



## Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries

Enric Cortés<sup>1,a</sup>, Freddy Arocha<sup>2</sup>, Lawrence Beerkircher<sup>3</sup>, Felipe Carvalho<sup>4</sup>, Andrés Domingo<sup>5</sup>, Michelle Heupel<sup>6</sup>, Hannes Holtzhausen<sup>7</sup>, Miguel N. Santos<sup>8</sup>, Marta Ribera<sup>1</sup> and Colin Simpfendorfer<sup>9</sup>

<sup>1</sup> National Oceanographic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, Panama City Laboratory, 3500 Delwood Beach Road, Panama City, Florida 32408, USA

<sup>2</sup> Instituto Oceanográfico de Venezuela, Universidad de Oriente, Cumaná 6101, Venezuela

<sup>3</sup> National Oceanographic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, Florida 33149, USA

<sup>4</sup> University of Florida, Department of Fisheries and Aquatic Sciences, Florida Program for Shark Research, Gainesville, Florida 32653, USA

<sup>5</sup> DINARA, Area de Recursos Pelágicos, CP 11200 Montevideo, Uruguay

<sup>6</sup> School of Earth and Environmental Sciences, James Cook University, Queensland 4811, Australia

<sup>7</sup> Ministry of Fisheries and Marine Resources, Namibia

<sup>8</sup> INRB I.P./IPIMAR, 8700-305 Olhão, Portugal

<sup>9</sup> Fishing and Fisheries Research Centre, School of Earth and Environmental Sciences, James Cook University, Queensland 4811, Australia

Received 18 April 2009; Accepted 16 June 2009

**Abstract** – An ecological risk assessment (ERA; also known as productivity and susceptibility analysis, PSA) was conducted on eleven species of pelagic elasmobranchs (10 sharks and 1 ray) to assess their vulnerability to pelagic longline fisheries in the Atlantic Ocean. This was a level-3 quantitative assessment consisting of a risk analysis to evaluate the biological productivity of these species and a susceptibility analysis to assess their propensity to capture and mortality in pelagic longline fisheries. The risk analysis estimated productivity (intrinsic rate of increase,  $r$ ) using a stochastic Leslie matrix approach that incorporated uncertainty in age at maturity, lifespan, age-specific natural mortality and fecundity. Susceptibility to the fishery was calculated as the product of four components, which were also calculated 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 several ICCAT nations was used to derive fleet-specific susceptibility values. Results indicated that most species of pelagic sharks have low productivities and varying levels of susceptibility to pelagic longline gear. A number of species were grouped near the high-risk area of the productivity-susceptibility plot, particularly the silky (*Carcharhinus falciformis*), shortfin mako (*Isurus oxyrinchus*), and bigeye thresher (*Alopias superciliosus*) sharks. Other species, such as the oceanic whitetip (*Carcharhinus longimanus*) and longfin mako (*Isurus paucus*) sharks, are also highly vulnerable. The blue shark (*Prionace glauca*) has intermediate vulnerability, whereas the smooth hammerhead (*Sphyrna zygaena*), scalloped hammerhead (*Sphyrna lewini*), and porbeagle (*Lamna nasus*) sharks are less vulnerable, and the pelagic stingray (*Pteroplatytrygon violacea*) and common thresher (*Alopias vulpinus*) sharks have the lowest vulnerabilities. As a group, pelagic sharks are particularly vulnerable to pelagic longline fisheries mostly as a result of their limited productivity.

**Key words:** Ecological risk assessment / Leslie matrix / Shark life history / Vulnerability / Pelagic fisheries

**Résumé** – Une évaluation des risques écologiques (ERA) et/ou analyse de productivité – sensibilité/vulnérabilité (PSA), pour les pêcheries capturant plusieurs espèces, est mise en œuvre pour douze espèces d'Elasmobranches pélagiques (10 requins et une raie) afin d'estimer leur vulnérabilité à la pêche à la palangre en Atlantique. Trois approches d'évaluation quantitative consistent en une analyse de risque pour évaluer la productivité biologique de ces espèces, l'analyse de leur vulnérabilité à la capture et leur mortalité lors de ces pêches hauturières à la palangre. Les analyses de risques estiment la productivité (taux de croissance intrinsèque de la population,  $r$ ) en utilisant une matrice stochastique de Leslie et en incorporant une incertitude au niveau de l'âge à la maturité sexuelle, la durée de vie, l'âge à la mortalité naturelle et la fécondité. La vulnérabilité à la pêche est calculée comme le produit de 4 composantes, qui sont également

<sup>a</sup> Corresponding author: Enric.Cortes@noaa.gov

calculées : disponibilité de l'espèce à la flottille, à la rencontre de l'engin de pêche d'après la répartition verticale de l'espèce, la sélectivité de l'engin de pêche et la mortalité après capture. Des informations des observateurs de la Commission internationale pour la Conservation des Thonidés (ICCAT) chargés du suivi des programmes de plusieurs pays sont utilisées pour en déduire la valeur de vulnérabilité spécifique à chaque flottille. Les résultats indiquent que la plupart des espèces de requins pélagiques ont une faible productivité et des niveaux divers de vulnérabilité aux palangres hauturières. Un certain nombre d'espèces sont groupées près de la zone de haut risque de productivité-vulnérabilité, en particulier le requin soyeux (*Carcharhinus falciformis*), le requin taupe bleu (*Isurus oxyrinchus*), et le requin renard à gros yeux (*Alopias superciliosus*). D'autres espèces telle que le requin océanique (*Carcharhinus longimanus*) et petite taupe (*Isurus paucus*), sont aussi très vulnérables. Le requin peau bleue (*Prionace glauca*) a une vulnérabilité intermédiaire tandis que le requin-marteau commun (*Sphyrna zygaena*), le requin-marteau halicorne (*Sphyrna lewini*), et le requin-taupe commun (*Lamna nasus*) sont moins vulnérables ; la raie pélagique (*Pteroplatytrygon violacea*) et le requin renard (*Alopias vulpinus*) ont les plus faibles vulnérabilités. En tant que groupe, les requins pélagiques sont particulièrement vulnérables à la pêche hauturière à la palangre, principalement due à leur productivité limitée.

