SCRS/2008/138

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

E. Cortés[1], F. Arocha[2], L. Beerkircher[3], F. Carvalho[4], A. Domingo[5], M. Heupel[6], H. Holtzhausen[7], M. N. Santos[8], M. Ribera[1], and C. Simpfendorfer[9]

SUMMARY

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 the species and a susceptibility analysis to assess their propensity to capture and death by pelagic longline fisheries. The risk analysis estimated productivity (intrinsic rate of increase, r) using a stochastic life table/Leslie matrix approach that incorporated uncertainty in age at maturity, lifespan, and 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 from 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 shortfin mako and bigeye thresher sharks. Other species, such as the oceanic whitetip, silky, and longfin mako sharks are also highly vulnerable, the scalloped and smooth hammerheads and porbeagle are less vulnerable, and the pelagic stingray, common thresher and blue shark have the lowest vulnerabilities.

KEYWORDS

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

[1] National Oceanographic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, Panama City Laboratory, 3500 Delwood Beach Road, Panama City, Florida 32408, U.S.A. E-mail: Enric.Cortes@noaa.gov
[2] Instituto Oceanográfico de Venezuela, Universidad de Oriente, Cumaná 6101, Venezuela
[3] National Oceanographic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, Florida 33149, U.S.A.
[4] University of Florida, Department of Fisheries and Aquatic Sciences, Florida Program for Shark Research, Gainesville, Florida 32653, U.S.A.
[5] DINARA, Area de Recursos Pelágicos, CP 11200 Montevideo, Uruguay
[6] School of Earth and Environmental Sciences, James Cook University, Queensland 4811, Australia
[7] Ministry of Fisheries and Marine Resources, Namibia
[8] INRB-IPIMAR, 8700-305 Olhão, Portugal
[9] Fishing and Fisheries Research Centre, School of Earth and Environmental Sciences, James Cook University, Queensland, 4811, Australia

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 more 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).

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 at least in one case a quantitative (level-3) approach was used for a shark species (Braccini et al. 2006). This 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), NOAA Fisheries Ecosystem Integrated Approach Team and National Standard 1 Guidelines Team, and ICCAT Ecosystems Working Group (SCRS/2007/010). Currently, it is also being applied to Atlantic sharks by several groups: Lenfest Working Group on “Scientific solutions for managing shark populations” (SCRS/2008/140), NOAA Vulnerability Evaluation Working Group, and 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 (or uncertainty in) series of catch and effort necessary to conduct analytical stock assessments for many of these species, this approach can be used to identify those species more, or less, at risk. We applied a fully quantitative analysis because the biological information was sufficient to estimate a direct measure of productivity (r, the intrinsic rate of increase of a population). Additionally, susceptibility was estimated using Walker’s (2004) approach, where it is expressed as the product of four conditional probabilities (availability, encounterability, selectivity and post-capture mortality).

2. MATERIALS AND METHODS

2.1 Productivity aspect

Productivity, expressed through the intrinsic rate of population increase (r), was 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 (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 (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, 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 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 six indirect life history methods (see Cortés 2002, 2004; 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/PSA are the mean of 10,000 iterations.

2.2 Susceptibility aspect

Susceptibility, in this case a measure of the 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 captured population dies.

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 for a number of ICCAT flags for the period 1950-2005 (H. Arrizabalaga, pers. comm.) and species distributions were made available by the IUCN (Global Marine Species Assessment distribution maps), both by 5º x 5º grids. We 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 at all. Information on species vertical distribution was obtained from various published and ongoing and yet unpublished studies using archival satellite tags, whereas pelagic longline gear depth came from observer programs of the USA, Venezuela, Brazil, Uruguay, Portugal and Namibia. Measures of selectivity are also very rare for pelagic sharks and necessarily vary by animal size, hence we estimated selectivity by: 1) determining the size range of animals caught in the fishery from a scientific observer program, 2) transforming the stable age distribution obtained from the life table/Leslie matrix (an output of the productivity analysis, see section 2.1) into a length distribution using published von Bertalanffy growth function parameters 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. We were also able to account for cryptic mortality (animals lost) when status (dead vs. alive) upon gear retrieval was available from the observer program.

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 (*C. 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 use a life table/Leslie matrix approach with this species. This species could be evaluated at a lower ERA level but the results would not be directly comparable to those reported herein. Although longfin mako and smooth hammerhead 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.

