SCRS/2012/167 Collect. Vol. Sci. Pap. ICCAT, 71(6): 2637-2688 (2015)

EXPANDED ECOLOGICAL RISK ASSESSMENT OF PELAGIC SHARKS CAUGHT IN ATLANTIC PELAGIC LONGLINE FISHERIES

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SUMMARY

*An Ecological Risk Assessment (ERA; also known as Productivity and Susceptibility Analysis, PSA) was conducted on sixteen species (15 sharks and 1 ray) or 20 stocks of pelagic elasmobranchs to assess their vulnerability to pelagic longline fisheries in the Atlantic Ocean. This was a quantitative assessment consisting of a risk analysis to evaluate the biological productivity of these stocks and a susceptibility analysis to assess their propensity to capture and mortality in pelagic longline fisheries. The risk analysis estimated productivity (maximum rate of increase, r) using a stochastic life table/Leslie matrix approach that incorporated uncertainty in age at maturity, lifespan, and both age-specific natural mortality and fecundity. Susceptibility to the fishery was calculated as the product of four components, which were also computed quantitatively: availability of the species to the fleet, encounterability of the gear given the species vertical distribution, gear selectivity, and post-capture mortality. Information from observer programs by ten ICCAT nations was used to derive fleet-specific susceptibility values. Three metrics were used to calculate vulnerability (Euclidean distance, a multiplicative index, and the arithmetic mean of the productivity and susceptibility ranks). The five stocks with the lowest productivity were the bigeye thresher (*Alopias superciliosus*), sandbar (*Carcharhinus plumbeus*), longfin mako (*Isurus paucus*), night (*Carcharhinus signatus*), and South Atlantic silky shark (*Carcharhinus falciformis*). The highest susceptibility values corresponded to shortfin mako (*Isurus oxyrinchus*), North and South Atlantic blue sharks (*Prionace glauca*), porbeagle (*Lamna nasus*), and bigeye thresher. Based on the arithmetic mean vulnerability index, which did not show preferential correlation with the productivity or susceptibility indices, the bigeye thresher, longfin and shortfin makos, porbeagle, and night sharks were the most vulnerable stocks. In contrast, North and South Atlantic scalloped hammerheads (*Sphyrna lewini*), smooth hammerhead (*Sphyrna zygaena*), and North and South Atlantic pelagic stingray (*Pteroplatytrygon violacea*) had the lowest vulnerabilities.*

RÉSUMÉ

Une évaluation des risques écologiques (ERA, connue comme une analyse de productivité et de susceptibilité, PSA) a été réalisée sur 16 espèces (15 requins et une raie) ou 20 stocks d'élasmobranches pélagiques en vue d'évaluer leur vulnérabilité face aux pêcheries palangrières pélagiques dans l'océan Atlantique. Il s'agissait d'une évaluation quantitative consistant en une analyse des risques en vue d'évaluer la productivité biologique de ces stocks et une analyse de susceptibilité en vue d'évaluer leur propension à la capture et à la mortalité dans le cadre des pêcheries palangrières pélagiques. L'analyse des risques estimait la productivité (taux maximum

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*d'augmentation, r) à l'aide d'une table de survie stochastique/approche de matrice de Leslie qui incorporait l'incertitude dans l'âge à la maturité, la durée de vie, et la mortalité naturelle et la fécondité spécifiques à l'âge. La susceptibilité à la pêcherie a été calculée comme le produit de quatre composantes, qui ont également été calculées quantitativement : disponibilité de l'espèce pour la flottille, probabilité de rencontre de l'engin compte tenu de la distribution verticale de l'espèce, sélectivité de l'engin et mortalité après la capture. On a utilité l'information provenant de programmes d'observateurs de 10 pays de l'ICCAT afin d'obtenir les valeurs de susceptibilité spécifiques aux flottilles. Trois métriques ont été employées pour calculer la vulnérabilité (distance euclidienne, un indice multiplicatif et la moyenne arithmétique des classements de la productivité et de la susceptibilité). Les cinq stocks présentant la productivité la plus basse étaient le renard à gros yeux (*Alopias superciliosus*), le requin gris (*Carcharhinus plumbeus*), la petite taupe (*Isurus paucus*), le requin de nuit (*Carcharhinus signatus*) et le requin soyeux de l'Atlantique Sud (*Carcharhinus falciformis*). Le requin-taupe bleu (*Isurus oxyrinchus*), le requin peau bleue de l'Atlantique Nord et de l'Atlantique Sud (*Prionace glauca*), le requin-taupe commun (*Lamna nasus*) et le renard à gros yeux ont présenté les valeurs de susceptibilité les plus élevées. Sur la base de la moyenne arithmétique de l'indice de vulnérabilité, qui n'a pas dégagé de corrélation préférentielle avec les indices de productivité ou de susceptibilité, le renard à gros yeux, la petite taupe, le requin-taupe bleu, le requin-taupe commun et le requin de nuit étaient les stocks les plus vulnérables. En revanche, le requin-marteau halicorne de l'Atlantique Nord et de l'Atlantique Sud (*Sphyrna lewini*), le requin-marteau commun (*Sphyrna zygaena*) ainsi que la pastenague violette de l'Atlantique Nord et de l'Atlantique Sud (*Pteroplatytrygon violacea*) présentaient les niveaux de vulnérabilité les plus faibles.*

RESUMEN

*Se llevó a cabo una evaluación del riesgo ecológico (ERA, también conocida como análisis de productividad y susceptibilidad, PSA) sobre dieciséis especies (15 tiburones y 1 raya) o 20 stocks de elasmobranquios pelágicos para evaluar su vulnerabilidad a las pesquerías de palangre pelágico en el océano Atlántico. Fue una evaluación cuantitativa que consistía en un análisis de riesgo para evaluar la productividad biológica de estos stocks y un análisis de susceptibilidad para evaluar su propensión a la captura y la mortalidad en las pesquerías de palangre pelágico. El análisis de riesgo estimó la productividad (tasa máxima de incremento, r) utilizando un tabla vital estocástica/enfoque de matriz de Leslie que incorporaba la incertidumbre en la edad de madurez, el ciclo vital y la mortalidad natural y fecundidad específicas de la edad. La susceptibilidad a la pesquería se calculó como el producto de cuatro componentes, que fueron calculados también cuantitativamente: disponibilidad de las especies para la flota, probabilidad de encuentro con el arte teniendo en cuenta la distribución vertical de la especie, la selectividad del arte y la mortalidad posterior a la captura. Se utilizó la informaicón de los programas de observadores de diez naciones de ICCAT para derivar los valores de susceptibilidad específicos de la flota. Se utilizaron tres tipos de mediciones para calcular la vulnerabilidad (distancia euclidiana, un índice multiplicativo y una media aritmética de las clasificaciones de productividad y susceptibilidad). Los cinco stocks con la productividad más baja fueron zorro ojón (*Alopias superciliosus*), tiburón trozo (*Carcharhinus plumbeus*), marrajo carite (*Isurus paucus*), tiburón de noche (*Carcharhinus signatus*) y tiburón jaquetón del Sur (*Carcharhinus falciformis*). Los valores más elevados de susceptibilidad correspondieron al marrajo dientuso (*Isurus oxyrinchus*), tintorera del Atlántico norte y sur (*Prionace glauca*), marrajo sardinero (*Lamna nasus*) y zorro ojón. Basándose en la media aritmética del índice de vulnerabilidad, que no mostraba una correlación preferencial con los índices de productividad o susceptibilidad, los stocks de zorro ojón, marrajo carite, marrajo dientuso, el marrajo sardinero y tiburón de noche eran los más vulnerables. Por el contrario, la cornuda común del Atlántico norte y sur (*Sphyrna lewini*), la cornuda cruz (*Sphyrna zygaena*) y la raya pelágica del Atlántico norte y del Atlántico sur (*Pteroplatytrygon violacea*) presentaban los niveles más bajos de vulnerabilidad.*

KEYWORDS

Natural mortality, Stochastic models, Ecological associations, Life history, Longevity, Sexual maturity, Vulnerability, Pelagic fisheries, Shark fisheries, By-catch

1. Introduction

Ecological Risk Assessment (ERA), or Productivity and Susceptibility Analysis (PSA), is a tool for data-poor situations that can be used to evaluate the relative vulnerability of a suite of stocks based on their biological productivity and susceptibility to the fishery or fisheries exploiting them. It's more immediate and practical use is to help management bodies identify the stock(s) that are more vulnerable to overfishing so that they can monitor and assess their management measures to protect the viability of these stocks. It can also be used to prioritize research efforts by focusing, for example, on species with high susceptibility but with poor biological information, or alternatively, by identifying and excluding species with low vulnerability from data-intensive assessments (Braccini *et al.* 2006).

There is a now a growing body of literature reporting studies that have applied this approach, mostly to bycatch species in situations where data are particularly scarce (Stobutzki *et al.* 2002, Milton 2001). Most of these studies have thus been qualitative or semi-quantitative PSAs (Hobday *et al.* 2007). The methodology has now been recommended for use by several fisheries management and conservation entities, including the Australian Fisheries Management Authority (Hobday *et al.* 2007, Smith *et al.* 2007), Lenfest Working Group (Rosenberg *et al.* 2007), the USA's National Oceanographic and Atmospheric Administration (NOAA) Fisheries Ecosystem Integrated Approach Team and National Standard 1 Guidelines Team, and the International Commission for the Conservation of Atlantic Tunas (ICCAT) Ecosystems Working Group (SCRS/2007/010). It has also been applied specifically to sharks by several groups: Lenfest Working Group on "Scientific solutions for managing shark populations" (SCRS/2008/140), NOAA's Vulnerability Evaluation Working Group (Patrick *et al.* 2010), and ICCAT's Shark Working Group (WG) (SCRS/2008/138, Cortés *et al.* 2010).

The previous ERA undertaken by ICCAT's Shark WG in 2008, which used a quantitative approach, has resulted in management actions. Based in part on the results of that assessment, ICCAT has prohibited retaining on board, transshipping or landing any part or whole carcasses of bigeye thresher (Rec. 09-07), oceanic whitetip (REC 10-07), and silky (REC 11-08) sharks. Also, based on that ERA, ICCAT generated a recommendation expressing that CPCs that do not report Task I data for Atlantic shortfin mako sharks, in accordance with SCRS data reporting requirements, should be prohibited from retaining this species (Rec. 10-06).

The purpose of the present study was to update and expand the 2008 ICCAT Shark WG ERA on pelagic sharks to provide a range of productivities, susceptibilities, and vulnerabilities of pelagic shark species subject to fishing by pelagic longline gear in the Atlantic Ocean. To that end the following changes and improvements with respect to the 2008 ERA were included: 1) five coastal-pelagic species were added to the suite of 11 species analyzed in 2008 (sandbar, dusky, great hammerhead, night, and tiger sharks); 2) new biological information, particularly for the southern hemisphere was incorporated; 3) in addition to the previous six CPCs, four additional CPCs provided fishery data from their observer programs (Canada, Japan, Mexico, and South Africa); 4) four species (blue, silky, scalloped hammerhead, and pelagic stingray) were split into North and South Atlantic stocks to reflect the availability of biological and fishery information for the two areas; 5) the computation of availability (overlap between the stock and fishery in the horizontal plane) was improved by using more recent and realistic information on species distribution, particularly for the southern hemisphere, and limiting the effort distribution of the fleets to the most recent 30 years available (vs. 55 in the 2008 ERA); 6) the computation of encounterability (overlap between the stock and fishing gear in the vertical plane) was also improved by incorporating additional and very recent data on time at depth obtained from archival satellite tags for several species (in the 2008 ERA encounterability was fixed at 1 in all cases); 7) several fleets were split into a surface and a deep water component for the calculation of availability and encounterability; 8) selectivity was estimated in a more straightforward way by directly comparing the overlap between the range of lengths of animals caught and the known biological range of the species; 9) post-capture mortality was based on more data on at-vessel mortality and fate of the animal and also included estimated post-release mortality; and 10) additional indices of vulnerability were explored. In all, we feel that the present analysis is an improvement with respect to the 2008 ERA.

2. Materials and Methods

We initially attempted to include 19 species of pelagic elasmobranchs in the analysis: blue (*Prionace glauca*; BSH), shortfin mako (*Isurus oxyrinchus*; SMA), longfin mako (*Isurus paucus*; LMA), bigeye thresher (*Alopias superciliosus*; BTH), common thresher (*Alopias vulpinus*; ALV), oceanic whitetip (*Carcharhinus longimanus*; OCS), silky (*C. falciformis*; FAL), porbeagle (*Lamna nasus*; POR), scalloped hammerhead (*Sphyrna lewini*; SPL), smooth hammerhead (*Sphyrna zygaena*; SPZ), great hammerhead (*Sphyrna mokarran*; SPK), sandbar (*Carcharhinus plumbeus*; CCP), dusky (*Carcharhinus obscurus*; DUS), night (*Carcharhinus signatus*; CCS), tiger

(*Galeocerdo cuvier*; TIG), crocodile (*Pseudocarcharias kamoharai*; PSK), and white (*Carcharodon carcharias*; WSH) sharks, and the pelagic stingray (*Pteroplatytrygon violacea*; PLS) and manta ray (*Manta birostris*; RMB). However, we could not conduct a quantitative risk analysis on the crocodile shark and manta ray owing to insufficient biological information and there was virtually no fishery information on the white shark. Although these species could be evaluated at a lower ERA level, the results would not be directly comparable to those obtained with the quantitative approach and we thus removed them from analysis. The analysis thus consisted of 16 species: 15 sharks and 1 ray. Five of these species were not included in the 2008 ERA (sandbar, dusky, great hammerhead, night, and tiger sharks). Furthermore, four species were split into North and South Atlantic stocks to reflect the availability of biological and fishery information for the two areas. Although some species may consist of more than one North and one South Atlantic stock (e.g., ICCAT's Shark WG has recognized four stocks for the porbeagle: northeastern, northwestern, southeastern, and southwestern) or a single stock across the Atlantic, as mentioned above the division into North and South Atlantic stocks was merely based on data availability rather than the existence of particular stocks.

We applied a quantitative risk analysis to estimate productivity because the biological information was sufficient and this framework allows incorporation of uncertainty in our knowledge of biological traits. Susceptibility was also estimated quantitatively using Walker's (2004) approach, where it is expressed as the product of four conditional probabilities (availability, encounterability, selectivity and post-capture mortality). We then combined both aspects (productivity and susceptibility) using several indices to calculate vulnerability and identify those species more, or less, at risk.

2.1 Productivity

Productivity was expressed through the maximum theoretical or intrinsic rate of population increase (r), estimated through a dual life table/Leslie matrix approach (Caswell 2001). These models were age-structured, based on a birth-pulse, prebreeding census (i.e., in the Leslie matrix each element in the first row is expressed as $f_x = m_x p_0$, where p_0 is the probability of survival of age-0 individuals and m_x is the number of female offspring produced annually by a female of age x), and a yearly time step applied to females only.

Life history variables were obtained from a dedicated shark life history database maintained by the first author (EC) and expanded with information collated by other co-authors (references used are available upon request). Biological inputs were mostly available for the North Atlantic (bigeye thresher, common thresher, dusky, sandbar, tiger, shortfin mako, longfin mako, porbeagle, great hammerhead, and smooth hammerhead) and in a few cases, for the South Atlantic Ocean (oceanic whitetip and night shark). In only four cases (blue, scalloped hammerhead and silky sharks, and pelagic stingray) they were available for both hemispheres and analyses were conducted separately for each area. In all other cases, even if the inputs corresponded to a particular hemisphere, the analysis represents the whole stock (North and South combined) (**Table 1**).

Uncertainty in life history variables (age at maturity, maximum age, age-specific fecundity and age-specific survival) was incorporated through Monte Carlo simulation by randomly drawing values from assumed statistical distributions for each of these variables. Typically, age at maturity (α) was represented by a triangular distribution with the likeliest value set equal to that reported in the literature and upper and lower bounds set to +-1 or more years. Maximum age (ω) was represented by a linearly decreasing distribution scaled to 1, wherein the highest empirical value of lifespan reported in the literature was given the likeliest (maximum) value, and the minimum value was set by arbitrarily adding 30% to the likeliest value (Cortés 2002). Fecundity at age was generally represented by a normal distribution, with mean and standard deviation obtained from the literature. A 1:1 female to male ratio was used in all cases and, due to the lack of maturity ogives in most cases, the proportion of mature females at age was assumed to be zero for ages 0 to α-1, 0.5 for α, and 1 for ages α +1. A one-year time lapse was allowed to account for the fact that females have to mate and gestate after becoming mature and before contributing offspring to the population. Fecundity at age was further divided by the length of the reproductive cycle (i.e., biannual, annual, biennial or triennial). The probability of annual survival at age was represented by a linearly increasing distribution, in which the lower and upper bounds were set to the minimum and maximum values estimated from seven indirect life history methods (see Cortés 2002; Cortés *et al.* 2012; Simpfendorfer 2004 and references therein for details). Giving the highest probability to the highest estimates of survival at age was intended to simulate a compensatory density-dependent response, thus the productivity estimates obtained with this approach should be regarded as maximum values. The values of r reported and used in the ERA are the median of 1,000 iterations. Also reported are approximate 80% confidence intervals (expressed as the 10th and 90th percentiles) and generation time (the time required for the population to increase by a factor of R_0, the net reproductive rate).

2.2 Susceptibility

Susceptibility, in this case a measure of the impact of pelagic longline fisheries, can be expressed as the product of four conditional probabilities: availability, encounterability, selectivity, and post-capture mortality (Walker 2004). 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 susceptibility analysis was conducted separately for ten fleets for which information from observer programs was made available for the analysis. In addition to information from Brazil, Namibia, Portugal, Uruguay, USA, and Venezuela, Canada, Japan, Mexico, and South Africa also provided data for the current ERA. The analysis was also conducted for these ten fleets combined.

Availability was estimated as the proportion of the spatial distribution of the fleet that overlaps that of the stock. Spatial effort distribution of pelagic longlines, expressed as total number of hooks reported by 5º x 5º or 1º x 1º resolution grids, was obtained for a number of ICCAT flags for the period 1980-2009 from the Task II catch and effort database. Effort distribution was further disaggregated into a "shallow" and a "deep" water component for those fleets included in the analysis that fished at different depths, which included Brazil, Uruguay, and South Africa. All the other fleets, except Japan (deep), had only a shallow water component. Longline effort data for Canada were only available for 2008 and 2009. Species distributions were obtained from the IUCN (Global Marine Species Assessment distribution maps). These maps were then fine-tuned, especially for the southern hemisphere, by incorporating observer records from the Uruguayan fleet. A combined availability for each fleet was then calculated as the sum of the surface and deep water components weighted by the effort exerted in each zone.

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 first assumed that the surface water component of all fleets had hooks that fished from about 15 to 100 m mostly at night, and the deep water component, from 100 to 300 m during the day (SCRS/2010/031). We then collated (often unpublished) information on depth preference of sharks tagged with archival satellite tags, summarized as histograms of time at depth during the day and night. The final step was to calculate the overlap between the species distribution and that of the gear in the shallow (at night, 15-100 m) and deep (during the day, 100-300 m) zones. As for availability, a combined encounterability for each fleet was then calculated as the sum of the surface and deep water components weighted by the effort exerted in each zone.

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. In contrast to the 2008 ERA, which estimated selectivity by comparing the size range of animals observed caught in the fishery with a length frequency distribution obtained by transforming a theoretical stable age distribution predicted in the productivity analysis through the von Bertalanffy growth function, we directly compared the size range of animals reported caught in the observer programs to the known range of lengths for the species (the shark life history database mentioned in section 2.1 was used as an aid). The value of selectivity was computed as the overlap between the two ranges after eliminating any length bins of observed animals with a sample size less than 0.1% of the total sample for the species, fleet, and sex considered. This approach was generally successful at removing lengths of animals that seemed unusually small or large compared to the published values of the species in question in nature. Selectivity for all fleets combined was calculated as the sum of selectivities for the individual fleets weighted by the total effort exerted by each fleet.

Post-capture mortality was estimated based on information on status (at-vessel, prior to boarding) and 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 at-vessel mortality (the proportion of animals found dead upon gear retrieval; 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 using at-vessel mortality as a proxy. 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 sum of PCM values for the individual fleets weighted by the total effort exerted by each fleet.

An arbitrarily small value (0.1%) was assigned to selectivity and post-capture mortality for any fleets that did not report a given species to be caught (i.e., where there were no length measurements or information on at-vessel mortality or fate of animals of that species provided). This was done in order to avoid susceptibility to become zero while greatly reducing its magnitude. A small value also recognizes the fact that animals of a particular species might still be caught by the fleet in question but not reported because 1) of identification issues (e.g., in the case of bigeye threshers all animals may be reported as "threshers"), 2) they are caught in very small quantities and not reported in observer reports, and 3) the observer program has not encountered them because of low coverage but the fleet may still catch them occasionally. In cases where a value of selectivity was available but a value of post-capture mortality was not for a given fleet, or vice versa, the mean of values for the other fleets was used as a proxy.

Susceptibility (s) was calculated as the product of the four components: availability, encounterability, selectivity, and post-capture mortality, which ranges from 0 to 1.

2.3 Vulnerability

Vulnerability (v) can be interpreted as a measure of the extent to which the impact of a fishery on a species will exceed its biological ability to renew itself (Stobutzki *et al.*, 2002). It considers both productivity and susceptibility to produce a single risk score. In level 2 (semi-quantitative) PSAs, it is typically calculated as the Euclidean distance from the origin of a PSA plot. We calculated v from the focal point (r=0, s=1), or $v=\sqrt{\left(p-0\right)^2+(s-1)^2}$, in our productivity (p) and susceptibility (s) scatter plot. In semi-quantitative approaches the X and Y axes have the same range and interpretation, making computation of the Euclidean distance more straightforward, but in our quantitative approach, productivity (X axis) can range in theory from 0 to a value >1. Since the behavior of this index has not been fully investigated when using a fully quantitative approach, we opted to include two additional indices. We used 1) a multiplicative index (Stobutzki *et al.*, 2002) defined as v=P(1-S), where P is productivity and S, susceptibility, and 2) the arithmetic mean of the productivity and susceptibility scores (i.e., the ranks, not the raw values). Thus, we computed three indices of vulnerability: based on Euclidean distance (v_1), multiplicative (v_2), and arithmetic mean (v_3). All scores were ranked from highest (rank=1) to lowest (rank=20) risk. We summarized results by using a modified Traffic Light procedure (Caddy 2002; Guijarro *et al.* 2012) with four colors: red for risk scores 1-5; yellow, for 6-10; blue, for 11-15; and green, for 16-20.