## 1 Introduction

Ecological risk assessment (ERA), also known as productivity and susceptibility analysis (PSA), is a tool that can be used to evaluate the vulnerability of a stock to becoming overfished, based on its biological productivity and susceptibility to the fishery or fisheries exploiting it. Its most practical use is to help management bodies identify the stock(s) that are most vulnerable to overfishing so that they can monitor and assess management measures to protect the viability of these stocks. ERA can also be used to prioritize research efforts by focusing on species with high susceptibility about which we have little biological information, or by identifying and excluding species with low vulnerability from data-intensive assessments (Braccini et al. 2006).

The approach is flexible because it can be undertaken at different levels (qualitative or level 1, semi-quantitative or level 2, and quantitative or level 3) according to the degree of data availability (Hobday et al. 2007), and results can easily be presented as X-Y scatter plots. Several studies have applied this methodology, mostly to bycatch species for which biological and fishery information is often sparse (Stobutzki et al. 2002; Milton 2001), but in at least one case a quantitative (level-3) approach was used for a shark species (Braccini et al. 2006). The methodology has also been recommended for use by several entities, including the Australian Fisheries Management Authority (Hobday et al. 2007, Smith et al. 2007), Lenfest Working Group (Rosenberg et al. 2007), the International Commission for the Conservation of Atlantic Tunas (ICCAT) Ecosystems Working Group (ICCAT 2008), and the United States National Oceanographic and Atmospheric Administration. Currently, it is also being applied to Atlantic coastal shark species (Cortés et al. 2008).

The purpose of the present study was to provide a range of vulnerabilities for the most important pelagic shark species subject to ICCAT surface longline fisheries in the Atlantic Ocean. Given the paucity of data series on catch and effort necessary to conduct analytical stock assessments and our uncertainty about these data for many of these species, this approach can be used to identify those species which are more, or less, at risk. We applied a fully quantitative analysis because biological information was sufficient to estimate a direct measure of productivity ( $r$ , the intrinsic rate of population increase). Additionally, susceptibility was estimated using Walker's (2004) approach, where it is expressed as the product of four con-

ditional probabilities (availability, encounterability, selectivity and post-capture mortality).

## 2 Materials and methods

### 2.1 Productivity

Productivity, expressed through the intrinsic rate of population increase ( $r$ ), was estimated through a Leslie matrix approach (Caswell 2001). 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 (references used are available upon request). 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 ( $\alpha$ ) 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  $\pm 1$  or more years. Maximum age ( $\omega$ ) 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, and further truncated with lower and upper bounds set to the minimum and maximum litter sizes reported. 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  $\alpha - 1$ , 0.5 for  $\alpha$ , and 1 for ages  $\alpha + 1$ . 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 six indirect life history methods (see Cortés 2002, 2004; Simpfendorfer et al. 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. The productivity estimates obtained with this approach should, thus, be regarded as maximum values. The values of  $r$  reported and used in the ERA/PSA are the median of 10 000 iterations. Approximate 95% confidence intervals are also reported as the 2.5th and 97.5th percentiles.

## 2.2 Susceptibility

Susceptibility, in this case a measure of the potential impact of surface 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 is actually captured by the fishing gear; and post-capture mortality is the probability that the fraction of the population captured dies as a result of its interaction with the gear.

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 was available as the total number of observed hooks for a number of ICCAT flags for the period 1950–2005 (H. Arrizabalaga, ICCAT Sub-Committee on Ecosystems, February 2008, pers. comm.). Additionally, effort data for Uruguay was provided by the scientific observer program of their tuna fleet for 1998–2007. Species distributions were made available by the International Union for the Conservation of Nature (IUCN; Global marine species assessment distribution maps). Both effort and species distribution data were summarized on  $5^\circ \times 5^\circ$  grids.

We initially attempted to estimate encounterability as the degree of overlap between the depth distribution of the stock and that of the hooks, but because of the paucity of information on depth preferences of pelagic sharks and the variability of the depths at which pelagic longline gear is deployed based on target species and other factors, we assigned an encounterability value of 1 whenever the depth distributions of the stock and fishing gear overlapped. Information on species vertical distribution was obtained from various published and ongoing (and as yet unpublished) studies using archival satellite tags, whereas pelagic longline gear depth came from information collected in scientific observer programs by pelagic longline fleets of the USA, Venezuela, Brazil, Uruguay, Portugal and Namibia.