The susceptibility analysis was conducted separately for several fleets for which information from observer programs was made available in time for the analysis. Thus, we conducted analyses for the USA, Venezuela, Brazil, Uruguay, Portugal and Namibia and an analysis for all fleets combined. Because the spatial effort distribution for Uruguay and Portugal was not available, we used that of Brazil and Spain, respectively, as a proxy, but the values of availability for Uruguay and Portugal are probably overestimates because these fleets are smaller than their Brazilian and Spanish counterparts (Fig. 1). For example, the Spanish fleet is about five times as large as the Portuguese fleet. The availability value for all fleets combined included spatial effort distribution for eighteen fleets. 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. 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 in the Portuguese observer program accounted for both the Equatorial Area and Northeastern Atlantic fleets. The values of encounterability, 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 (number of observed hooks) for each fleet.

Vulnerability, a measure of the extent to which the impact of the fishery on a species will exceed its biological ability to renew itself (Stobutzki et al. 2002), was calculated as the Euclidean distance of the productivity and susceptibility values on an X-Y scatter plot and values ranked.

3. RESULTS

According to this analysis, most species of pelagic sharks have low productivity and variable levels of susceptibility to 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 silky and oceanic whitetip sharks have similar levels of intermediate productivity and high susceptibility. The bigeye thresher, shortfin mako, and longfin mako (by proxy) have very low productivity and high susceptibility, except the longfin mako, which has intermediate susceptibility. The more recent life history variables used in the productivity analysis show that this species 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 5 clusters identified the same groupings of species as described above by visually inspecting Figure 3. The most vulnerable species were the bigeye thresher and shortfin mako, whereas the common thresher and pelagic stingray were the least vulnerable.

Figure 4 shows the PSA plots for the individual species by fleet. The productivity aspect (X-axis) remains constant, but the susceptibility aspect varies according to the fleet included in the analysis. 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 spread (common thresher, pelagic stingray, porbeagle, scalloped hammerhead and smooth hammerhead sharks). Susceptibility was generally highest for the combined fleets, although there were two exceptions (common thresher and pelagic stingray; Table 2). This is due to the way in which the selectivity and post-capture mortality attributes for the combined fleets were calculated, 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, Brazil, Uruguay and Portugal tended to have the highest susceptibilities and vulnerabilities (but as noted before, the susceptibility values for Portugal and Uruguay are likely overestimates). Namibia, with a reduced fleet, consistently had the lowest susceptibility and vulnerability values.

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 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. It appears, however, that the combination of low productivity and high susceptibility to pelagic longline gear places several species at high risk of overexploitation, most notably the shortfin mako and bigeye thresher sharks. Other species, such as the oceanic whitetip, silky and longfin mako sharks are also highly vulnerable, the scalloped and smooth hammerheads and porbeagle have a lower risk, and the pelagic stingray, common thresher and blue shark have the lowest risk. Further, it should be pointed out that the susceptibility aspect we used was calculated as the product of four attributes, hence susceptibility values obtained here are likely lower than those obtained in analyses that use additive measures for example.

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 life tables/Leslie matrices came from one hemisphere only or in some cases from another ocean (e.g., smooth hammerhead and bigeye thresher). It also became apparent that very little is known of 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 there should be an effort 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 well as recording of the status of each animal before it is brought on board. In all, information from observer programs from other ICCAT nations can be included as it becomes available and ERA analyses updated periodically.

While this analysis is not intended to replace formal analytical stock assessments of these species, it helps to identify those species 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.

Acknowledgments

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 available unpublished archival satellite tag data.

References

BRACCINI, J.M., B.M. Gillanders and T.I. Walker. 2006. Hierarchical approach to the assessment of fishing effects on non-target chondrichthyans: case study of *Squalus megalops* in southeastern Australia. Can. J. Fish. Aquat. Sci. 63: 2456-2466.

CASWELL, H. 2001. Matrix population models. 2nd edition, Sinauer Associates, Sunderland, MA.

CORTÉS, E. 2002. Incorporating uncertainty into demographic modeling: Application to shark populations and their conservation. Cons. Biol. 16: 1048-1062.

CORTÉS, E. 2004. Life history patterns, demography, and population dynamics. Chapter 15 (pp. 449-469) In: (J.C. Carrier, J.A. Musick, and M.R. Heithaus, eds.) Biology of Sharks and Their Relatives (CRC Press).

CORTÉS, E., M. Heupel, M. Ribera and C.A. Simpfendorfer. 2008. Productivity and susceptibility analysis (Ecological Risk Assessment) of Atlantic sharks. 88th Annual Meeting of the American Society of Ichthyologists and Herpetologists (ASIH), 24th Annual Meeting of the American Elasmobranch Society (AES), Montreal, Canada, July 23-28 (abstract, presentation).