3. Results

3.1 Productivity

Productivity ranged from 0.009 yr^{-1} for the bigeye thresher to 0.314 yr^{-1} for the South Atlantic blue shark and generation time, from 6 yr for the North Atlantic pelagic stingray to 30 yr for the dusky shark (**Table 2**). Common thresher, oceanic whitetip, tiger, both blue shark stocks, smooth hammerhead, and North Atlantic pelagic stingray and scalloped hammerhead had r values ≥0.10, whereas bigeye thresher, sandbar, longfin mako, night, South Atlantic silky, and dusky sharks had r values < 0.05, and the rest of species, r values between 0.05 and 0.10. The bigeye thresher, the more coastal-pelagic sandbar shark, and the longfin mako (whose biological inputs, except reproduction, were "borrowed" from its congener the shortfin mako) were the least productive species (r < 0.03), whereas the two blue shark stocks, the North Atlantic pelagic stingray, and the smooth hammerhead were the most productive (r > 0.20).

3.2 Susceptibility

The spatial distribution of the sixteen species included in the analysis is shown in **Figures 1-16** and the effort distribution of the ten fleets included is shown in **Figures 17-26**. The range of most species in the southern hemisphere has been extended based on information collected by the Uruguayan pelagic longline observer program. Several species are very widely distributed across the Atlantic Ocean (bigeye thresher, common thresher, silky, oceanic whitetip, smooth hammerhead, shortfin mako, longfin mako, blue, and pelagic ray), whereas other species have a much more coastal or coastal-pelagic distribution (dusky, sandbar, night, tiger, great hammerhead, and scalloped hammerhead) and the porbeagle has a sub-tropical distribution, associated with temperate and cold waters. Although pelagic species tended to have higher availability (mean=0.89, n=12) to pelagic longline fleets than coastal-pelagic species (mean=0.84, n=7), the differences were not significant (*t* test, P=0.16; **Table 3**). The porbeagle had a considerably lower availability (0.56).

Figure 27 shows the four susceptibility attributes by fleet and stock. More eccentric values reflect higher susceptibility. Japan has high availability values because of both the geographical coverage and effort magnitude of its fleet, but in contrast, encounterability tends to be very low because the fleet fishes deep and the interaction of the gear with most species is reduced. Selectivity tends to be high for most species and more homogeneous across fleets. Post-capture mortality also tends to be high, particularly in the case of Uruguay and especially, Venezuela, where all sharks caught are retained. As explained in section 2.2., fleets were assigned arbitrarily low values of selectivity and post-capture mortality when a given species did not appear in the data provided. The value of selectivity for pelagic stingray assigned to the Portuguese and USA fleets was that of Uruguay, which reported observed lengths for this species. The values of encounterability for the great and smooth hammerheads were those from scalloped hammerhead and the value for the pelagic stingray was from the smooth stingray (*Dasyatis brevicaudata*) because no depth use data from electronic tags were available for the two hammerhead species or the pelagic stingray.

Susceptibility for combined fleets varied from a very low 0.0002 for South Atlantic pelagic stingray to 0.22 for shortfin mako (**Table 4**). Based on this analysis restricted to ten fleets, the greatest risk from pelagic longlines is to shortfin mako, followed by North Atlantic blue shark, porbeagle, bigeye thresher, and South Atlantic blue shark. Species with the lowest risk rankings include the pelagic stingray, scalloped hammerhead, and dusky and sandbar sharks, likely due to reduced interactions with the gear in the case of the coastal-pelagic hammerhead and the dusky and sandbar sharks. **Table 5** shows susceptibility disaggregated by fleet for each stock. Susceptibility values for multiple fleets and stocks are very low owing to the multiplicative nature of the index.

3.3 Vulnerability

Vulnerability calculated as the Euclidean distance (v_1) to the point of highest risk (upper right hand corner of the PSA plot) assigned the highest risk (rank=1) to the shortfin mako, followed by porbeagle, bigeye thresher, oceanic whitetip, and longfin mako (**Table 6**; **Figure 28**). Blue, silky, common thresher, tiger, smooth hammerhead, night, great hammerhead, and sandbar sharks had vulnerabilities ranging from 6 to 15, and the lowest vulnerabilities corresponded to pelagic stingrays, scalloped hammerheads, and dusky shark (ranks 16 to 20). Vulnerability expressed as v_1 was very highly and significantly correlated to susceptibility (Spearman rank correlation, r=0.99, P<0.0001) but not to productivity (Spearman rank correlation, r=0.16, P=0.53), thus explaining the similarity of ranks between v_1 and susceptibility (compare Tables 4 and 6). Vulnerability calculated as a multiplicative index (v_2) assigned the highest risk to bigeye thresher, followed by sandbar, longfin mako, night shark, and South Atlantic silky shark. Intermediate vulnerabilities ranging from rank 6 to 15 corresponded to dusky, porbeagle, shortfin mako, South Atlantic pelagic stingray, great hammerhead, North Atlantic silky shark, North Atlantic scalloped hammerhead, oceanic whitetip, common thresher, and South Atlantic scalloped hammerhead, whereas the lowest ranks (16 to 20) were assigned to tiger, smooth hammerhead, North Atlantic pelagic stingray, and North and South Atlantic blue sharks, respectively. Vulnerability expressed as v_2 was very highly and significantly correlated to productivity (Spearman rank correlation, r=0.99, P<0.0001) but not to susceptibility (Spearman rank correlation, r=0.17, P=0.48), thus explaining the similarity of ranks between v_2 and productivity (compare Tables 4 and 6). Finally, vulnerability calculated as the arithmetic mean of the productivity and susceptibility ranks (v_3) assigned the highest risk to bigeye thresher, followed by longfin and shortfin makos (tied), porbeagle, and night shark. South Atlantic silky, sandbar, oceanic whitetip, North Atlantic silky, blue sharks, common thresher, dusky, great hammerhead, and tiger had vulnerabilities ranging from 6 to 15, and the lowest vulnerabilities corresponded to scalloped hammerheads, smooth hammerhead, and pelagic stingrays (ranks 16 to 20). Vulnerability expressed as v_3 was significantly correlated both to susceptibility (Spearman rank correlation, r=0.69, P=0.001) and productivity (Spearman rank correlation, r=0.76, P=0.0002).

All three vulnerability indices classified bigeye thresher and longfin mako as highest risk according to the Traffic Light approach, and two of the indices assigned the highest risk to shortfin mako, porbeagle, and night shark (red in Table 6). Only the North Atlantic pelagic stingray received the lowest risk from the three indices and two of the indices assigned the lowest risk to the two scalloped hammerhead stocks, smooth hammerhead, and South Atlantic pelagic stingray (green in **Table 6**).

4. Discussion

The present analysis helps to categorize the relative risk posed by pelagic longline fleets to pelagic and coastal-pelagic sharks in the Atlantic Ocean. While the productivity estimates obtained have a more direct value in the sense that they can be used for example to inform Bayesian priors used in stock assessment models, the main value of the susceptibilities is for comparative purposes. Indeed, while this was a quantitative analysis, susceptibility does not inform us about the actual level of fishing mortality (F), but rather the relative propensity of each stock to capture by the different fleets. In that respect, it is important to note that a species with a higher susceptibility to a particular fleet should not be necessarily interpreted as indicative of a more harmful effect by that fleet compared to other fleets. It may simply mean, for example, that the selectivity (animals measured) and post-capture mortality information collected by the corresponding observer program of that CPC is better (collects more detailed records) than that collected by other observer programs from CPCs that also reported data and of course CPCs that do not have observer programs or did not report any data for this analysis. It is not surprising that Japan tended to influence the overall susceptibility values for all fleets combined given the size of its fleet and the fact that selectivity and post-capture mortality for fleets combined was computed as an average of the individual fleets weighted by the effort exerted by each fleet. We would expect other large fleets, such as those of Spain and Chinese Taipei, to have a similar effect on susceptibility. It should also be pointed out that because the susceptibility aspect we used was calculated as the product of four attributes, susceptibility values obtained here are much lower than those that would be obtained in semi-quantitative analyses that use additive measures for computation of susceptibility.

The current analysis differs from the ERA conducted in 2008 (Cortés *et al.* 2010) in several fundamental ways. Availability was now calculated as the spatial overlap between the effort distribution of the fleet in 1980-2009 (vs. 1950-2005 in the 2008 ERA) and that of the stock. Geographic distribution of most stocks also changed with respect to that used in the 2008 ERA with the incorporation of new records obtained by the Uruguayan observer program. Despite this improvement, we were still not able to incorporate in time for this report all information on species occurrence from additional observer programs and other sources that must still be validated and which will likely alter the known range of several of the species analyzed. Similarly, the effort distribution maps obtained from the ICCAT Task II catch and effort database for some of the nations included in the analysis will require closer scrutiny.

Encounterability was fixed at 1 in all cases in the 2008 ERA, whereas in the present analysis it varied from 0.30 to 0.79 for shallow water (15-100 m) at night and from 0.03 to 0.70 for deep water (100-300 m) during the day. These new values were obtained by incorporating to the extent possible the growing amount of information that is becoming available from sharks tagged with electronic tags. In some cases depth use information came from individuals that remained in close proximity to the continental shelf and could therefore not necessarily be representative of the species behavior across its distribution range. Selectivity was now calculated in a more intuitive way, as the overlap between the length range of animals caught and their known length range in nature. In addition to including data collected over a longer time period, post-capture mortality now also includes an estimate of post-release mortality that was not included in the 2008 ERA. These changes explain why the susceptibility values obtained in the present analysis are much lower than those obtained in the 2008 ERA.

As in the 2008 ERA, our analysis also highlights the need for better basic biological information, notably for species like the longfin mako, crocodile shark, and manta ray, but also for several of the other species included in the analysis, for which the life history variables used to construct life tables/Leslie matrices came from one hemisphere only. It also became apparent that little is still known of the vertical distribution and habitat preferences of pelagic sharks, although as mentioned earlier an increasing amount of archival satellite tags is providing very valuable information. The data gathered by the different observer programs around the Atlantic Ocean is becoming more standardized, but there is still a need for reporting all the information necessary to inform ERAs, such as the list of species included, length measurements, and status and fate of animals caught. We also hope that additional CPCs will provide information from their respective observer program to update and expand future ERAs.

Vulnerability calculated as the arithmetic mean of the productivity and susceptibility ranks (v_3) had similar correlations with productivity and susceptibility, indicating that neither of these two aspects affected it disproportionately, in contrast to vulnerability metrics v_1 and v_2. Based on this metric, the most vulnerable species to the combined effect of the ten CPC pelagic longline fleets included in the analysis were the bigeye thresher, longfin and shortfin makos, porbeagle, and night sharks. We also found that the five-least productive species were the bigeye thresher, sandbar, longfin mako, night, and South Atlantic silky shark and that the greatest risk from pelagic longlines in terms of susceptibility was to shortfin mako, blue sharks, porbeagle, and bigeye thresher. Leaving aside species with more coastal-pelagic habits, such as the sandbar and night shark, of the remaining six species mentioned above, ICCAT has conducted stock assessments for three (blue, shortfin mako, porbeagle) and two have received protection (bigeye thresher and silky shark) based on the 2008 ERA, reflecting their importance to Atlantic pelagic longline fisheries.

Ecological risk assessments still provide only a snapshot of a complex combination of dynamic processes that lead to the death of an animal. By necessity, we attempted to capture an average value for each of the four factors considered in our susceptibility parameter, but as we described above the present analysis included some substantial improvements compared to the 2008 ERA. While ERAs should be updated periodically as new and more accurate biological and fishery information becomes available, the approach will inevitably provide only a snapshot of a combination of time- and space-dependent factors that determine the vulnerability of a stock to the fishing gear. Future analyses can attempt to incorporate time-dependent (e.g., quinquennial or seasonal) measures of effort distribution, selectivity, and post-capture mortality to calculate susceptibility. In that respect, ICCAT management measures based on recommendations that arose from the 2008 ERA were only implemented starting in 2010 and thus the effect of those measures would not have been reflected in the current analysis. Overall, this approach can still be helpful for identifying (new) species at risk based on their intrinsic productivity and susceptibility to capture by fishing gears.

Acknowledgments

We thank the IUCN SSG for providing GMSA species distribution maps. We also thank B. Wetherbee, E. Hoffmayer, J. Carlson, S. Gulak, G. Skomal, F. Carvalho and L. Howey-Jordan for making available unpublished archival satellite tag data, J. Carvalho for life history information on bigeye threshers, and X. Zhang for discussions on vulnerability indices. P. Miller acknowledges the support received from the Society for Conservation GIS and the ESRI Conservation Program and R. Coelho was funded by a grant from FCT, the Portuguese Science and Technology Foundation.

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Table 1. Biological input parameters used in the calculation of productivity for 20 stocks of pelagic sharks.

Species/Stock	*Mean litter size*	*Reproductive Periodicity (yr)*	*Female K (yr^{-1})*	*L_∞ (cm FL)*	*t_0*	*Median age at maturity (yr)*	*Female longevity (yr)*	*Mean S_0 (yr^{-1})*	*S_{1+} range (yr^{-1})*
Alopias superciliosus (BTH)	2	1	0.06	293	102*	13.5	22	0.88	0.83-0.92
Alopias vulpinus (ALV)	4	1	0.11	264	81*	6	24	0.83	0.76-0.93
Carcharhinus falciformis (FAL) NA	11	2	0.091	315	-3.18	9.5	22	0.80	0.77-0.91
Carcharhinus falciformis (FAL) SA	9.6	2	0.086	303	-4.71	12.5	20	0.86	0.80-0.91
Carcharhinus longimanus (OCS)	5.4	1	0.099	285	-3.39	6	17	0.82	0.78-0.90
Carcharhinus obscurus (DUS)	7.1	3	0.039	421	-7.04	20	40	0.90	0.80-0.98
Carcharhinus plumbeus (CCP)	8.4	2.5	0.12	181	-2.33	15.5	24	0.82	0.71-0.94
Carcharhinus signatus (CCS)	11	2	0.114	265	-2.69	10	17	0.80	0.73-0.89
Galeocerdo cuvier (TIG)	55	2	0.124	347	62*	10	29	0.80	0.78-0.93
Isurus oxyrinchus (SMA)	12.5	3	0.054	393	70*	18	32	0.87	0.78-0.97
Isurus paucus (LMA) **	4	2	0.054	393	70*	18	32	0.87	0.78-097
Lamna nasus (POR)	4	1	0.061	289	-5.9	14	25	0.88	0.81-0.93
Prionace glauca (BSH) NA	37	1	0.15	375	-0.87	6	16	0.71	0.72-091
Prionace glauca (BSH) SA	30	1	0.157	352	-1.01	5	12	0.72	0.72-0.91
Pteroplatytrigon violacea (PLS) NA	6	0.5	0.20	116	17*	3	12	0.64	0.58-0.88
Pteroplatytrigon violacea (PLS) SA***	4	1	0.20	116	17*	3	12	0.64	0.58-0.88
Sphyrna lewini (SPL) NA	24	2	0.09	303	-2.22	15	31	0.84	0.76-0.94
Sphyrna lewini (SPL) SA	18.5	1	0.05	300	51*	15	32	0.83	0.72-0.94
Sphyrna mokarran (SPK)	15	2	0.13	287	-2.51	20	42	0.89	0.81-0.98
Sphyrna zygaena (SPZ)	33.5	1	0.07	285	-7.3	9	18	0.85	0.79-0.90

NA is North Atlantic, and SA, South Atlantic

*L_0 (cm FL)

** All parameters, except for litter size and reproductive frequency, as for shortfin mako

*** All parameters, except for litter size and reproductive frequency, as for pelagic stingray in the North Atlantic

Table 2. Productivity (r, intrinsic rate of population increase, yr^{-1}) and generation time for 20 stocks of pelagic sharks listed from highest to lowest values of productivity.

Stock	*Productivity (r)*	*LCL*	*UCL*	*Generation time*
BSH SA	0.314	0.279	0.345	8.2
BSH NA	0.299	0.264	0.327	9.8
PLS NA	0.230	0.181	0.279	6.2
SPZ	0.225	0.213	0.237	13.4
TIG	0.190	0.180	0.200	15.6
OCS	0.121	0.104	0.137	10.4
SPL SA	0.121	0.110	0.132	21.6
ALV	0.121	0.099	0.143	11.0
SPL NA	0.096	0.093	0.107	21.6
FAL NA	0.078	0.065	0.090	14.4
SPK	0.070	0.069	0.071	27.1
SMA	0.058	0.049	0.068	25.0
POR	0.052	0.044	0.059	20.3
PLS SA	0.051	0.004	0.096	6.6
DUS	0.043	0.035	0.050	29.6
FAL SA	0.042	0.029	0.054	16.5
CCS	0.041	0.028	0.053	14.9
LMA	0.029	0.020	0.038	25.2
CCP	0.010	-0.005	0.024	21.8
BTH	0.009	-0.001	0.018	17.8

NA is North Atlantic, and SA, South Atlantic

Values are medians.

LCL and UCL are the lower and upper 80% percentiles.

Generation time is defined as the time required for the population to increase by R_0 (the net reproductive rate)

Table 3. Availability (overlap between species geographical distribution and that of the fleet) values for 20 stocks of pelagic sharks by fleet component (surface, deep, combined) for the ten fleets included in the analysis combined.

Stock	*Shallow*	*Deep*	*Combined*
BTH	0.89	0.93	0.92
ALV	0.72	0.84	0.82
FAL NA	0.96	0.87	0.89
FAL SA	0.94	0.99	0.98
OCS	0.85	0.88	0.88
DUS	0.87	0.87	0.87
CCP	0.69	0.76	0.73
CCS	0.88	0.84	0.86
TIG	0.88	0.82	0.85
SMA	0.79	0.87	0.86
LMA	0.87	0.90	0.90
POR	0.35	0.60	0.56
BSH NA	0.72	0.83	0.81
BSH SA	0.83	0.95	0.94
PLS NA	0.79	0.87	0.85
PLS SA	0.95	0.98	0.98
SPL NA	0.86	0.75	0.80
SPL SA	0.91	0.97	0.95
SPK	0.83	0.83	0.83
SPZ	0.74	0.82	0.80

Table 4. Susceptibility values (listed from highest to lowest) and ranks for all fleets included in the analysis combined for 20 stocks of pelagic sharks. Productivity ranks are also listed for comparison. A lower rank indicates higher risk.

Stock	*Susceptibility*	*Susceptibility rank*	*Productivity rank*
SMA	0.220	1	9
BSH NA	0.166	2	19
POR	0.162	3	8
BTH	0.142	4	1
BSH SA	0.141	5	20
OCS	0.135	6	13
LMA	0.116	7	3
FAL NA	0.081	8	11
ALV	0.072	9	13
TIG	0.065	10	16
SPZ	0.054	11	17
CCS	0.043	12	4
FAL SA	0.042	13	5
SPK	0.021	14	10
SPL NA	0.014	15	12
CCP	0.012	16	2
DUS	0.010	17	6
PLS NA	0.002	18	18
SPL SA	0.002	19	13
PLS SA	0.0002	20	7

Table 5. Susceptibility values by fleet for 20 stocks of pelagic sharks.

Stock	*Brazil*	*Canada*	*Portugal*	*Japan*	*Mexico*	*Namibia*	*South Africa*	*USA*	*Uruguay*	*Venezuela*
BTH	2.36E-07	1.23E-08	0.10	0.12	2.77E-08	5.84E-08	3.07E-08	0.24	0.04	0.24
ALV	0.06	1.16E-08	4.53E-08	0.04	0.01	2.44E-08	0.01	0.09	0.02	0.09
FAL NA	6.00E-08	2.14E-08	0.05	0.02	3.86E-08			0.30		0.20
FAL SA	2.36E-07		0.06	0.02		5.93E-08	0.01	0.08	0.03	0.15
OCS	0.09	1.85E-08	0.08	0.07	2.78E-08	3.08E-08	4.97E-09	0.17	0.02	0.23
DUS	1.24E-07	1.35E-08	1.01E-07	1.12E-07	3.37E-08	6.06E-08	3.73E-08	0.23	0.01	1.95E-07
CCP	1. 50E-07	1.80E-08	1.08E-07	7.20E-08	8.10E-08	9.00E-09	1.00E-06	0.28	0.02	1.89E-07
CCS	0.04	2.59E-08	6.47E-08	1.12E-07	1.29E-08	5.18E-08	2.80E-09	0.25	0.04	0.18
TIG	1.33E-07	1.19E-08	0.05	0.01	0.03	1.19E-08	3.00E-10	0.02	0.01	0.19
SMA	0.08	0.01	0.06	0.18	0.01	0.03	0.02	0.18	0.04	0.10
LMA	1.67E-07	1.72E-08	0.05	0.11	1.94E-08	4.53E-08	3.41E-08	0.19	0.01	0.11
POR	4.22E-08	0.01	0.01	0.23	1.00E-06	1.09E-08	0.01	0.02	0.03	8.73E-09
BSH NA	0.04	3.45E-03	0.04	0.13	0.01			0.07		0.10
BSH SA	0.16		0.04	0.14		0.05	0.04	0.03	0.06	0.07
PLS NA	1.10E-07	3.48E-08	0.02	6.09E-07	3.48E-08			0.06		1.93E-07
PLS SA	4.59E-07		0.01	6.44E-07		1.19E-07	7.90E-08	0.03	0.06	1.58E-07
SPL NA	1.32E-08	3.54E-08	0.04	1.24E-07	7.96E-08			0.31		0.12
SPL SA	2.95E-07		0.09	4.00E-08		6.97E-08	1.12E-03	0.09	0.05	0.14
SPK	1.06E-07	0	0.02	3.85E-08	5.60E-08	3.11E-08	5.87E-10	0.07	2.00E-08	0.06
SPZ	1.40E-07	1.66E-08	0.06	0.02	4.15E-09	2.90E-08	2.25E-08	0.08	0.04	0.07

Table 6. Vulnerability ranks for 20 stocks of pelagic sharks calculated with three methods: Euclidean distance (v_1), multiplicative (v_2), and arithmetic mean (v_3). A lower rank indicates higher risk. Stocks listed in decreasing risk order according to the sum of the three indices. Red highlight indicates risks scores 1-5; yellow, 6-10; blue, 11-15; and green, 16-20.