Measures of selectivity are also very rare for pelagic sharks and necessarily vary with animal size. Hence, we estimated selectivity by 1) determining the size range of animals caught in the fishery from the corresponding scientific observer program, 2) transforming the stable age distribution obtained

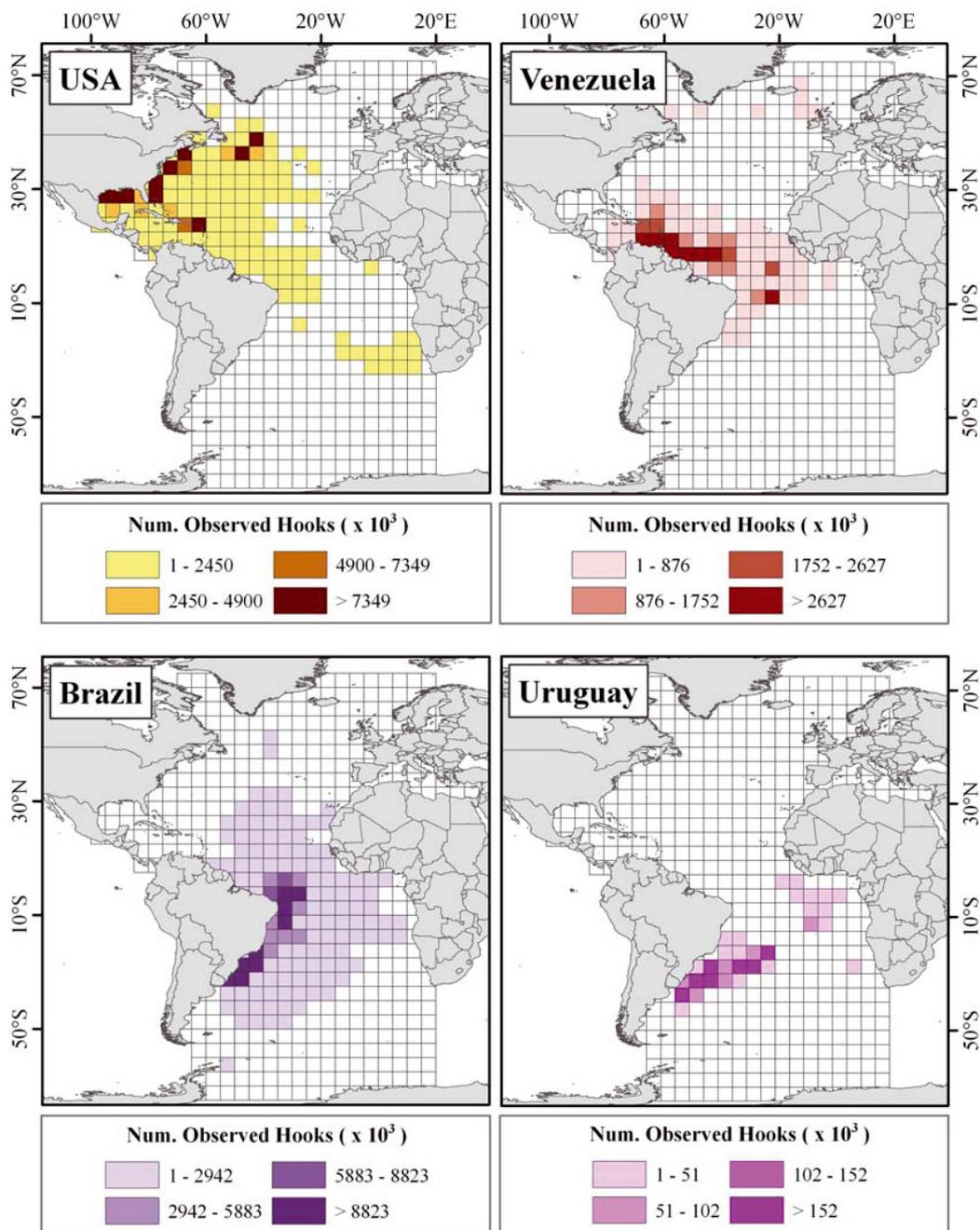
from the Leslie matrix (an output of the productivity analysis, see Sect. 2.1) into a length distribution using published von Bertalanffy growth function parameter estimates for each species, and 3) summing the frequencies of the “stable length distribution” covering the range of lengths observed caught in (1). Post-capture mortality was calculated as the sum of the proportions of animals retained and discarded dead from scientific observer programs. For the US observer program we were also able to estimate the proportion of animals that would die, out of those whose disposition was designated as “lost” (cryptic mortality), by applying the observed proportion of dead animals upon gear retrieval.

As originally conceived (Walker 2004), this method of estimating catch susceptibility assigns arbitrary risk categories (e.g., low, moderate, high) to each of the four attributes, which are then given a corresponding categorical value (e.g., 0.33, 0.66, and 1.00). Instead, we calculated a probability value ranging between 0 and 1 for each of them, as described above.

## 2.3 Analysis

We included eleven species of pelagic elasmobranchs in our 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 (*Carcharhinus falciformis*; FAL), porbeagle (*Lamna nasus*; POR), scalloped hammerhead (*Sphyrna lewini*; SPL), and smooth hammerhead (*Sphyrna zygaena*; SPZ) sharks, and the pelagic stingray (*Pteroplatytrygon violacea*; PST). We did not include the crocodile shark (*Pseudocarcharias kamoharai*) because the biological information available was insufficient to allow a Leslie matrix approach to be used with this species. It could be evaluated at a lower ERA level but the results would not be directly comparable to those reported herein. Also, although longfin mako and smooth hammerhead sharks were included in the analysis, the quality and extent of the biological information available for these two species were considerably lower than those available for the other species, particularly for longfin makos, for which productivity was set equal to that of shortfin makos.

