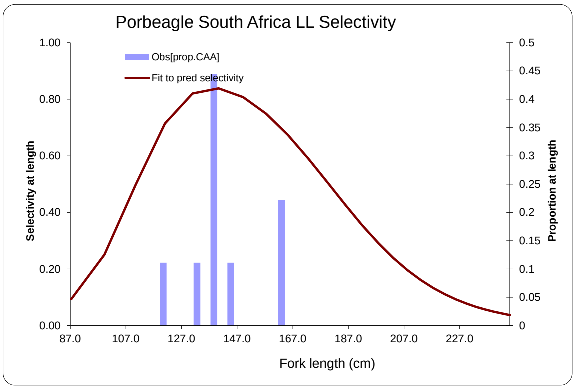

Porbeagle Portugal LL selectivity
Obs[prop.CAA]
Fit to pred selectivity
Selectivity at length
Proportion at length
0.00
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
87.0 107.0 127.0 147.0 167.0 187.0 207.0 227.0
Fork length (cm)


Porbeagle Canada LL selectivity
Obs[prop.CAA]
Fit to predicted selectivity
Selectivity at length
Proportion at length
1.00
0.80
0.60
0.40
0.20
0.00
0.12
0.1
0.08
0.06
0.04
0.02
0
87.0 107.0 127.0 147.0 167.0 187.0 207.0 227.0
Fork length (cm)


Porbeagle Canada LL selectivity
Obs[prop.CAA]
Fit to predicted selectivity
Selectivity at length
Proportion at length
1.00
0.80
0.60
0.40
0.20
0.00
0.12
0.1
0.08
0.06
0.04
0.02
0
87.0 107.0 127.0 147.0 167.0 187.0 207.0 227.0
Fork length (cm)


Porbeagle South Africa LL selectivity
Obs[prop.CAA]
Fit to pred selectivity
Selectivity at length
Proportion at length
0.00
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
87.0 107.0 127.0 147.0 167.0 187.0 207.0 227.0
Fork length (cm)


Porbeagle South Africa LL selectivity
Obs[prop.CAA]
Fit to pred selectivity
Selectivity at length
Proportion at length
0.00
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
87.0 107.0 127.0 147.0 167.0 187.0 207.0 227.0
Fork length (cm)


Porbeagle South Africa LL Selectivity
Obs[prop.CAA]
Fit to pred selectivity
Selectivity at length
Proportion at length
1.00
0.80
0.60
0.40
0.20
0.00
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
87.0 107.0 127.0 147.0 167.0 187.0 207.0 227.0
Fork length (cm)