Stock	v_1	v_2	v_3
BTH	3	1	1
LMA	5	3	2
SMA	1	8	2
POR	2	7	4
CCS	11	4	5
FAL SA	12	5	6
CCP	15	2	6
OCS	4	13	8
FAL NA	8	11	8
ALV	9	14	11
BSH NA	6	19	10
DUS	17	6	12
SPK	14	10	13
BSH SA	7	20	14
TIG	10	16	15
PLS SA	18	9	16
SPL NA	16	12	16
SPZ	13	17	18
SPL SA	19	15	19
PLS NA	20	18	20

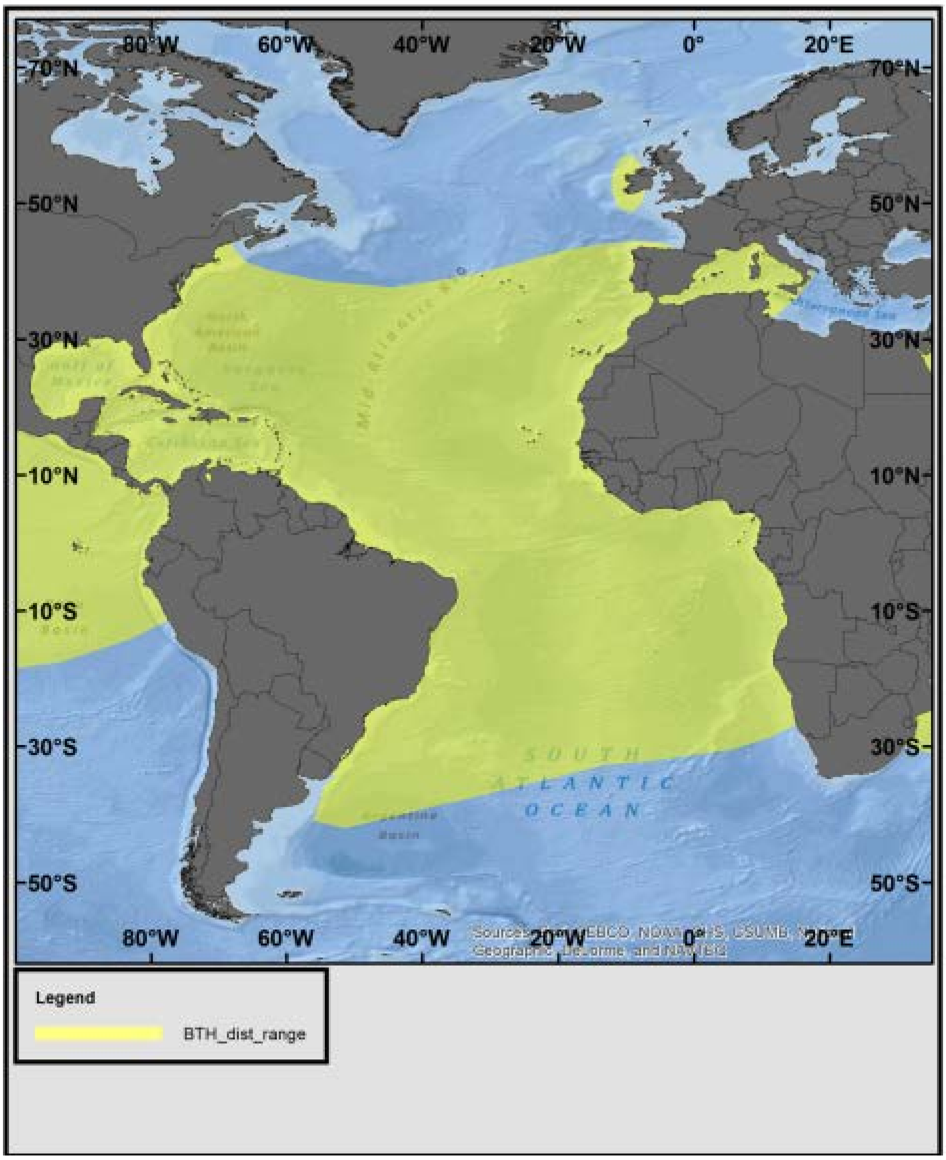


Figure 1. Species distribution of *Alopias superciliosus*.

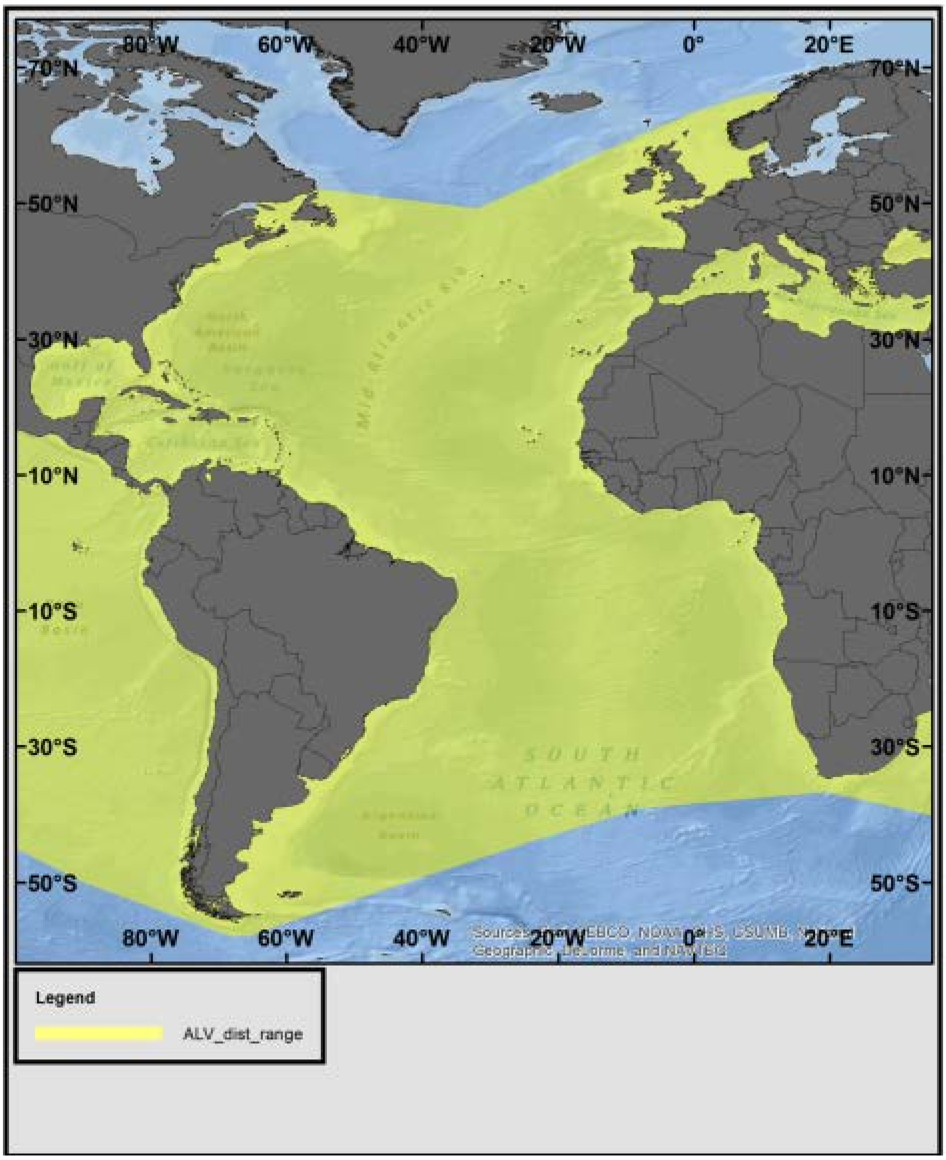


Figure 2. Species distribution of *Alopias vulpinus.*

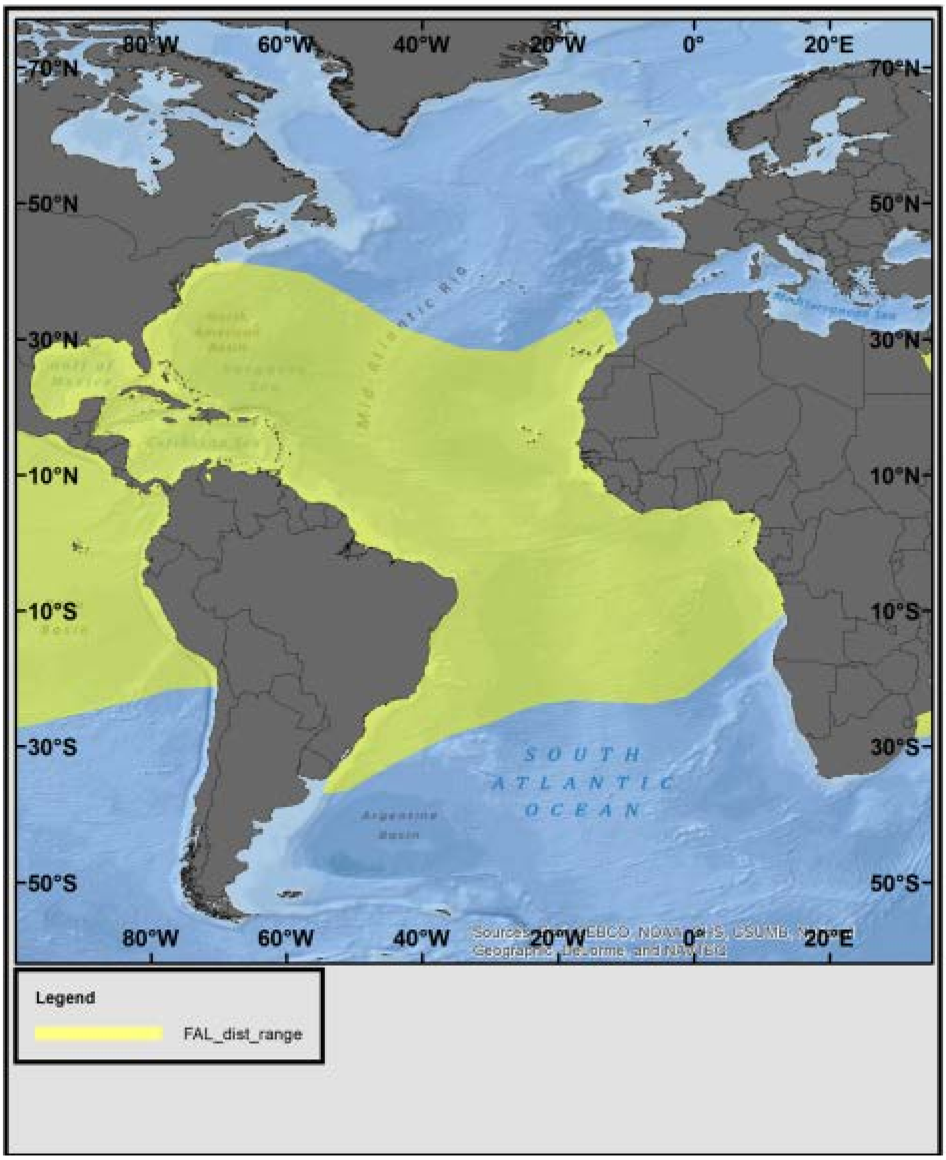


Figure 3. Species distribution of *Carcharhinus falciformis*.