The susceptibility analysis was conducted separately for several fleets for which information from observer programs was made available. Thus, we conducted analyses for fleets from the USA, Venezuela, Brazil, Uruguay, Portugal, and Namibia and on all fleets combined. Because the spatial effort distribution for Portugal was not available, we used that of Spain as a proxy, but the value of availability for Portugal is probably an overestimate because this fleet is five times smaller than its Spanish counterpart (MS, unpublished data, Fig. 1). The availability value for all fleets combined included spatial effort distribution for eighteen fleets (Belize, Brazil, China, Taiwan, Cuba, Cyprus, Spain, Greece, Japan, Korea, Mexico, Namibia, Panama, South Africa, Uruguay, USA, Vanuatu, and Venezuela and a collection of several small fleets). As an example, the spatial distribution of the eleven species included in the analysis (and that of the crocodile shark) in relation to the effort distribution of the USA pelagic longline fleet is shown in Figure 2.



**Fig. 1.** Effort (number of observed hooks) distribution for the USA, Venezuela, Brazil, Uruguay, Spain, Namibia, and all fleets combined.

The value of post-capture mortality for Portugal was the mean of those for the Equatorial Area and Northeastern Atlantic fleets, which tended to be identical. Similarly, the range of lengths observed by the Portuguese observer program accounted for both the Equatorial Area and Northeastern Atlantic fleets. The values of selectivity and post-capture mortality for the analysis with all fleets combined were the means of values for the individual fleets weighted by the effort (total number of observed hooks) for each fleet. For the Portuguese fleet, the total number of observed hooks corresponding to the Spanish fleet was divided by five to account for the smaller size of the Portuguese fleet.

Vulnerability ( $v$ ), 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), was calculated as the Euclidean distance from the focal point ( $r = 0$ ,  $s = 1$ ), or  $v = \sqrt{(p - 0)^2 + (s - 1)^2}$ , in the productivity ( $p$ ) and susceptibility ( $s$ ) scatter plot and the values were ranked.

### 3 Results

According to this analysis, most species of pelagic shark have low productivity and variable levels of susceptibility to