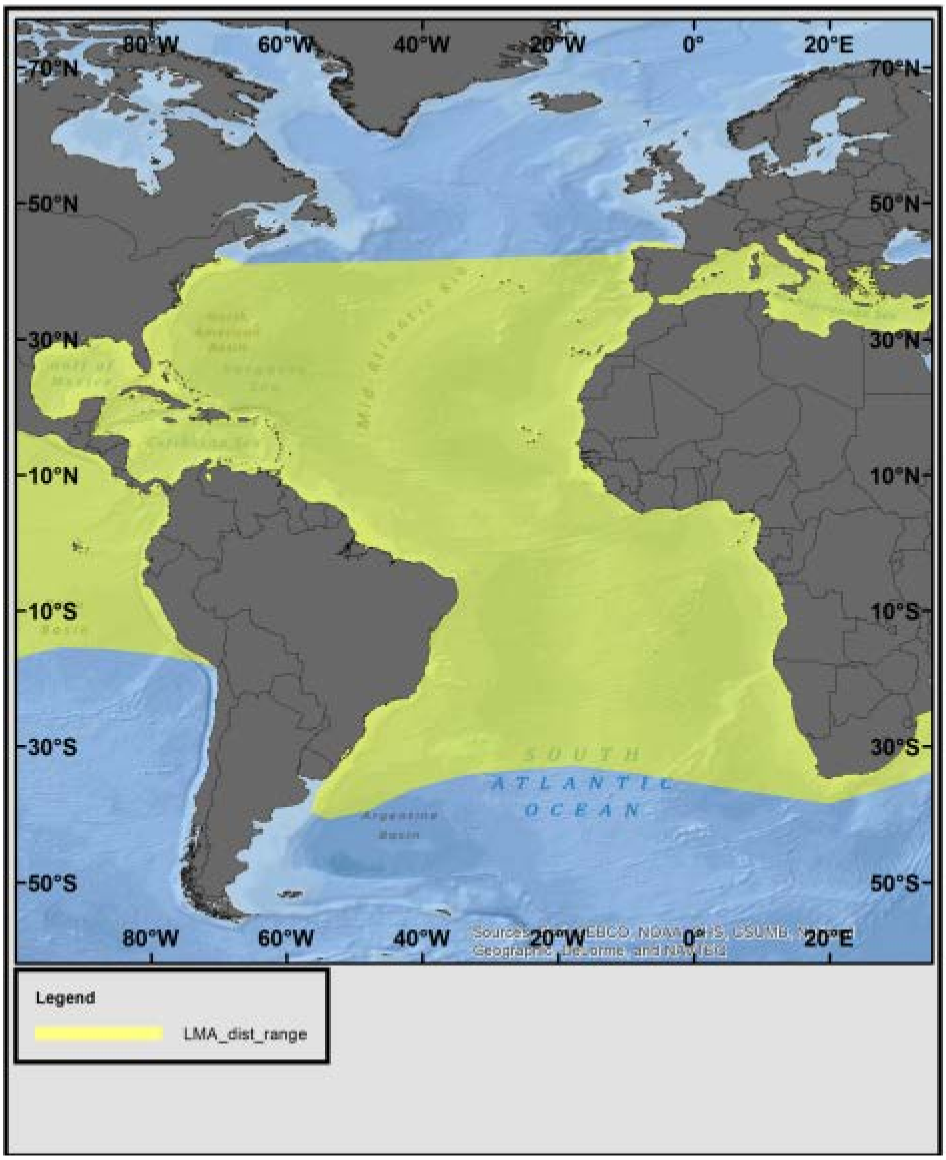


Figure 4. Species distribution of *Carcharhinus longimanus.*

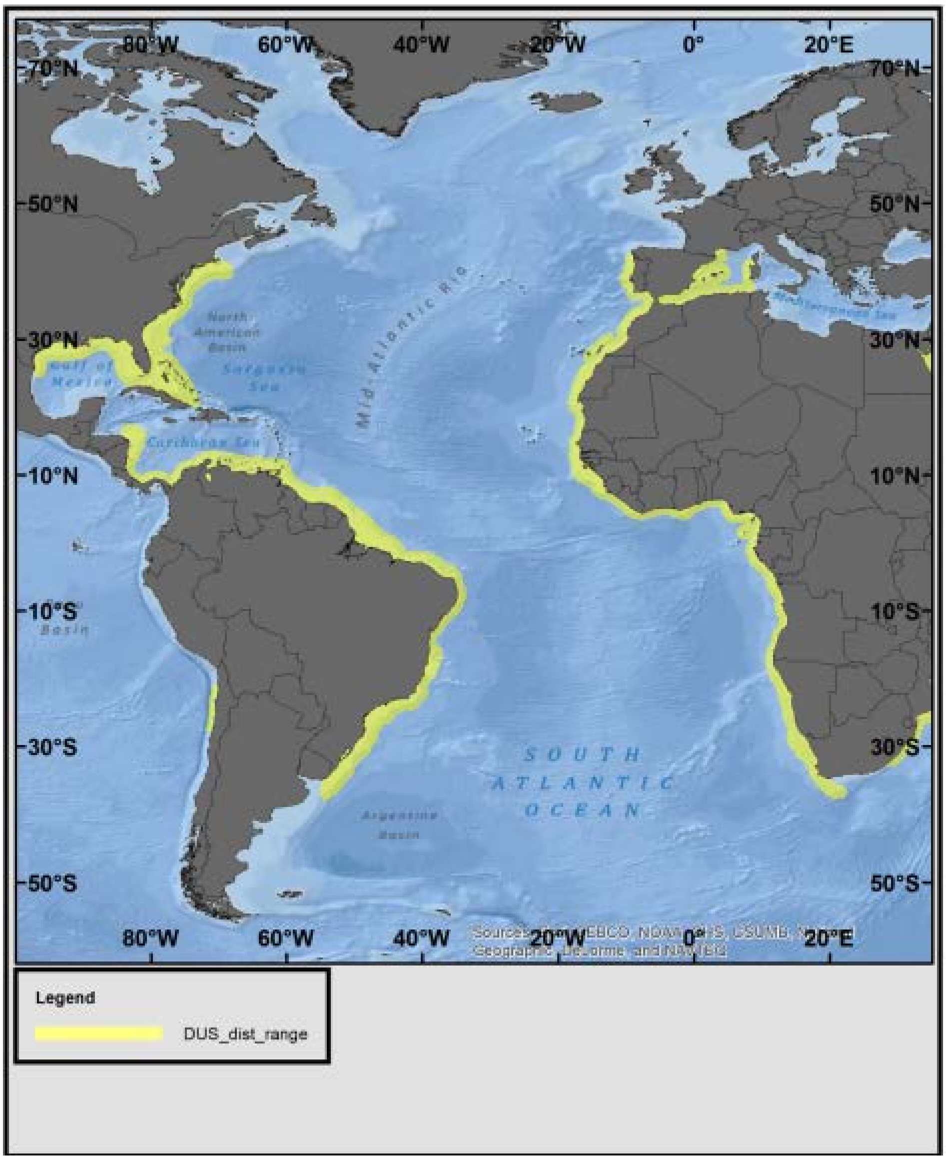


Figure 5. Species distribution of *Carcharhinus obscurus.*

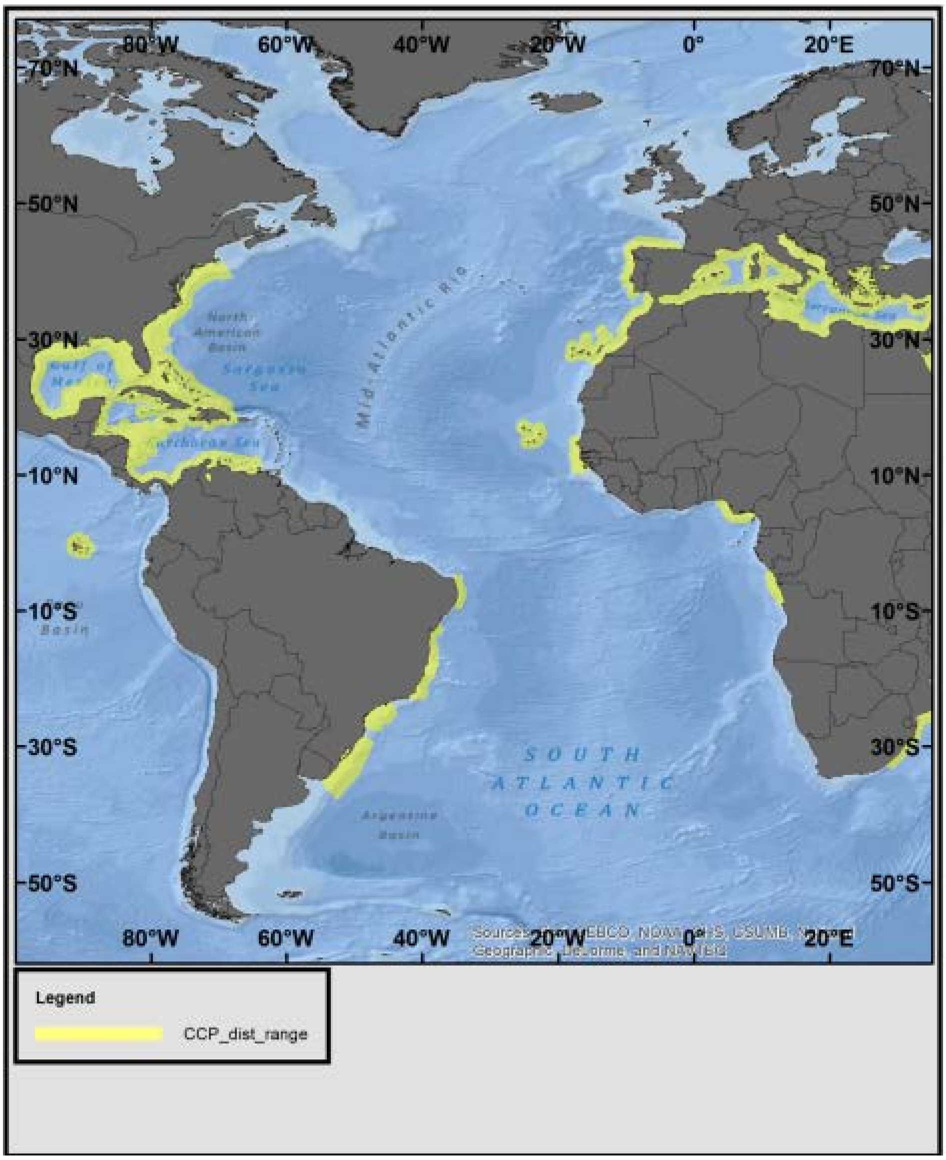


Figure 6. Species distribution of *Carcharhinus plumbeus.*

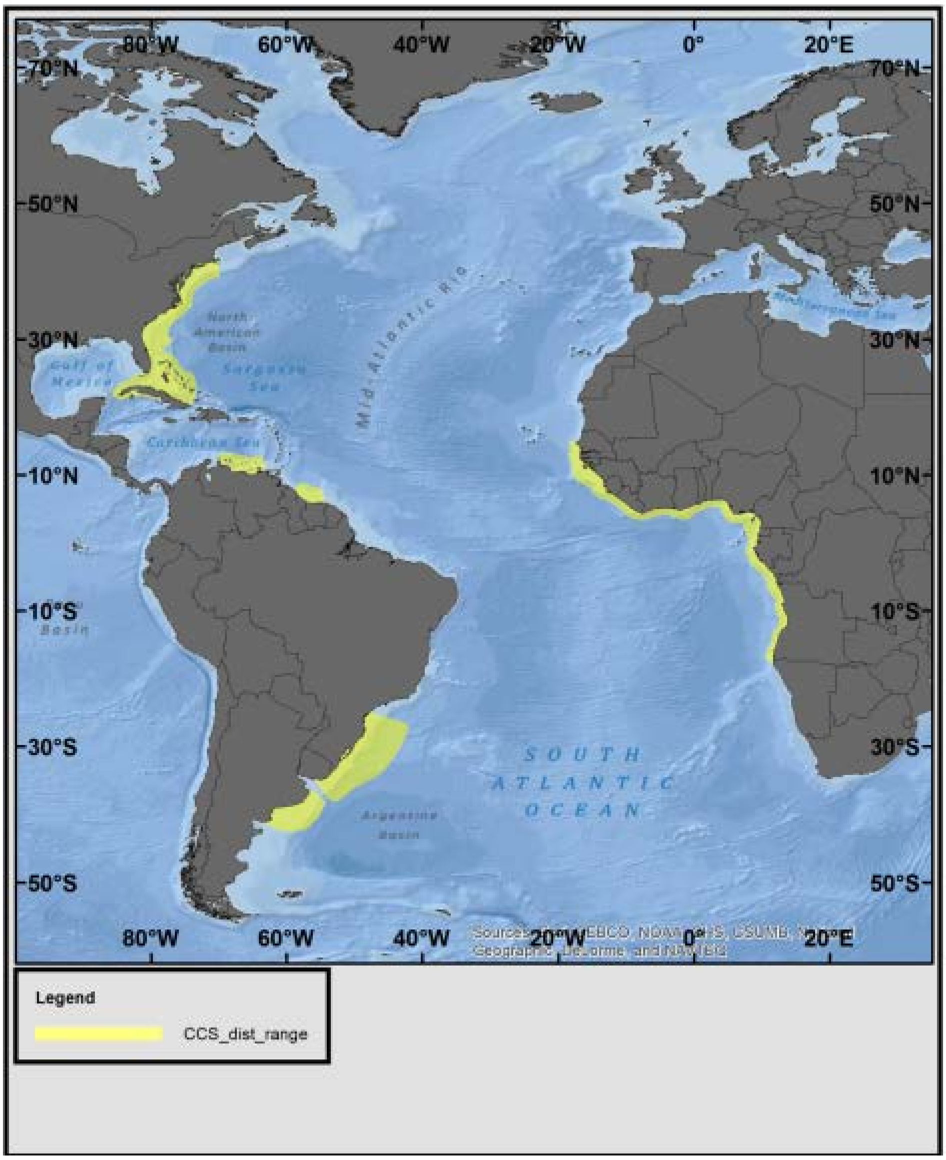


Figure 7. Species distribution of *Carcharhinus signatus.*

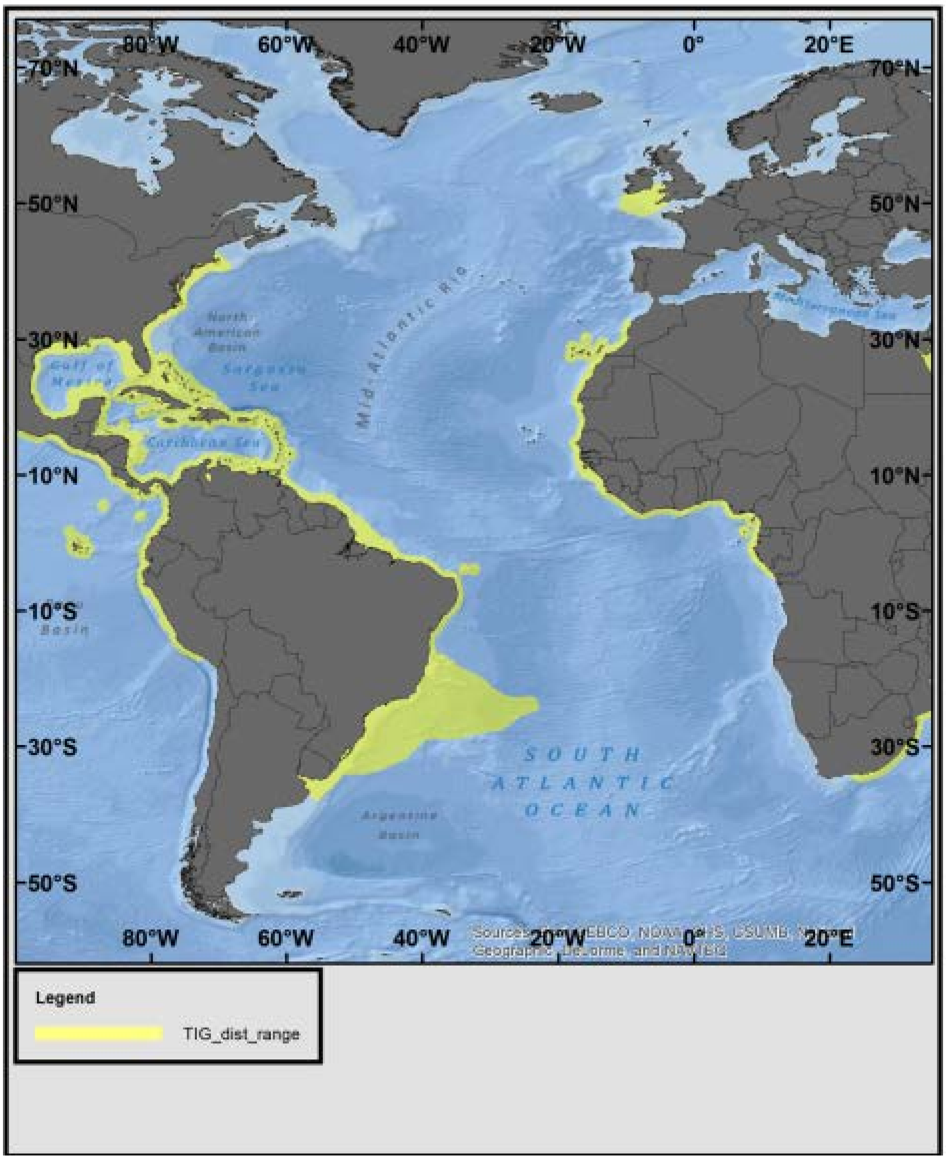


Figure 8. Species distribution of *Galeocerdo cuvier*.

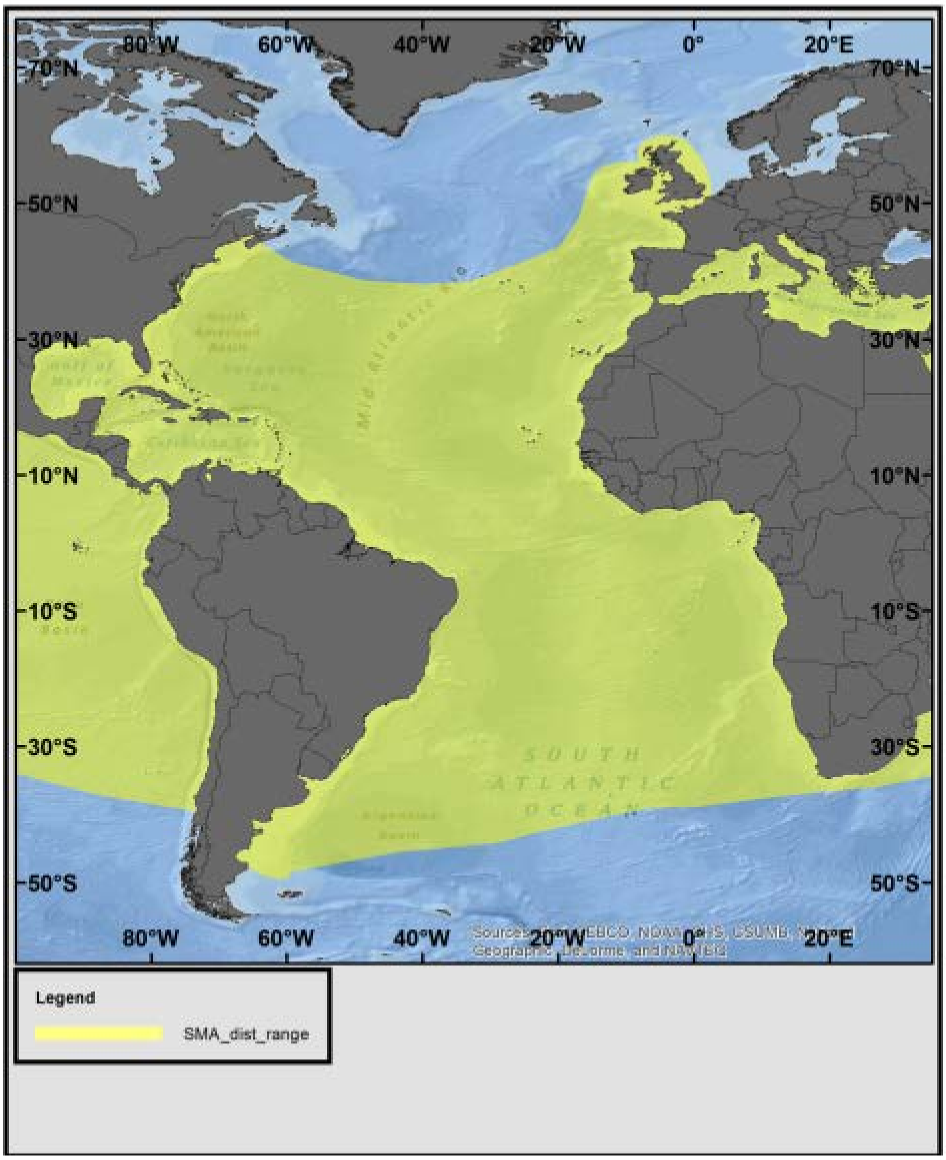


Figure 9. Species distribution of *Isurus oxyrinchus.*

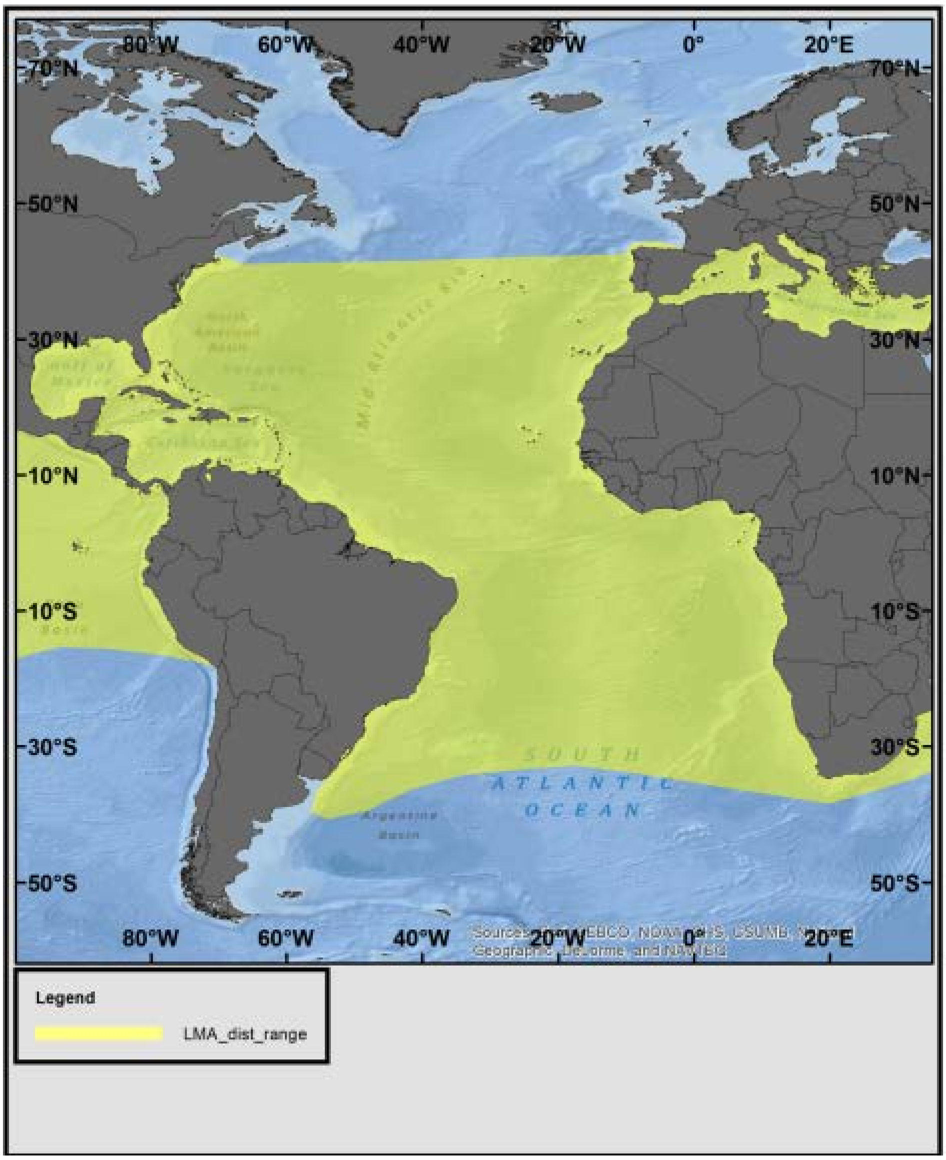


Figure 10. Species distribution of *Isurus paucus.*

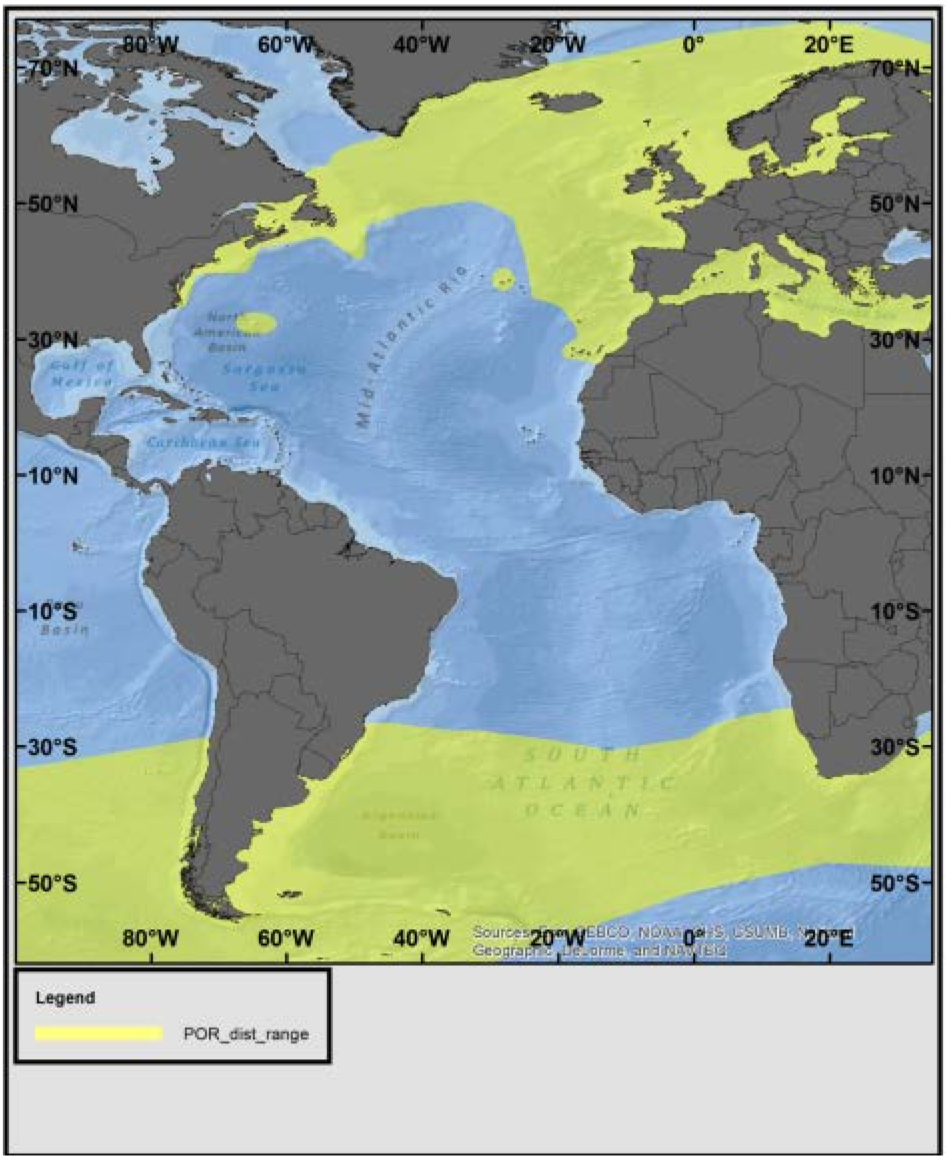


Figure 11. Species distribution of *Lamna nasus.*

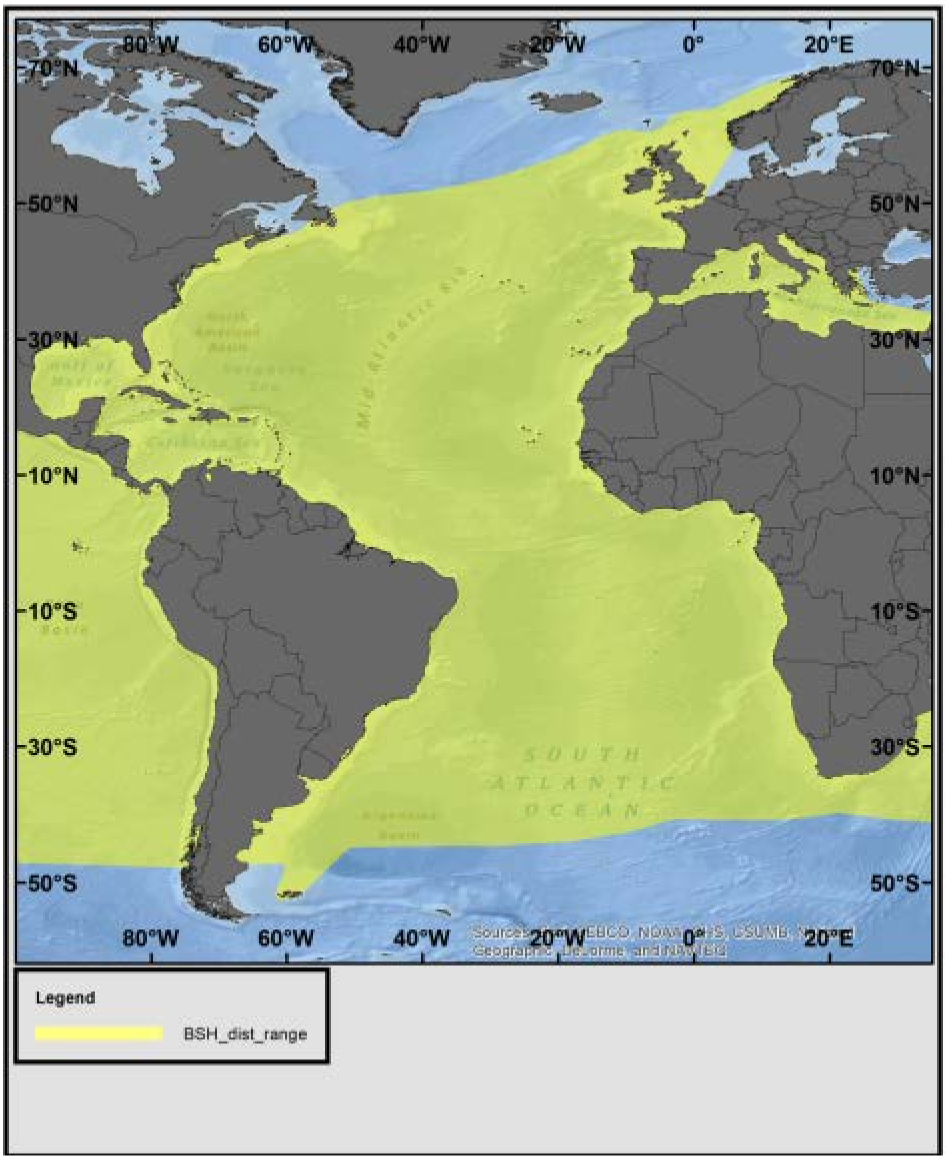


Figure 12. Species distribution of *Prionace glauca.*

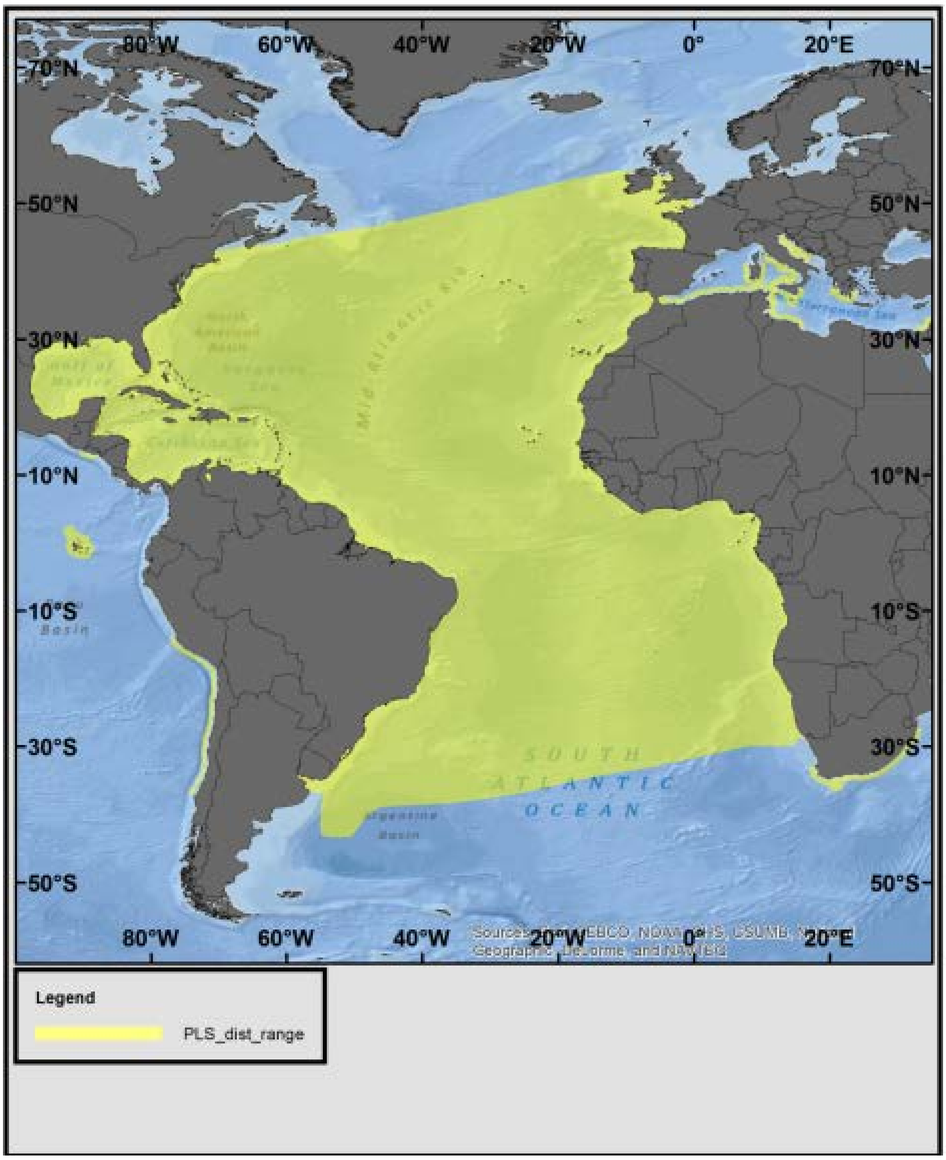


Figure 13. Species distribution of *Pteroplatytrygon violacea.*

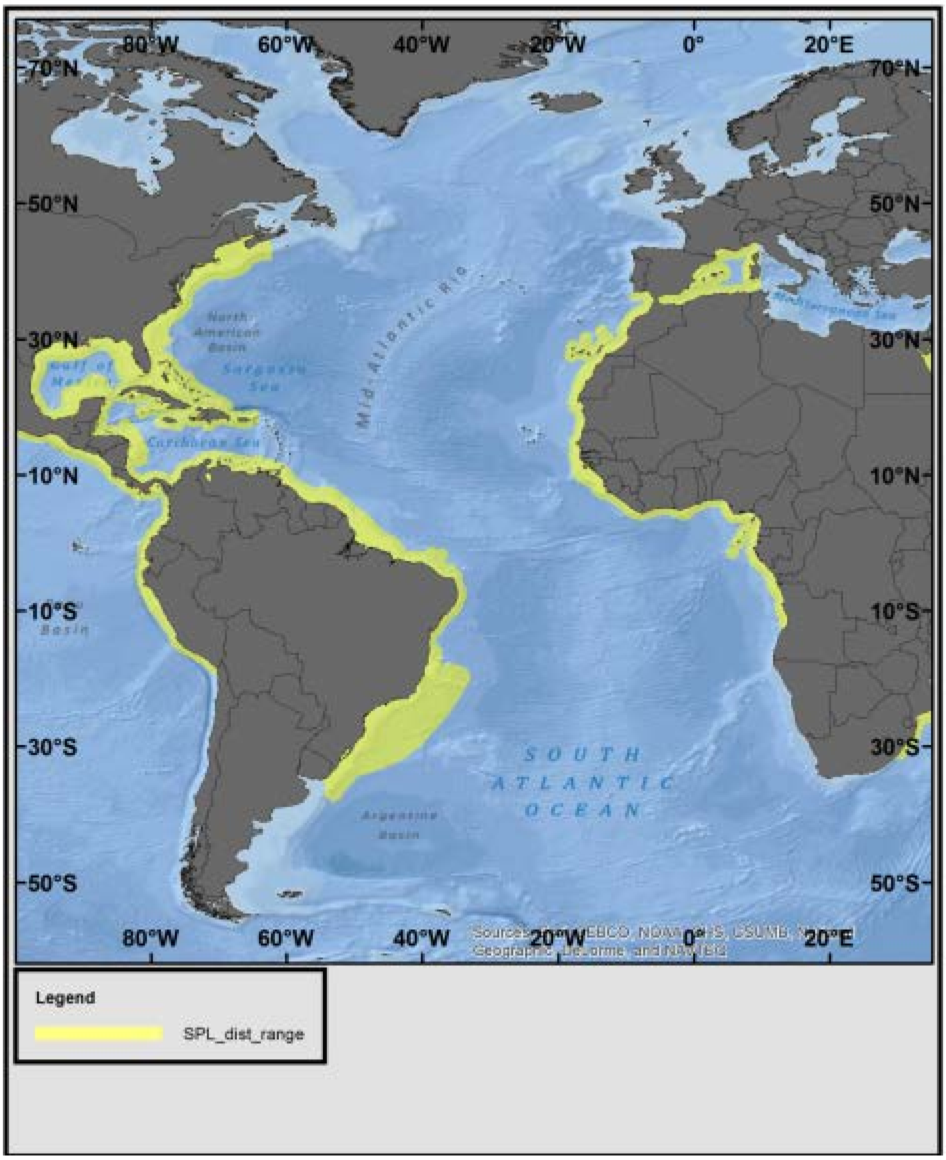


Figure 14. Species distribution of *Sphyrna lewini.*

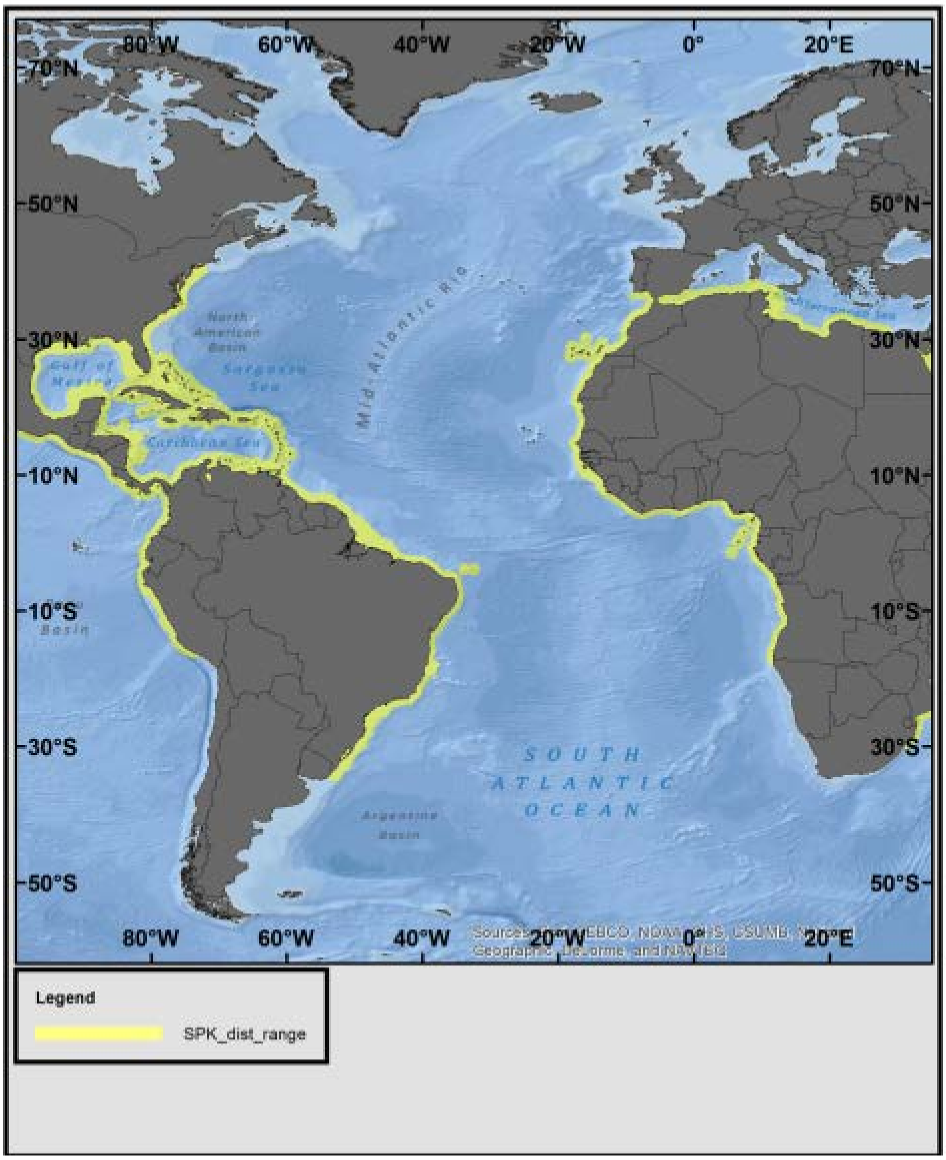


Figure 15. Species distribution of *Sphyrna mokarran.*

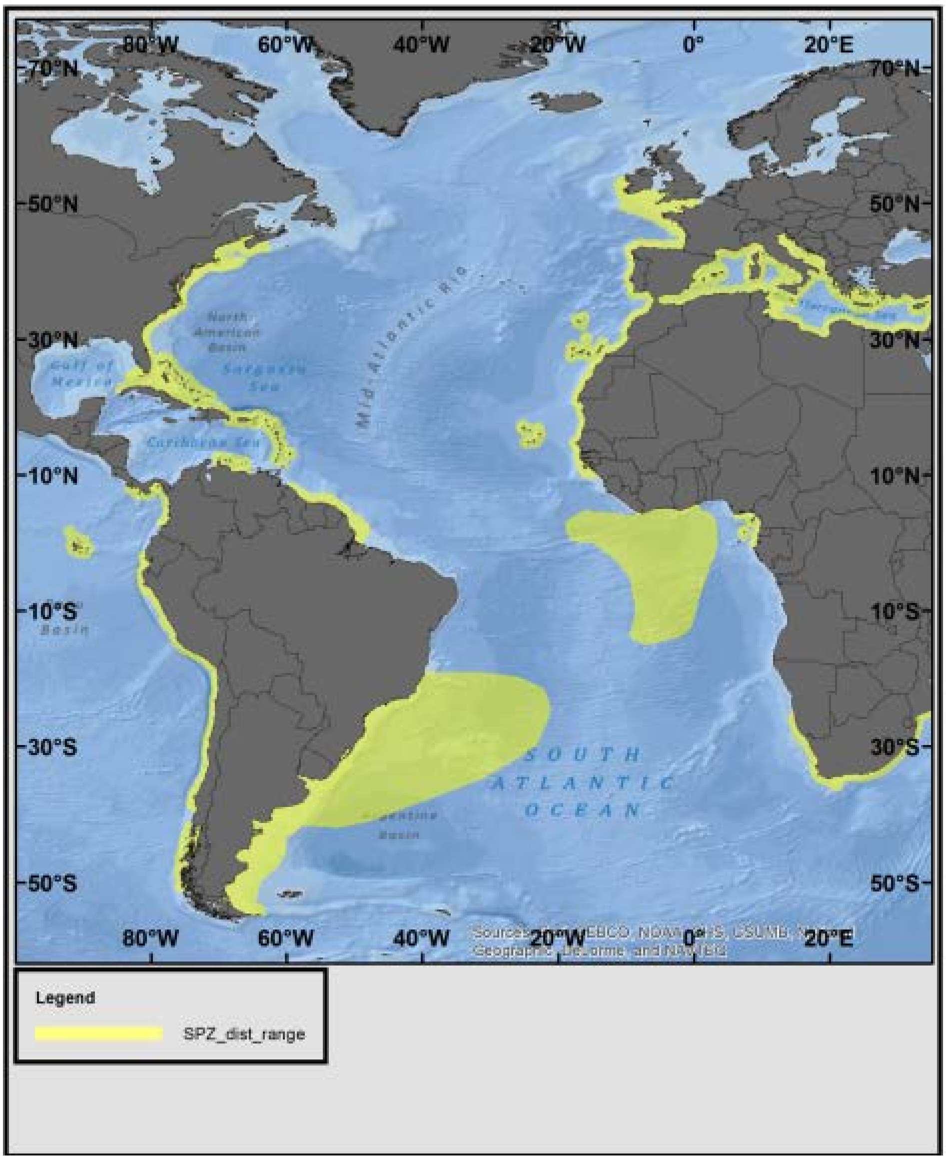


Figure 16. Species distribution of *Sphyrna zygaena*.

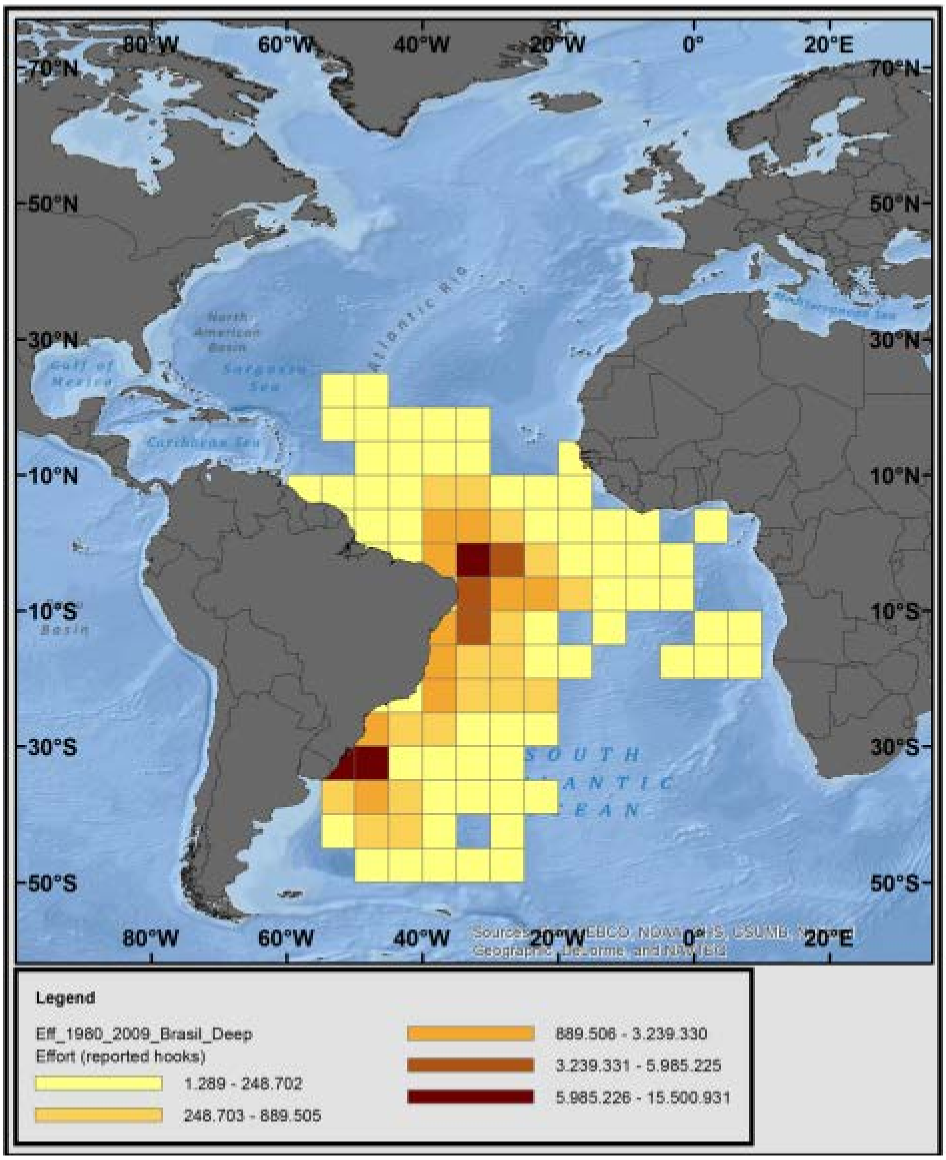


Figure 17A. Effort distribution (number of hooks) of pelagic longline fleet for Brazil, 1980-2009 (deep water).

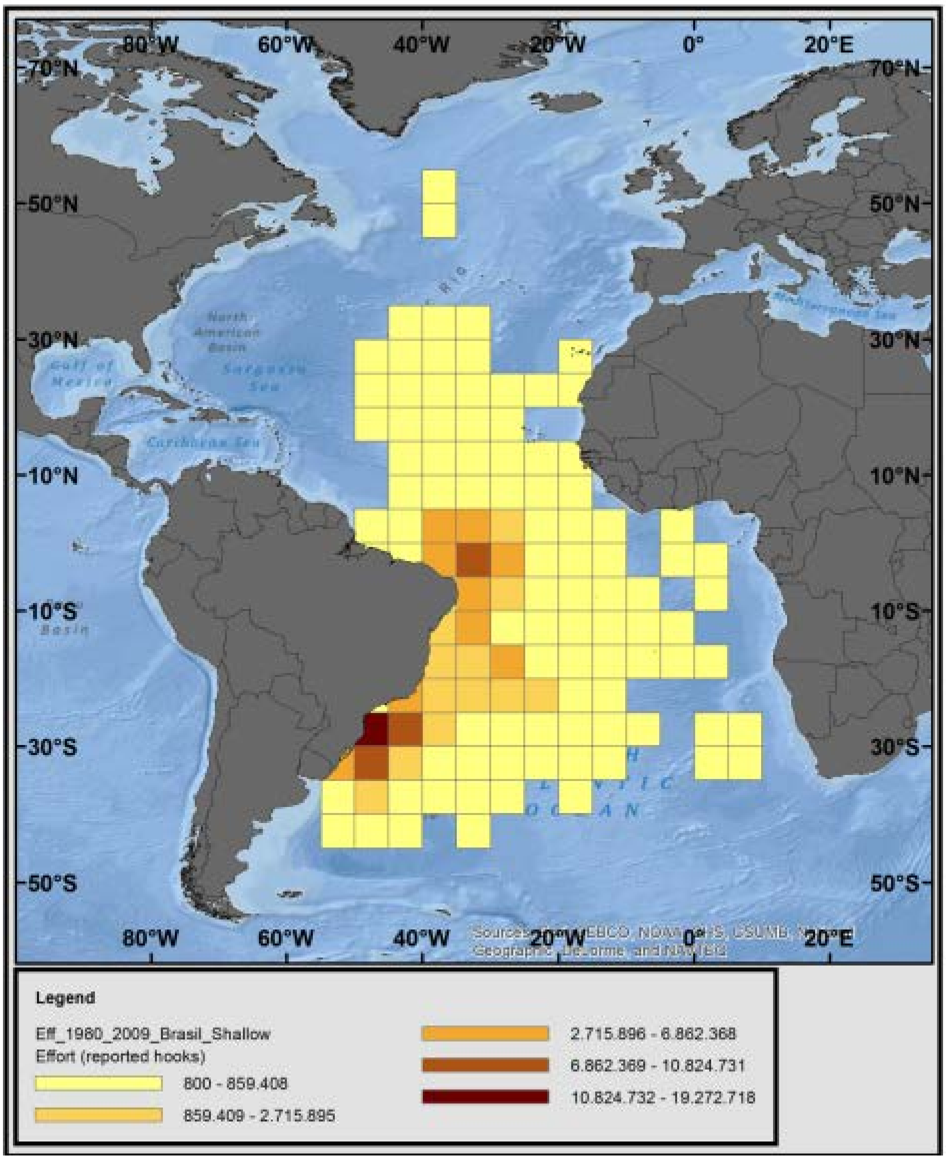


Figure 17B. Effort distribution (number of hooks) of pelagic longline fleet for Brazil, 1980-2009 (shallow water).

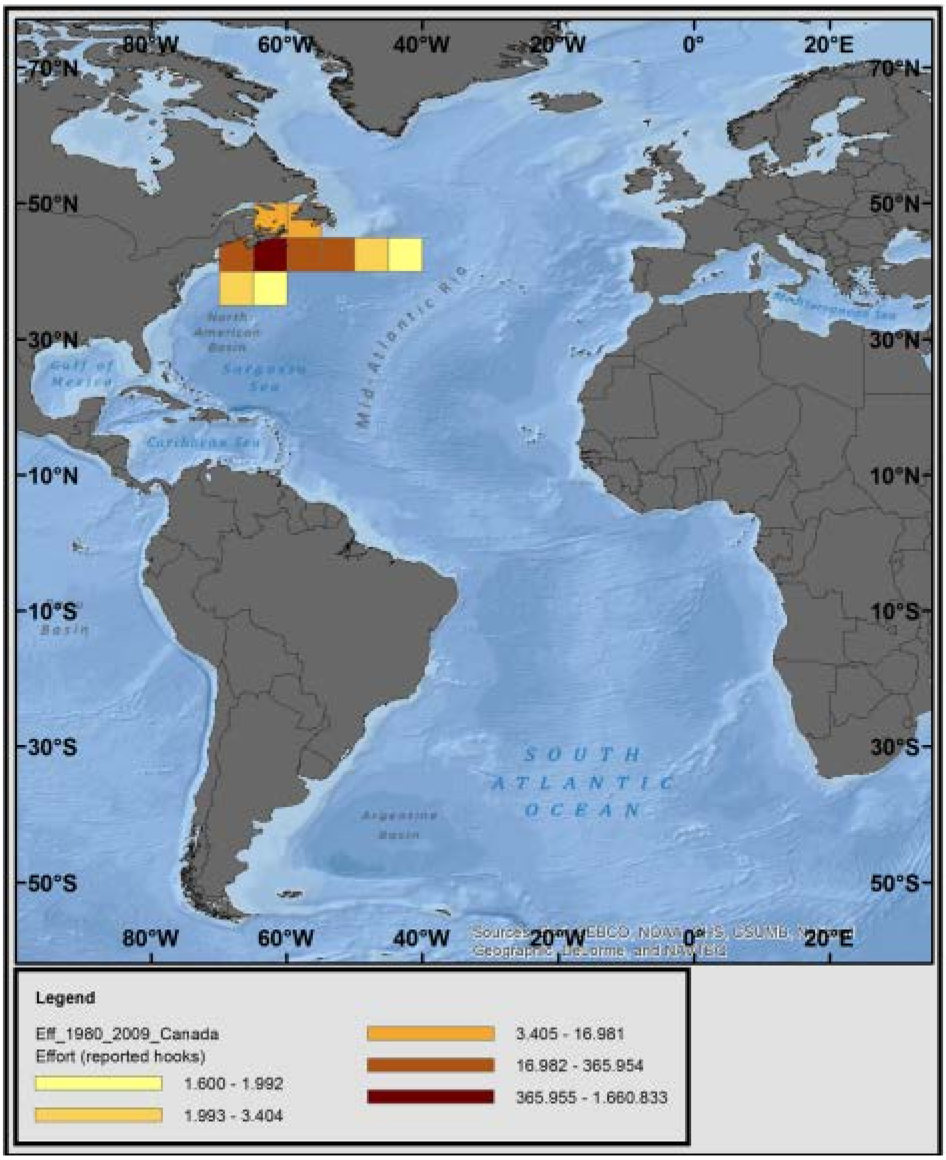


Figure 18. Effort distribution (number of hooks) of pelagic longline fleet for Canada, 1980-2009.