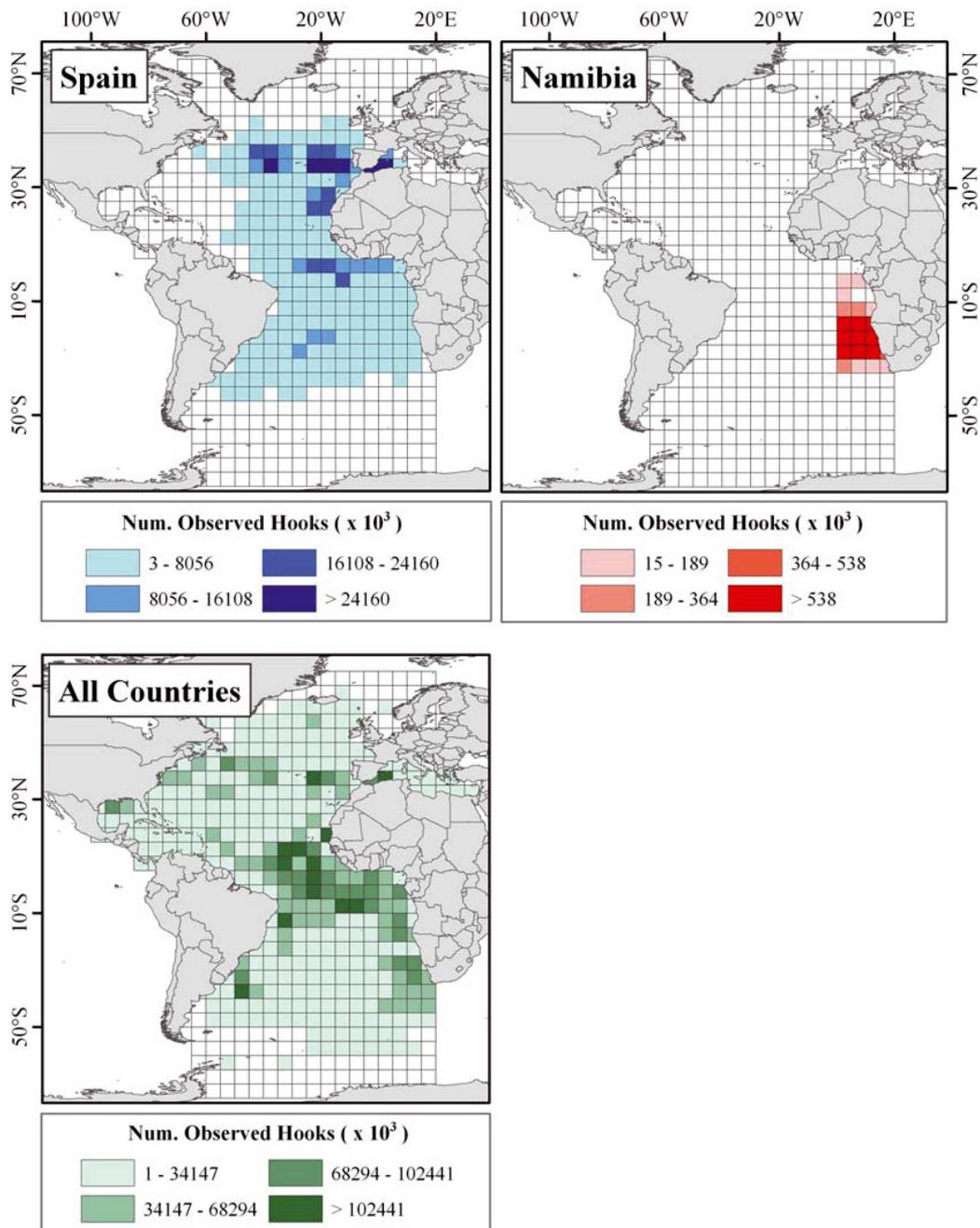
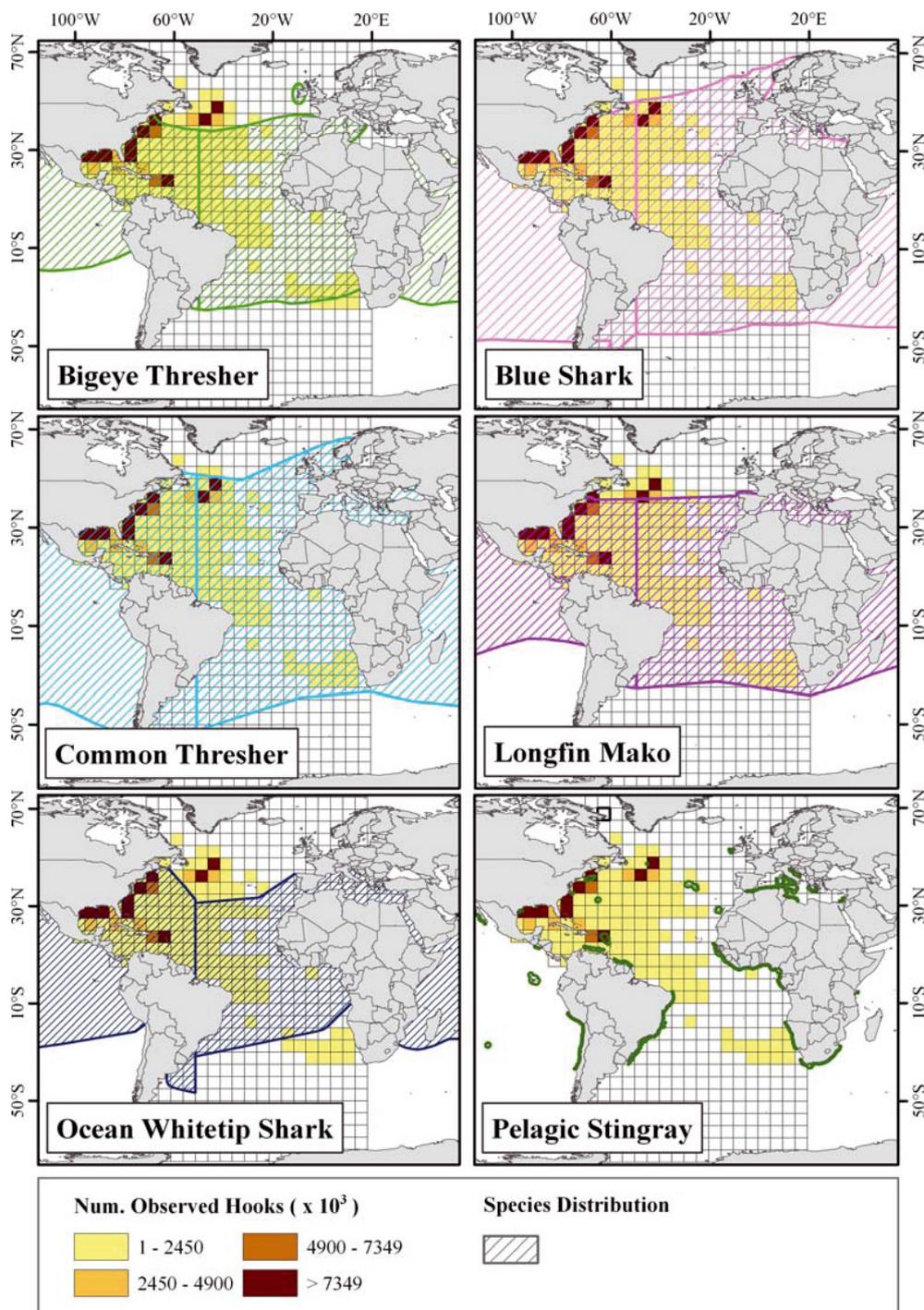


Fig. 1. Continued.

the combined pelagic longline fisheries in the Atlantic Ocean (Fig. 3, Table 1). Blue sharks have relatively high productivity and intermediate susceptibility, whereas common threshers and pelagic stingrays are relatively productive species that show very low susceptibility. The two hammerhead species included and the porbeagle show variable productivity but low susceptibility, whereas the oceanic whitetip and longfin mako (by proxy) sharks have similar levels of rather high susceptibility and varying productivity. The shortfin mako, bigeye thresher, and silky sharks have high susceptibility, but the silky shark is more productive than the first two species. The more recent life history variables used in the productivity

analysis show that the shortfin mako is less productive than previously thought (see SMA(i) data point in Figure 3 corresponding to the  $r$  value used in the 2004 ICCAT stock assessment). A cluster analysis, using k-means and specifying 4 clusters, identified the same groupings of species as described above and visible on Figure 3. The most vulnerable species were the silky, shortfin mako, and bigeye thresher sharks, whereas the common thresher and pelagic stingray were the least vulnerable (Table 1).