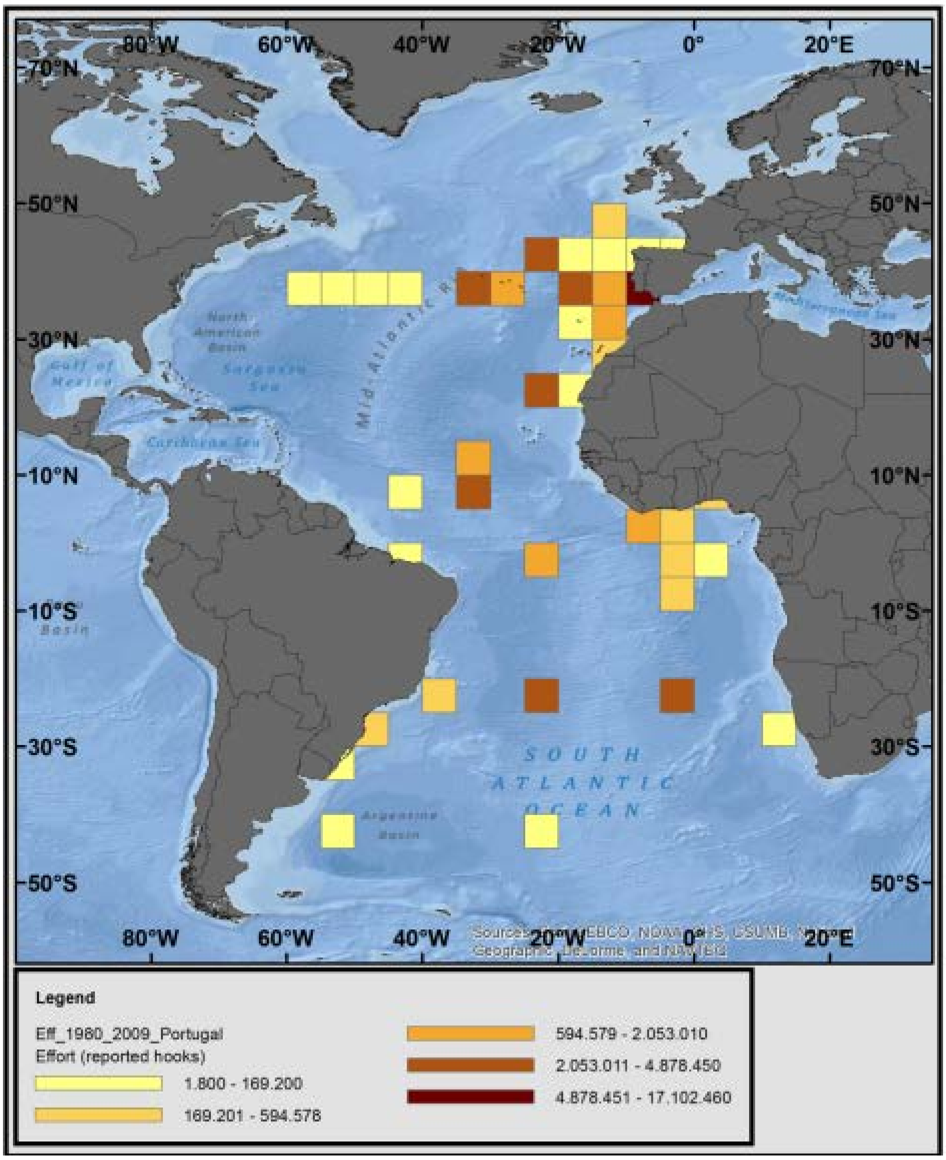


Figure 19. Effort distribution (number of hooks) of pelagic longline fleet for Portugal, 1980-2009.

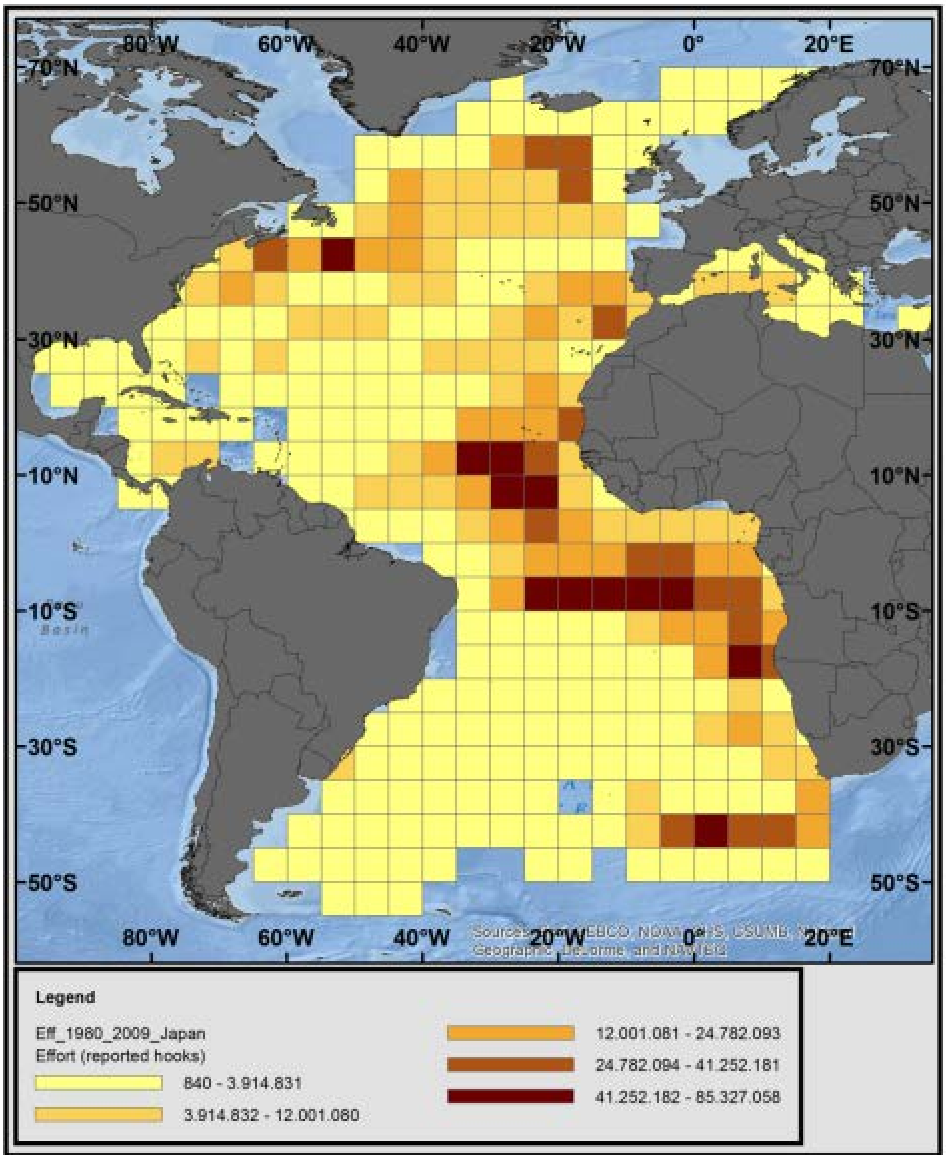


Figure 20. Effort distribution (number of hooks) of pelagic longline fleet for Japan, 1980-2009.

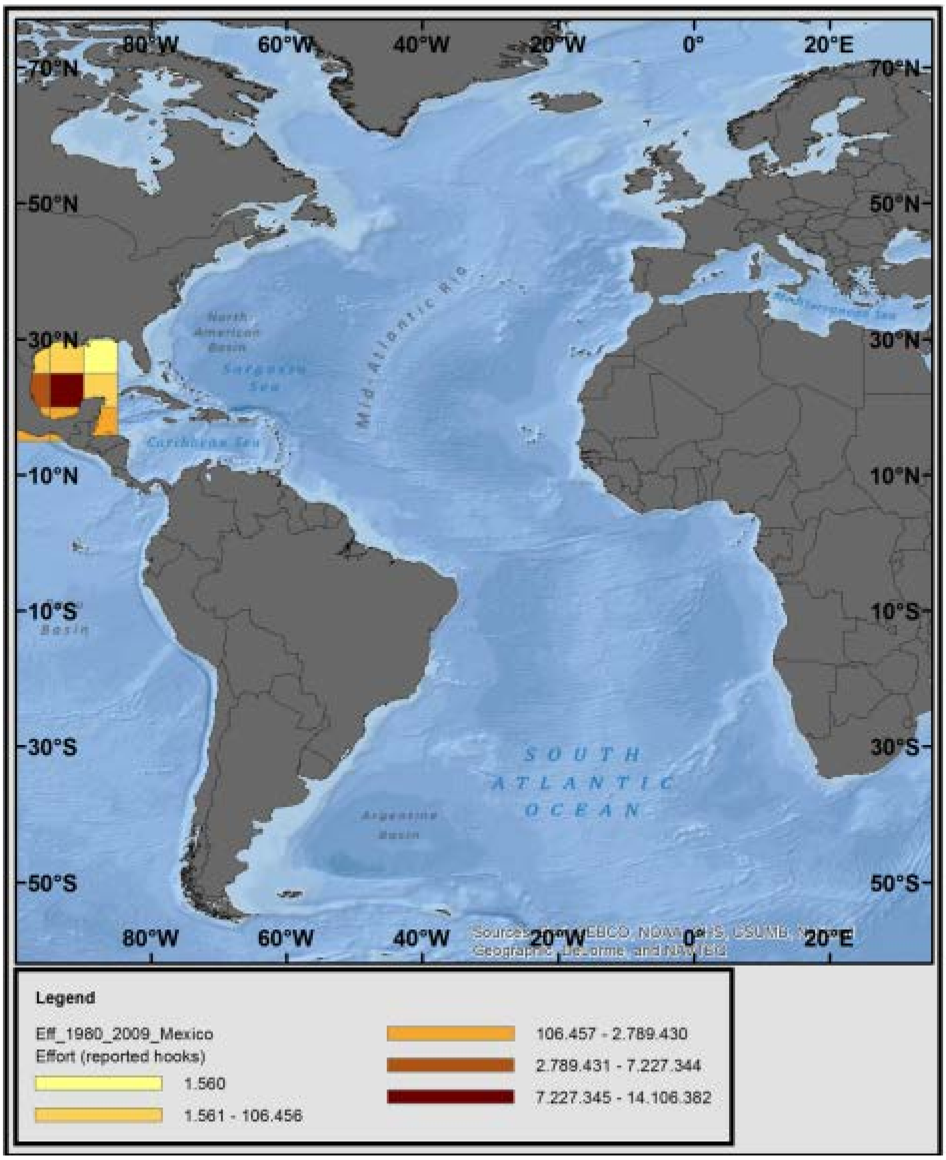


Figure 21. Effort distribution (number of hooks) of pelagic longline fleet for Mexico, 1980-2009.

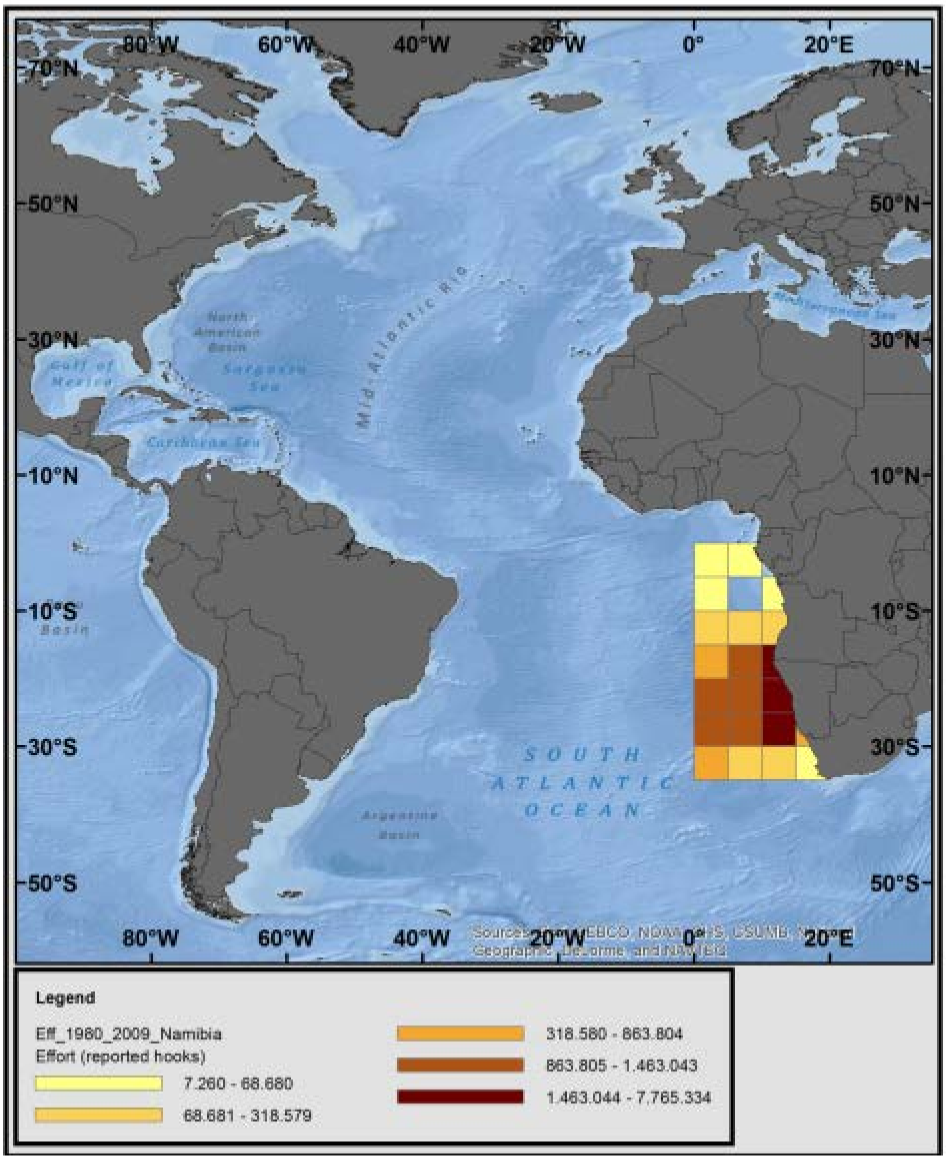


Figure 22. Effort distribution (number of hooks) of pelagic longline fleet for Namibia, 1980-2009.

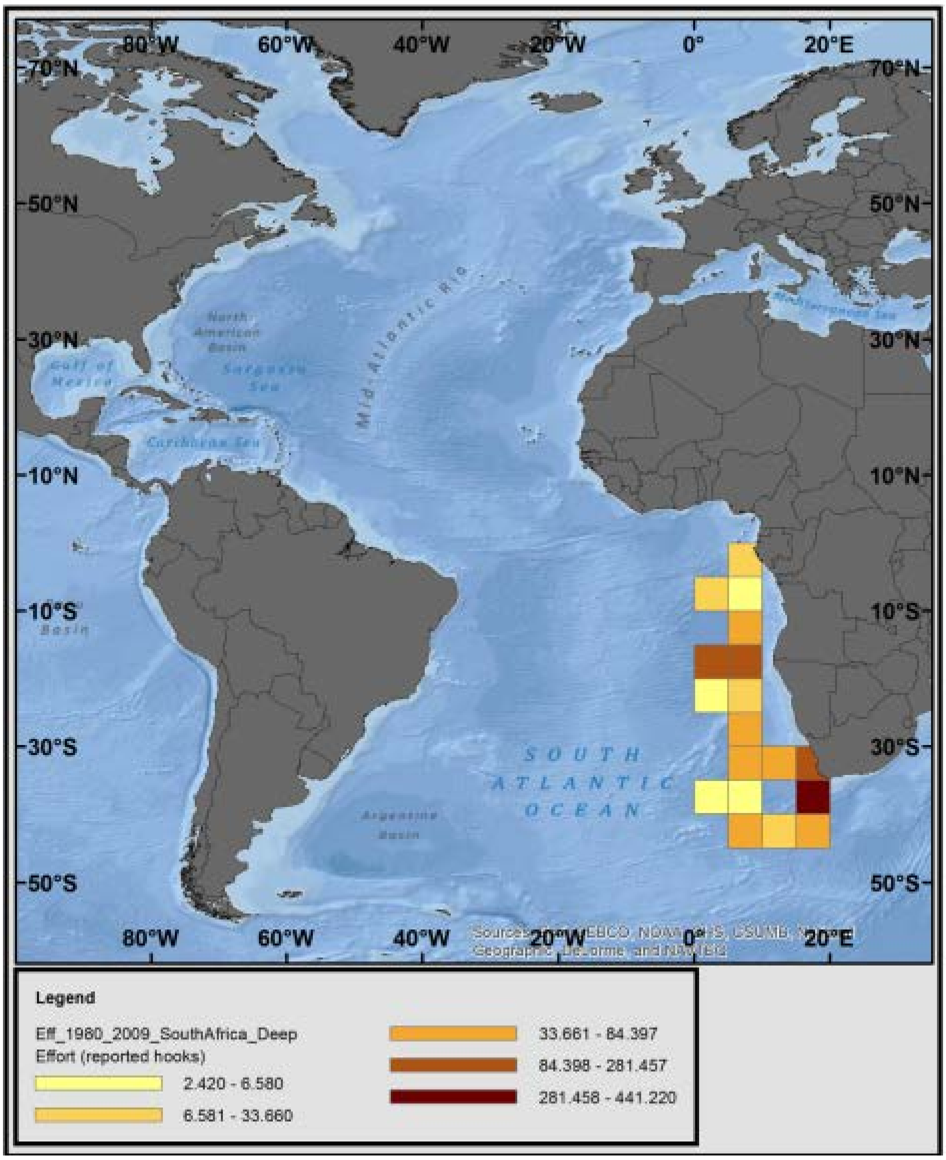


Figure 23A. Effort distribution (number of hooks) of pelagic longline fleet for South Africa, 1980-2009 (deep water).

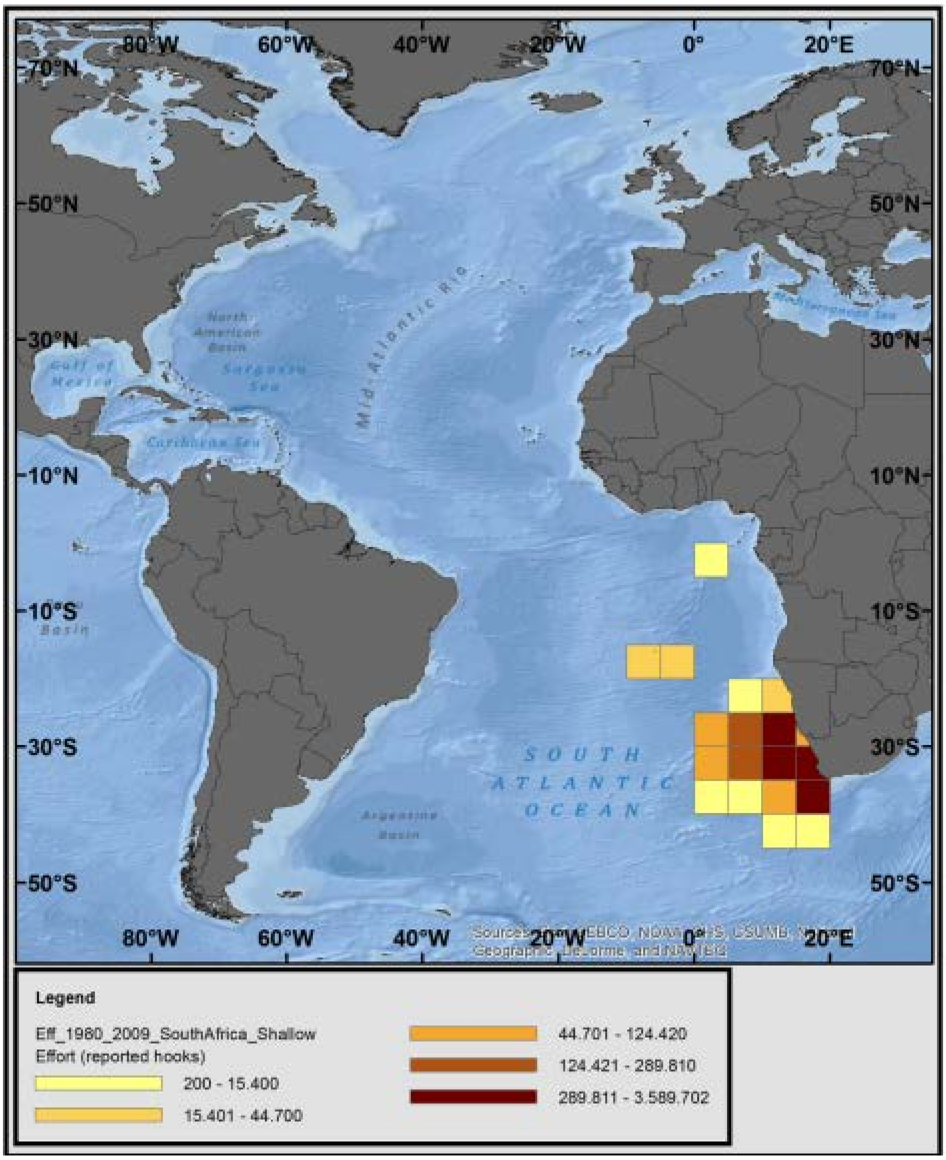


Figure 23B. Effort distribution (number of hooks) of pelagic longline fleet for South Africa, 1980-2009 (shallow water).