Availability varied widely among species and fleets, but for the analysis of all fleets combined it was very high, ranging from a minimum of 72% for the porbeagle shark to a maximum



**Fig. 2.** Spatial distribution of the 11 species of pelagic elasmobranch included in the analysis, plus the crocodile shark superimposed on the effort distribution of the USA pelagic longline fleet.

of 100% for the pelagic stingray (Table 2). Encounterability was 100% in all cases because there was always some degree of overlap between the depth distributions of each species and pelagic longline gear. Estimated selectivity ranged from 14% in the common thresher shark to 91% in the silky shark, and post-capture mortality spanned from 18% in both the common thresher shark and pelagic stingray to 92% in the shortfin mako shark (Table 2). In all, the silky shark had the highest sus-

ceptibility values and the common thresher shark and pelagic stingray, the lowest (Table 2, Fig. 4).

Fleet-specific plots for the individual species show that susceptibility varies with fleet within and among species (Fig. 4). Several species showed considerable spread in susceptibility values among fleets (bigeye thresher, blue, longfin mako, oceanic whitetip, shortfin mako and silky sharks), whereas other species showed much less variability (common

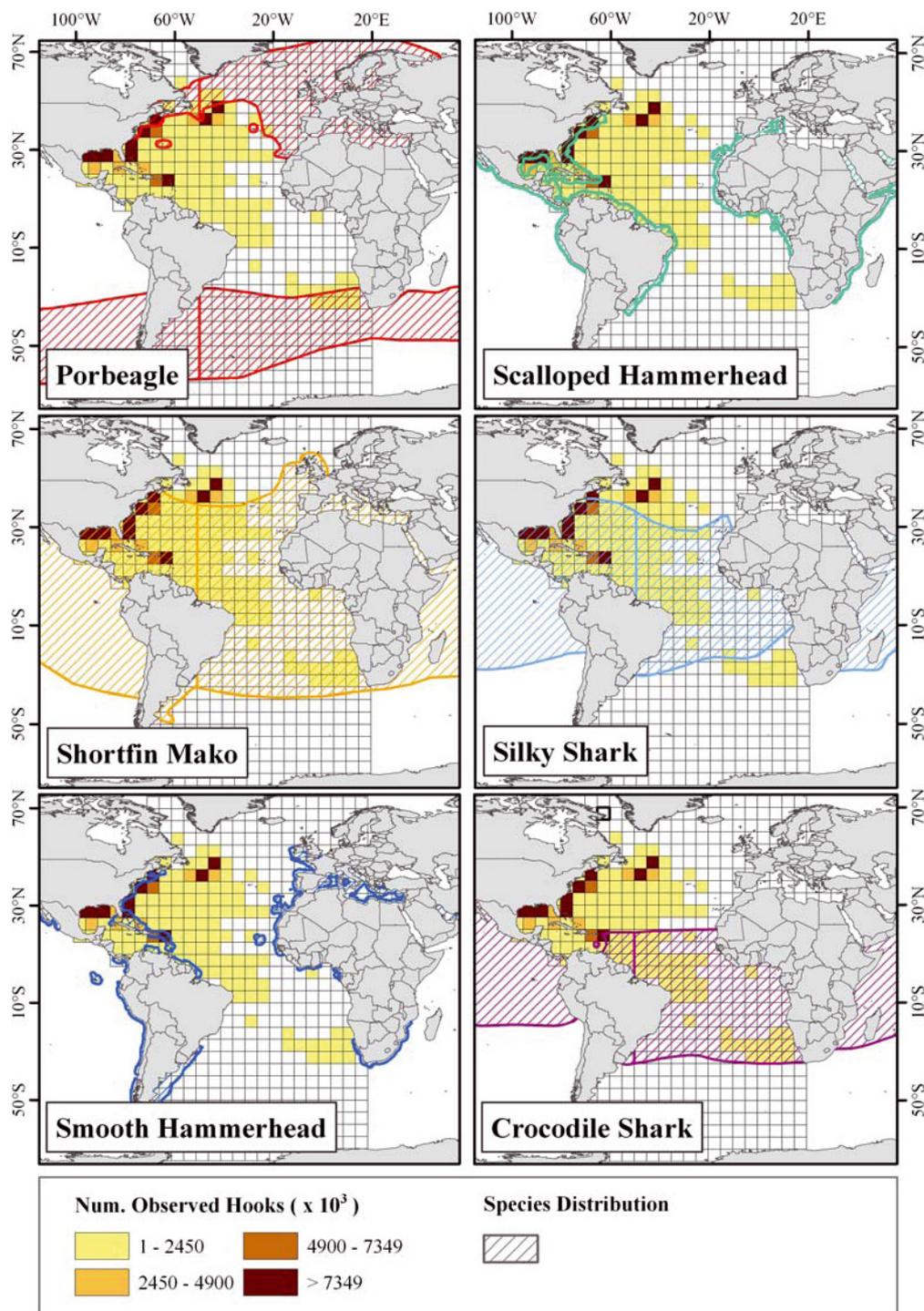


Fig. 2. Continued.

thresher, pelagic stingray, porbeagle, scalloped hammerhead and smooth hammerhead sharks). Susceptibility and vulnerability were generally highest for the combined fleets, although there were two exceptions (common thresher and pelagic stingray; Table 3, Fig. 4). This is due to the way in which the selectivity and post-capture mortality attributes were calculated for the combined fleets, i.e., as a weighted mean

that took into account the relative effort exerted by each fleet. Of the individual fleets included in this analysis, Portugal and Brazil tended to have the highest susceptibilities and vulnerabilities, but, as mentioned before, the susceptibility value for Portugal is probably an overestimate. Uruguay, and especially Namibia, both with reduced fleets, had the lowest susceptibility and vulnerability values in most cases (Table 3, Fig. 4).