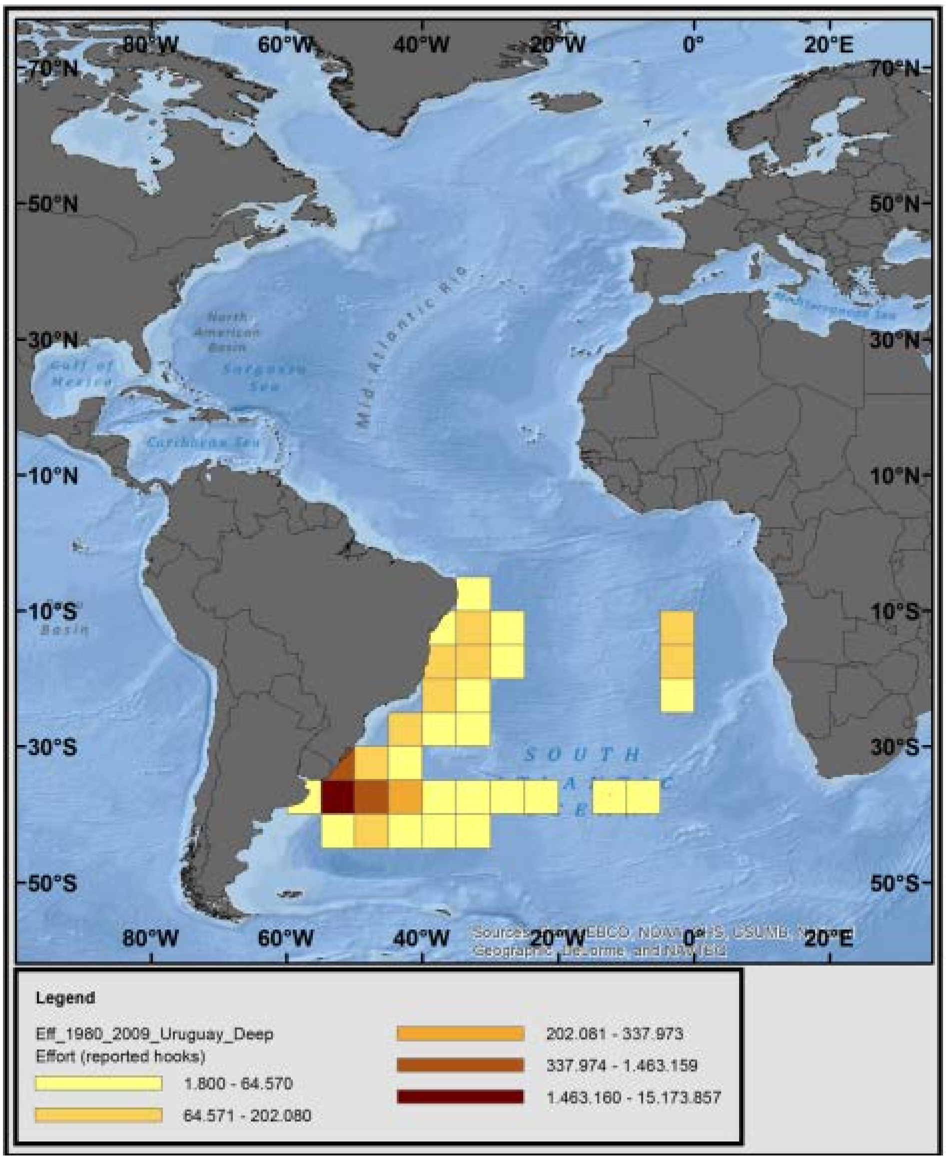


Figure 24A. Effort distribution (number of hooks) of pelagic longline fleet for Uruguay, 1980-2009 (deep water).

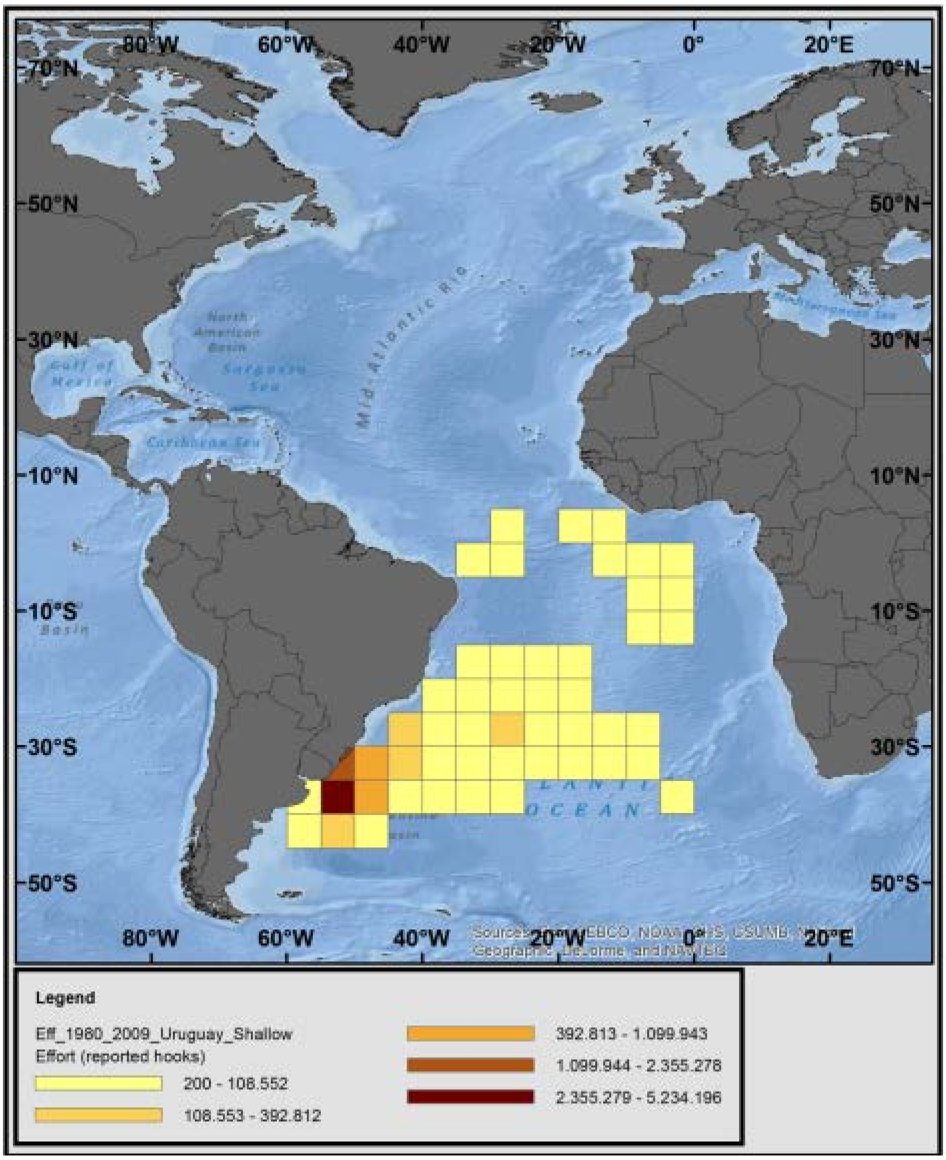


Figure 24B. Effort distribution (number of hooks) of pelagic longline fleet for Uruguay, 1980-2009 (shallow water).

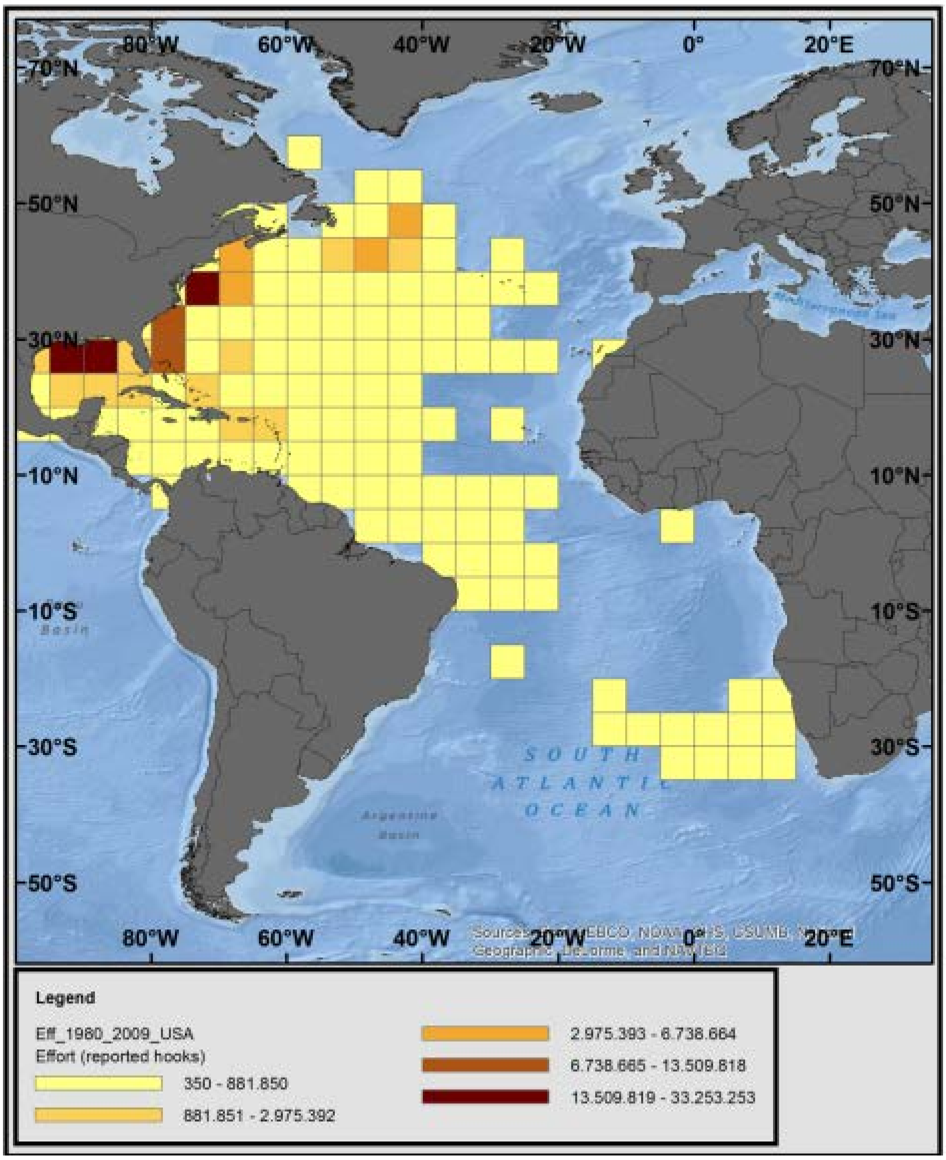


Figure 25. Effort distribution (number of hooks) of pelagic longline fleet for USA, 1980-2009.

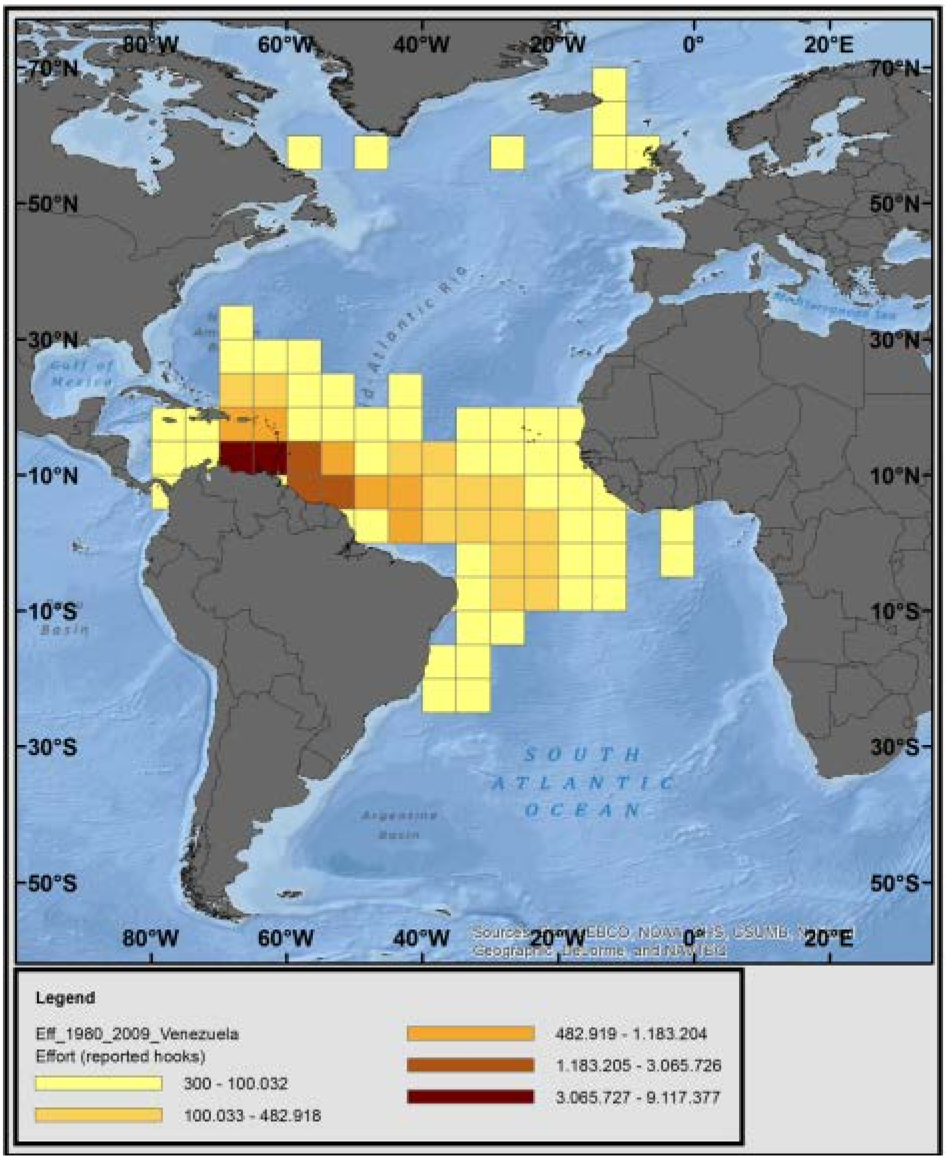


Figure 26. Effort distribution (number of hooks) of pelagic longline fleet for Venezuela, 1980-2009.

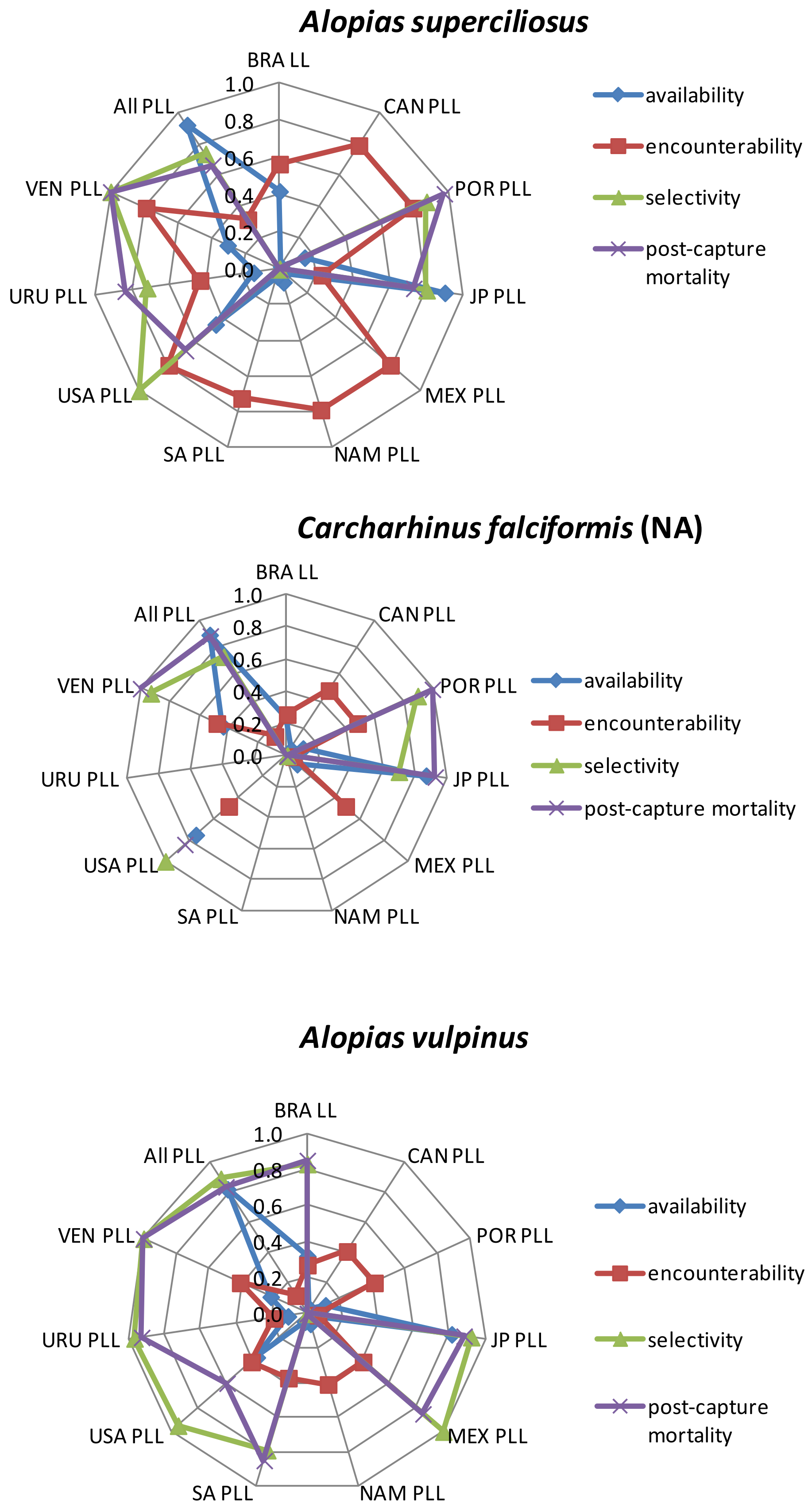
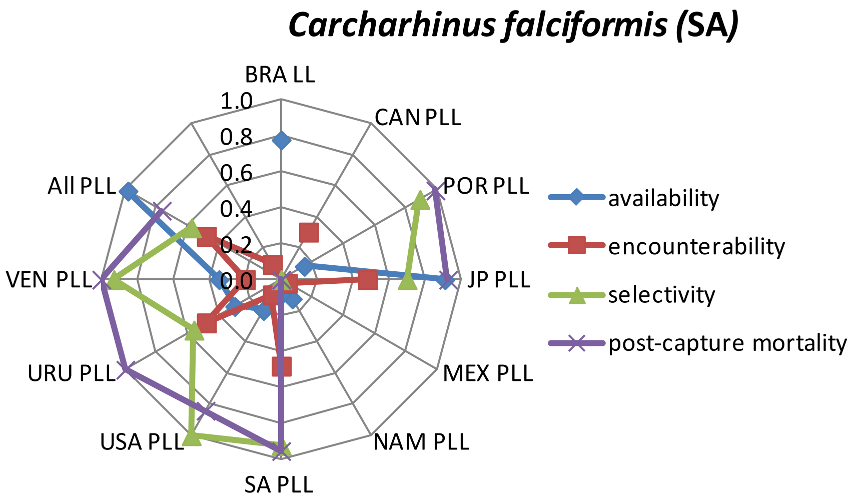
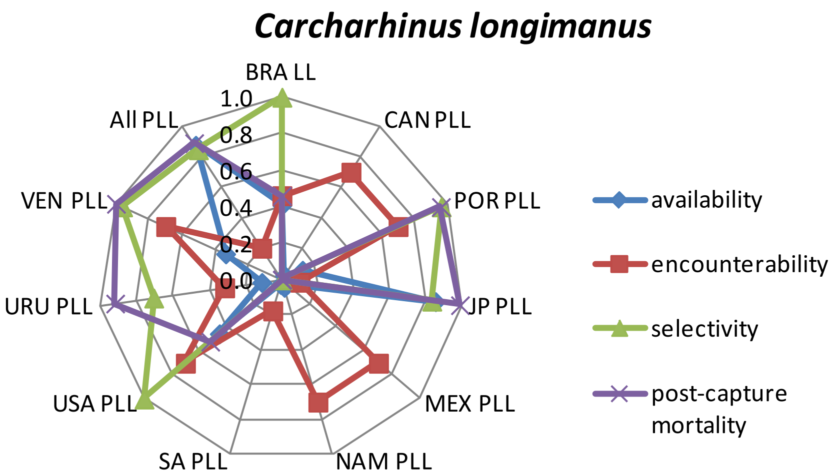


Figure 27. Radar plots of the four susceptibility attributes (availability, encounterability, selectivity, and post-capture mortality) by fleet and stock.