**Table 1.** Productivity and susceptibility values for 11 species of pelagic elasmobranchs. Values for  $r$  (productivity) are the median and lower and upper confidence limits expressed as the 2.5th and 97.5th percentiles. Vulnerability rank (based on Euclidean distance; lower number indicates higher vulnerability) is also indicated.

Species	Common name	Code	Productivity ( $y^{-1}$ )	Susceptibility	Vulnerability rank
<i>Isurus oxyrinchus</i>	Shortfin mako	SMA <sup>1</sup>	0.073	0.741	3
<i>Alopias superciliosus</i>	Bigeye thresher	BTH	0.010 (–0.006–0.025)	0.684	4
<i>Prionace glauca</i>	Blue shark	BSH	0.286 (0.237–0.334)	0.514	7
<i>Alopias vulpinus</i>	Common thresher	ALV	0.133 (0.119–0.148)	0.023	12
<i>Isurus paucus</i>	Longfin mako	LMA <sup>2</sup>	0.018 (0.010–0.026)	0.583	6
<i>Carcharhinus longimanus</i>	Oceanic whitetip	OCS	0.094 (0.060–0.137)	0.622	5
<i>Pteroplatytrygon violacea</i>	Pelagic stingray	PST	0.153 (0.104–0.201)	0.058	11
<i>Lamna nasus</i>	Porbeagle	POR	0.048 (0.038–0.057)	0.149	10
<i>Sphyrna lewini</i>	Scalloped hammerhead	SPL	0.105 (0.080–0.157)	0.218	9
<i>Isurus oxyrinchus</i>	Shortfin mako	SMA	0.018 (0.010–0.026)	0.741	2
<i>Carcharhinus falciformis</i>	Silky	FAL	0.063 (0.037–0.083)	0.759	1
<i>Sphyrna zygaena</i>	Smooth hammerhead	SPZ	0.110 (0.086–0.133)	0.324	8

<sup>1</sup> Value for shortfin mako used in the 2004 ICCAT shark stock assessment.

<sup>2</sup> Values for LMA are those for SMA.

**Table 2.** Values for the four attributes of susceptibility (the product of the four attributes) for 11 species of pelagic elasmobranchs in the analysis of all fleets combined. Species codes are as in Table 1.

Species	Availability	Encounterability	Selectivity	Post-capture mortality	Susceptibility
BTH	0.98	1.00	0.89	0.78	0.68
BSH	0.93	1.00	0.70	0.79	0.51
ALV	0.91	1.00	0.14	0.18	0.02
LMA	0.98	1.00	0.68	0.88	0.58
OCS	0.97	1.00	0.83	0.77	0.62
PST	1.00	1.00	0.32	0.18	0.06
POR	0.72	1.00	0.39	0.53	0.15
SPL	0.95	1.00	0.28	0.83	0.22
SMA	0.95	1.00	0.85	0.92	0.74
FAL	0.97	1.00	0.91	0.86	0.76
SPZ	0.91	1.00	0.42	0.85	0.32

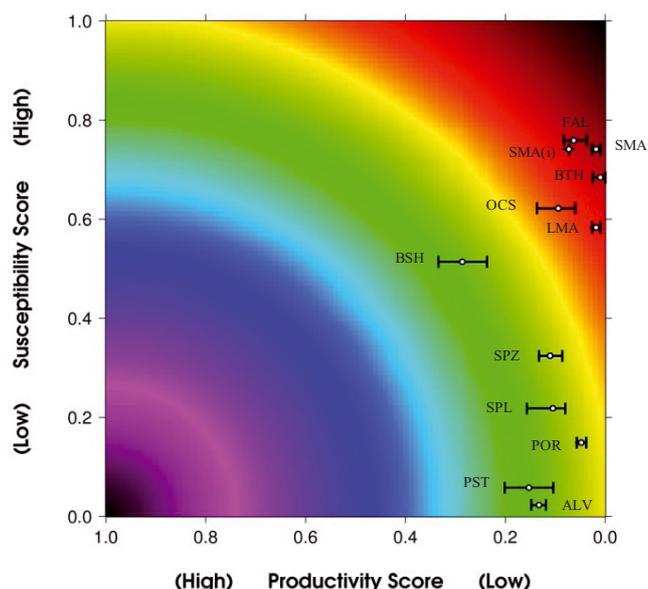
**Table 3.** Vulnerability ranks (smaller is riskier) for 11 species of pelagic elasmobranchs by fleet. The relative size of each fleet (expressed in millions of observed hooks for 1950–2005) is included. Species codes are as in Table 1.

ICCAT fleet	Species											Effort
	BTH	BSH	ALV	LMA	OCS	PST	POR	SPL	SMA	FAL	SPZ	
USA	5	5	2	4	5	3	5	3	4	5	4	274.6
Venezuela	3	4	1	5	3	5	6	7	5	4	7	67.3
Brazil	4	3	5	3	4	1	6	2	3	3	2	226.3
Uruguay	6	6	3	6	6	4	3	5	6	6	6	3.0
Portugal	2	2	5	2	2	5	2	4	2	2	3	429.4
Namibia	7	7	5	7	6	5	4	6	7	6	5	22.8
Combined	1	1	4	1	1	2	1	1	1	1	1	10 531.6

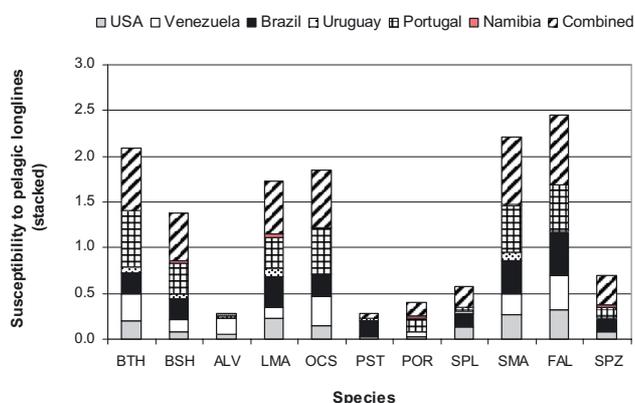
## 4 Discussion

The present analysis helps categorize the relative risk of overexploitation of the main species of pelagic elasmobranchs by pelagic longline fleets in the Atlantic Ocean, as well as the relative risk posed by each fleet. While this was a level-3 quantitative analysis, it still did not account for the actual level of fishing mortality ( $F$ ) exerted by each fleet. However, it appears that the combination of low productivity and high susceptibility to pelagic longline gear places several species at high

risk of overexploitation, most notably the silky, shortfin mako, and bigeye thresher sharks. Other species, such as the oceanic whitetip and longfin mako sharks are also highly vulnerable, the blue shark shows intermediate vulnerability, the smooth and scalloped hammerheads and porbeagle have a lower risk, and the pelagic stingray and common thresher shark have the lowest risk. It should be pointed out that the susceptibility aspect we used was calculated as the product of four attributes. Susceptibility values obtained here are therefore likely lower than those obtained in analyses that use additive measures. In



**Fig. 3.** Productivity and susceptibility plot for 11 species of Atlantic pelagic elasmobranch. Productivity is expressed as  $r$  (intrinsic rate of increase of the population) and susceptibility to pelagic longline fisheries as the product of availability, encounterability, selectivity and post-capture mortality (see text for details). Error bars denote lower and upper confidence limits of  $r$  expressed as the 2.5th and 97.5th percentiles. The upper right corner of the graph denotes the area of high risk, whereas the lower left corner denotes the low risk area. Species codes are as in Table 1.



**Fig. 4.** Susceptibility (expressed as stacked proportions) for the 11 species of Atlantic pelagic elasmobranch by fleet (see text for details). Species codes are as in Table 1.

all, pelagic sharks as a group are considerably vulnerable to the effect of pelagic longline fisheries, owing mostly to their limited productivity.

The analysis also highlights the need for better basic biological information, notably for species like the longfin mako and crocodile shark, but also for most of the other species included in the analysis, for which the life history variables used to construct Leslie matrices came only from one hemisphere or, in some cases, from a different ocean (e.g., smooth hammerhead and bigeye thresher). It also became apparent that very little is known about the vertical distribution and habitat

preferences of pelagic sharks, although archival satellite tags deployed on a number of species are slowly providing valuable information. The data gathered by the various observer programs around the Atlantic is also variable, but an effort should be made to standardize and maximize the amount and quality of information collected, regardless of funding constraints. For example, measurement of as many observed animals as possible should be encouraged, as should the recording of the status of each animal before it is brought on board.

Ecological risk assessments attempted thus far 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. For example, the availability of a given stock to pelagic longline gear will vary in space and time as a function of the stock and fleet distributions. The spatial effort distribution of the fleets we considered was an aggregated value that is a better reflection of the historical distribution of the fleets from 1950 to 2005 than of current fishing grounds, which have likely changed owing to regulations, market conditions, and other factors. Encounterability of the gear by the fish is influenced by many factors, including target species (depth of gear), time of operation, visibility conditions, bait type, and attractants (e.g., lightsticks) to cite a few. Selectivity or vulnerability to the gear is also a function of multiple factors, including attractants, hunger, bait type, gear saturation, bait loss, hook size and type, line tension, and animal strength (Ward 2008). Finally, post-capture mortality may also depend on animal size and quality, market conditions, and safety and regulatory considerations. While ERA should be updated periodically as new, more modern, 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 determining the vulnerability of a stock to the fishing gear.

The ERA we conducted is not intended to replace formal analytical stock assessments because it does not inform us about the status of the stocks, i.e., whether they are above or below overfished and overfishing thresholds. However, it is a convenient first step to help identify which species are more at risk based on our present knowledge of their biology and the effect that fleets operating in the Atlantic Ocean can have on their stocks.

**Acknowledgements.** We thank Haritz Arrizabalaga for providing the re-estimated effort information for ICCAT fleets and the IUCN SSG for providing the GMSA species distribution maps. We also thank S. Campana, J. Loefer, M. Musyl, G. Skomal and J. Stevens for making unpublished archival satellite tag data available. We are indebted to Don Kobayashi for his assistance in developing the scatter plot.

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