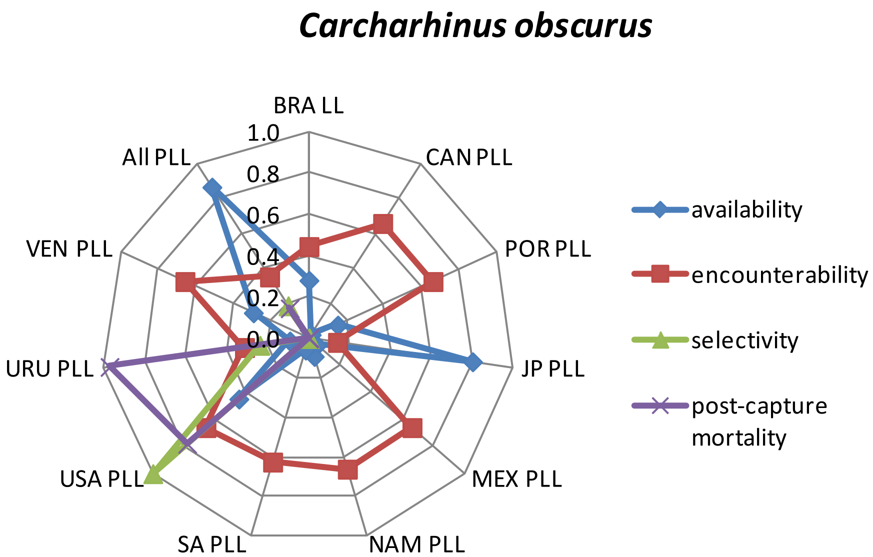
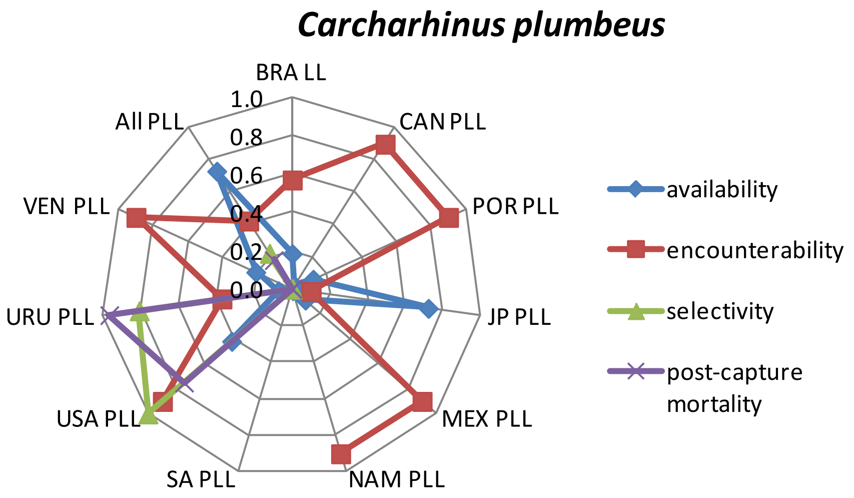
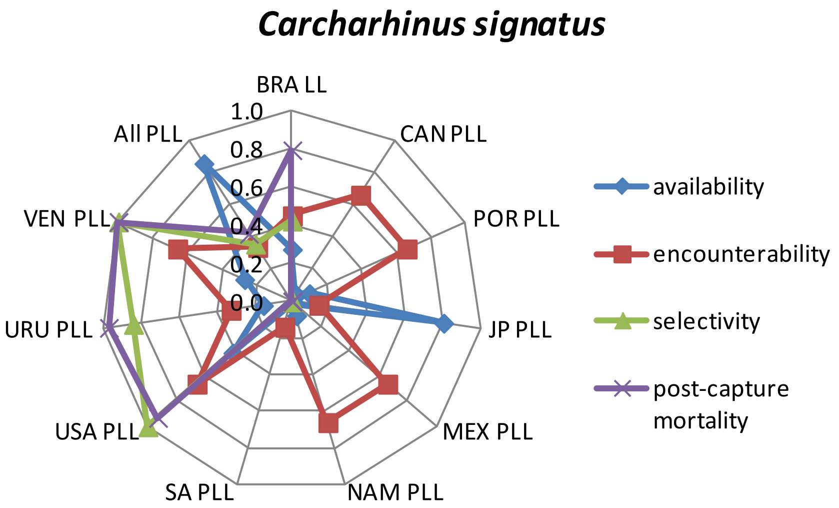
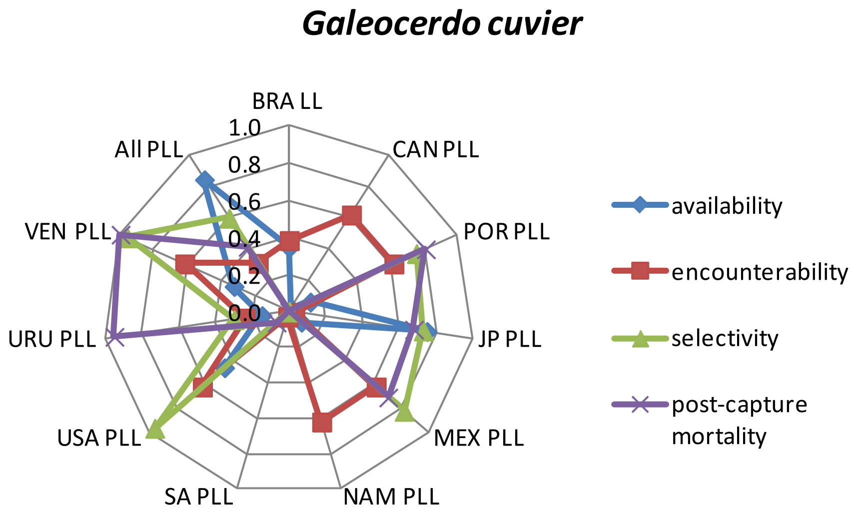


Figure 27 (continued).







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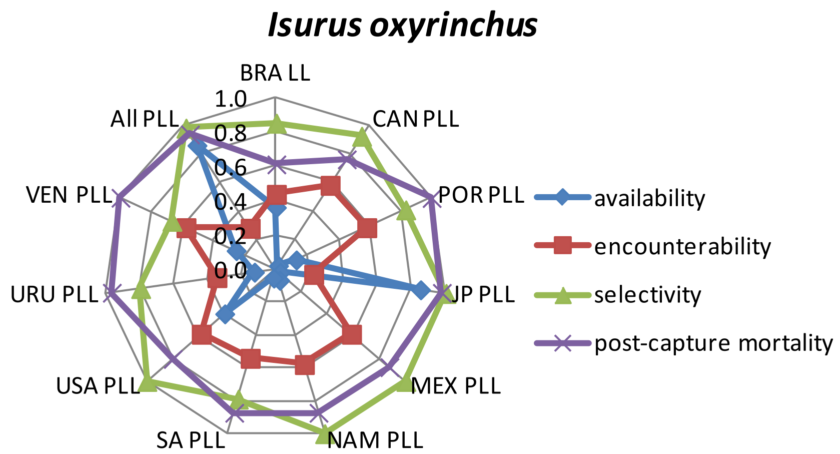

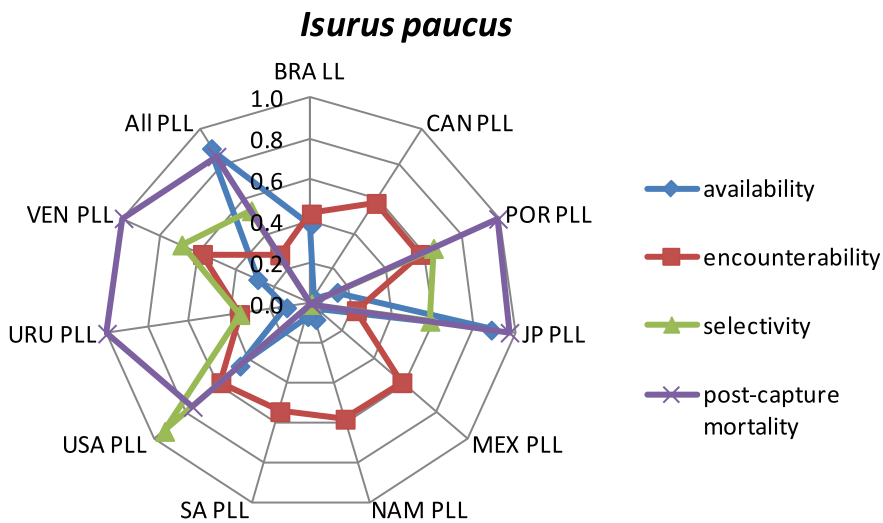

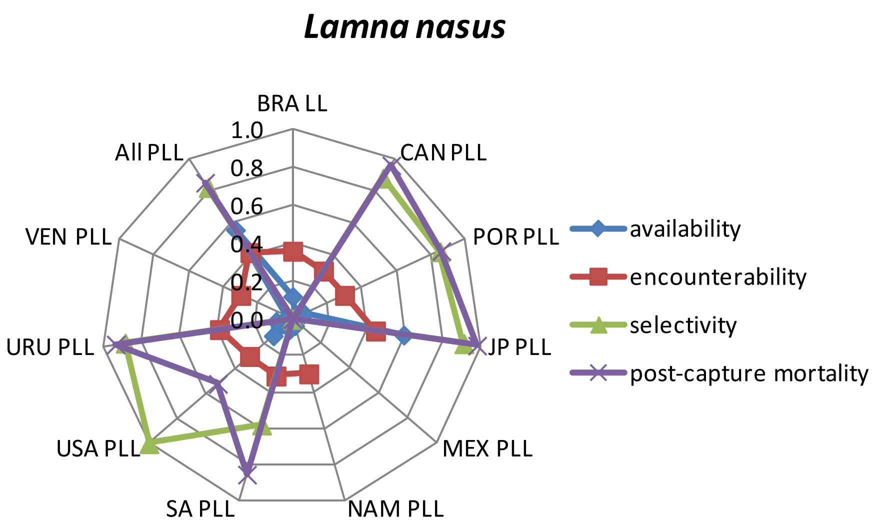

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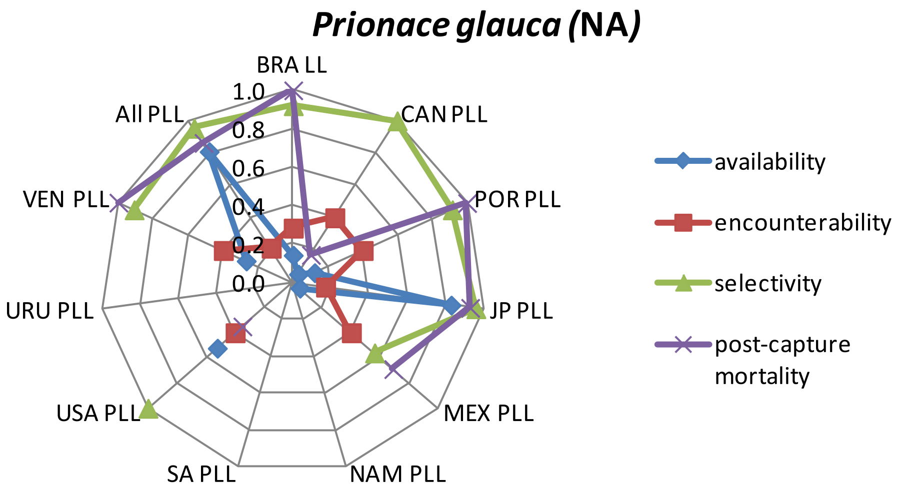

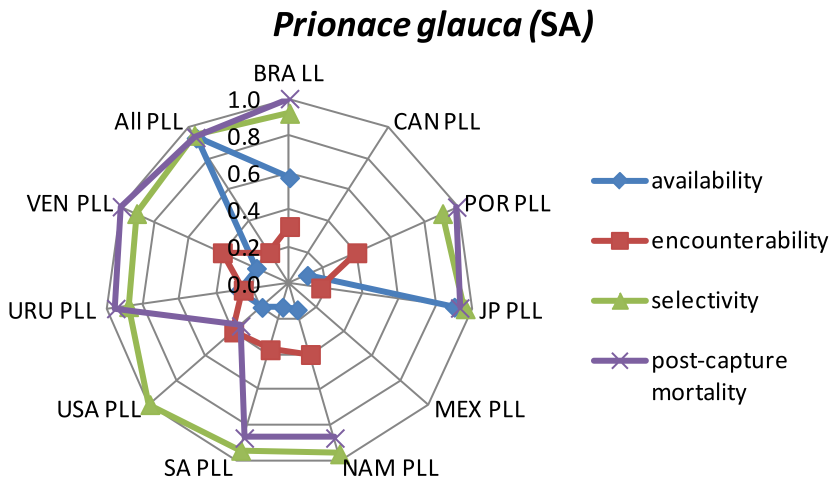

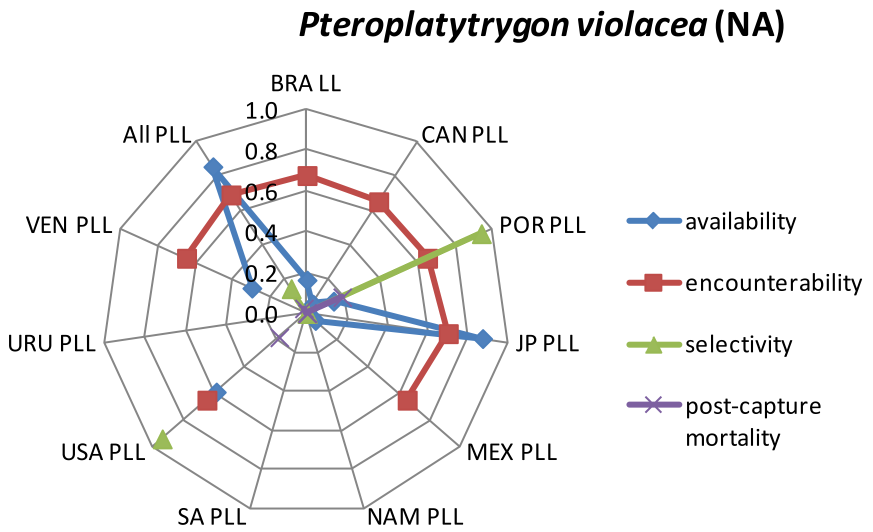

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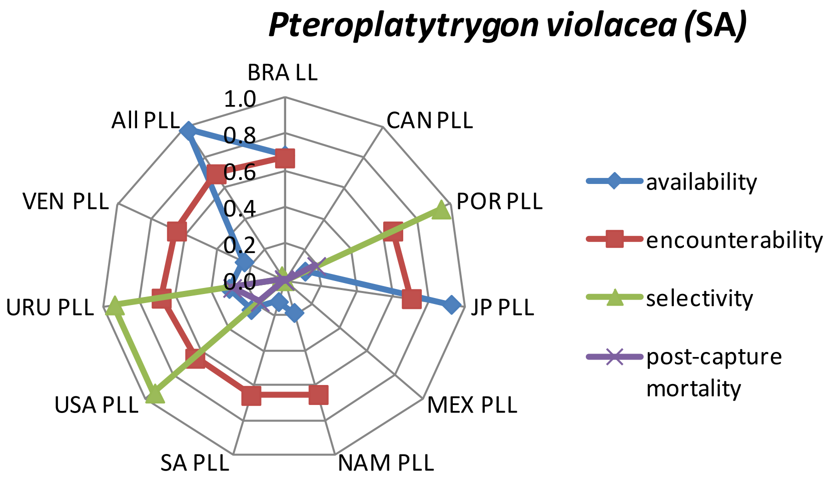

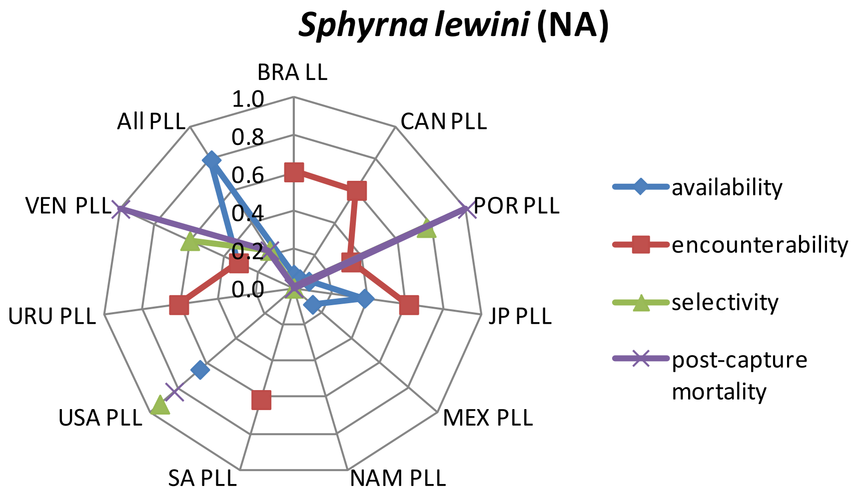

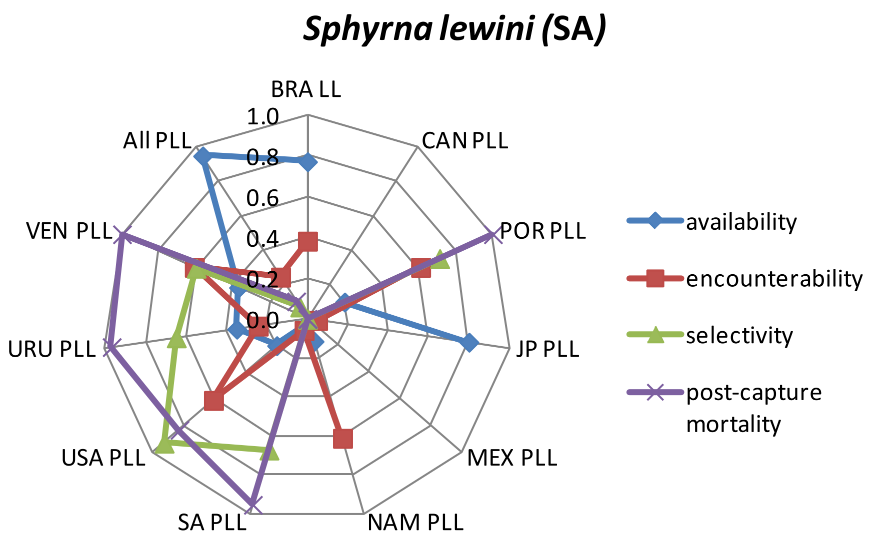

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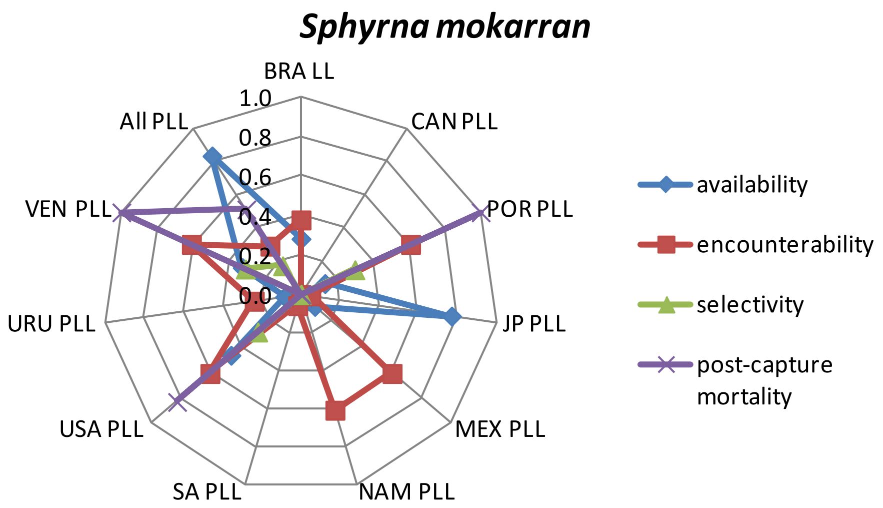

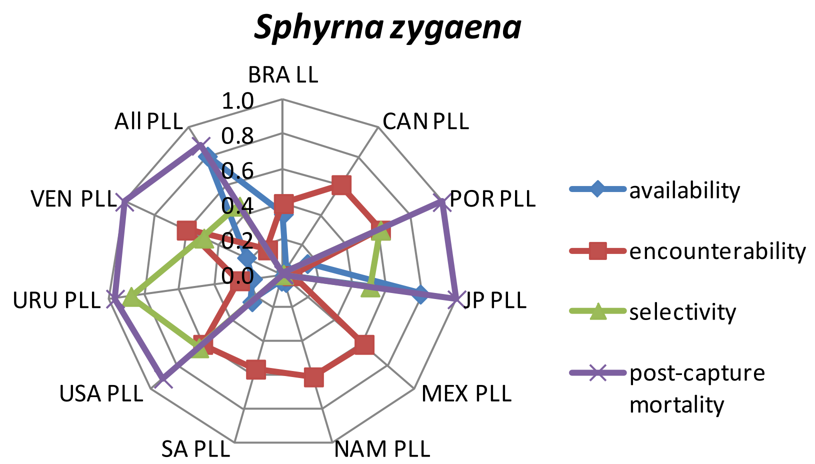

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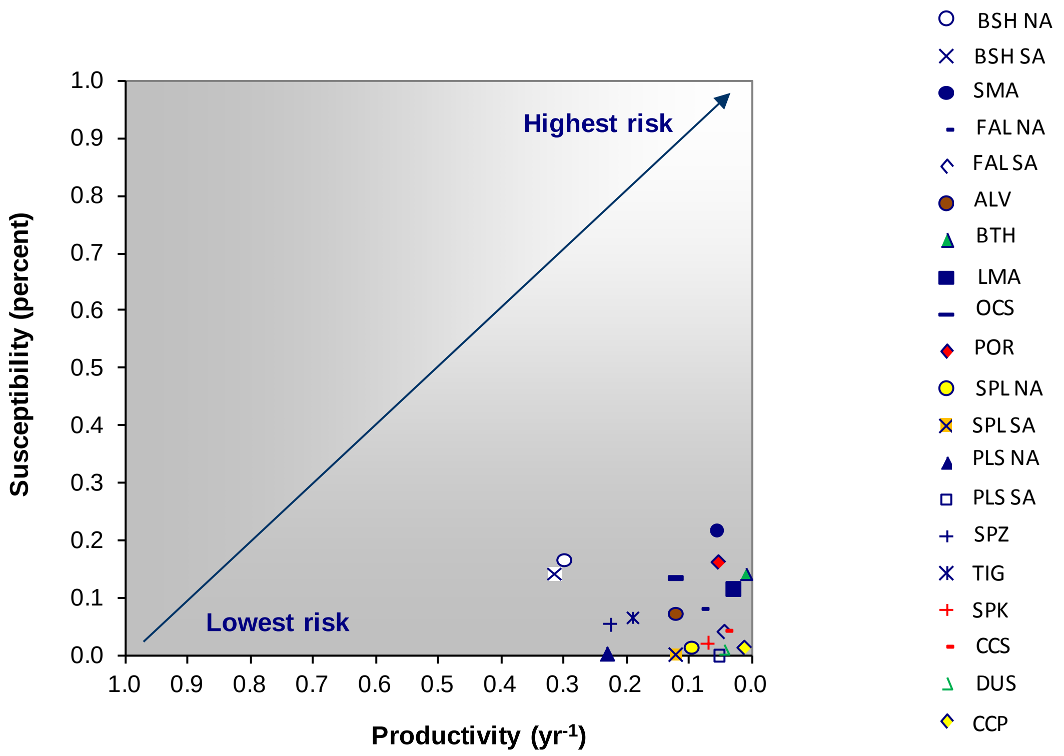

Figure 28. Productivity-susceptibility plot for 20 stocks of pelagic sharks. Productivity is expressed as r (intrinsic rate of population increase) and susceptibility to the combined effect of the pelagic longline fisheries of 10 CPCs, as the product of availability, encounterability, selectivity, and post-capture mortality (see text for details). The upper right corner denotes the area of highest risk (lowest productivity and highest susceptibility). Species codes are as in **Table 1**.