HOBDAY, A.J., A. Smith, H. Webb, R. Daley, S. Wayte, C. Bulman, J. Dowdney, A. Williams, M. Sporcic, J. Dambacher, M. Fuller and T.I. Walker. 2007. Ecological Risk Assessment for the Effects of Fishing: Methodology. Report R04/1072 for the Australian Fisheries Management Authority, Canberra: 173 pp.

MILTON, D. A. 2001. Assessing the susceptibility to fishing of populations of rare trawl bycatch: sea snakes caught by Australia’s Northern Prawn Fishery. Biol. Cons. 101: 281-290.

ROSENBERG, A. and 8 others. 2007. Setting Annual Catch Limits for U.S. Fisheries: An Expert Working Group Report. Lenfest Ocean Program.

SCRS/2007/010. 2007. Report of the 2007 inter-sessional meeting of the sub-committee on ecosystems. Madrid, Spain, February 19-23, 2007.

SCRS/2008/140. Simpfendorfer and 11 others. 2008. Status of pelagic sharks in the Atlantic based on an integrated risk approach.

SIMPFENDORFER, C.A., R. Bonfil and R.J. Latour. 2004. Mortality estimation. Chapter 8 (pp. 165-186) In: (J.A. Musick and R. Bonfil, eds.) Elasmobranch Fisheries Management Techniques, APEC Secretariat, Singapore.

SMITH, A.D.M., E.J. Fulton, A.J. Hobday, D.C. Smith and P. Shoulder. 2007. Scientific tools to support the practical implementation of ecosystem-based fisheries management. ICES J. Mar. Sci. 64: 633-639.

STOBUTSKI, I.C., M.J. Miller, D.S. Heales and D.T. Brewer. 2002. Sustainability of elasmobranchs caught as bycatch in a tropical prawn (shrimp) trawl fishery. Fish. Bull. 100: 800-821.

WALKER, T.I. 2004. Management measures. Chapter 13 (pp. 285-321) In: (J.A. Musick and R. Bonfil, eds.) Elasmobranch Fisheries Management Techniques, APEC Secretariat, Singapore.

Table 1. Productivity and susceptibility values for 11 species of pelagic elasmobranchs. Vulnerability rank (based on Euclidean distance; lower number indicates higher vulnerability) is also indicated.

Species	Productivity (r)	Susceptibility	Vulnerability rank
SMA (i)[1]	0.073	0.791	3
BTH	0.010	0.819	1
BSH	0.301	0.540	10
ALV	0.141	0.009	11
LMA	0.014	0.585	6
OCS	0.087	0.724	4
PST[2]	0.169	0.015	12
POR	0.053	0.283	7
SPL	0.090	0.166	9
SMA	0.014	0.791	2
FAL	0.076	0.695	5
SPZ	0.124	0.346	8

[1] Value for shortfin mako used in the 2004 ICCAT shark stock assessment
[2] Pelagic stingray

Table 2. Susceptibility (A) and vulnerability rank (B; smaller number is riskier) values for 11 species of pelagic elasmobranchs by fleet.

A)

ICCAT fleet	Species										
	BTH	BSH	ALV	LMA	OCS	PST	POR	SPL	SMA	FAL	SPZ
USA	0.20	0.08	0.05	0.23	0.15	0.03	0.03	0.14	0.27	0.33	0.07
Venezuela	0.30	0.14	0.17	0.12	0.32	0.00	0.00	0.00	0.23	0.37	0.00
Brazil	0.22	0.22	0.00	0.33	0.24	0.16	0.00	0.14	0.35	0.47	0.13
Uruguay	0.26	0.21	0.15	0.38	0.00	0.10	0.14	0.11	0.41	0.00	0.09
Portugal	0.61	0.33	0.00	0.35	0.51	0.00	0.14	0.04	0.51	0.52	0.12
Namibia	0.001	0.04	0.00	0.03	0.00	0.00	0.03	0.01	0.02	0.00	0.02
Combined	0.82	0.54	0.01	0.58	0.72	0.02	0.28	0.17	0.79	0.69	0.35

B)

ICCAT fleet	Species										
	BTH	BSH	ALV	LMA	OCS	PST	POR	SPL	SMA	FAL	SPZ
USA	6	6	3	5	5	3	5	3	5	5	5
Venezuela	3	5	1	6	3	5	6	7	6	4	7
Brazil	5	3	5	4	4	1	6	2	4	3	2
Uruguay	4	4	2	2	6	2	3	4	3	6	4
Portugal	2	2	5	3	2	5	2	5	2	2	3
Namibia	7	7	5	7	6	5	4	6	7	6	6
Combined	1	1	4	1	1	4	1	1	1	1	1

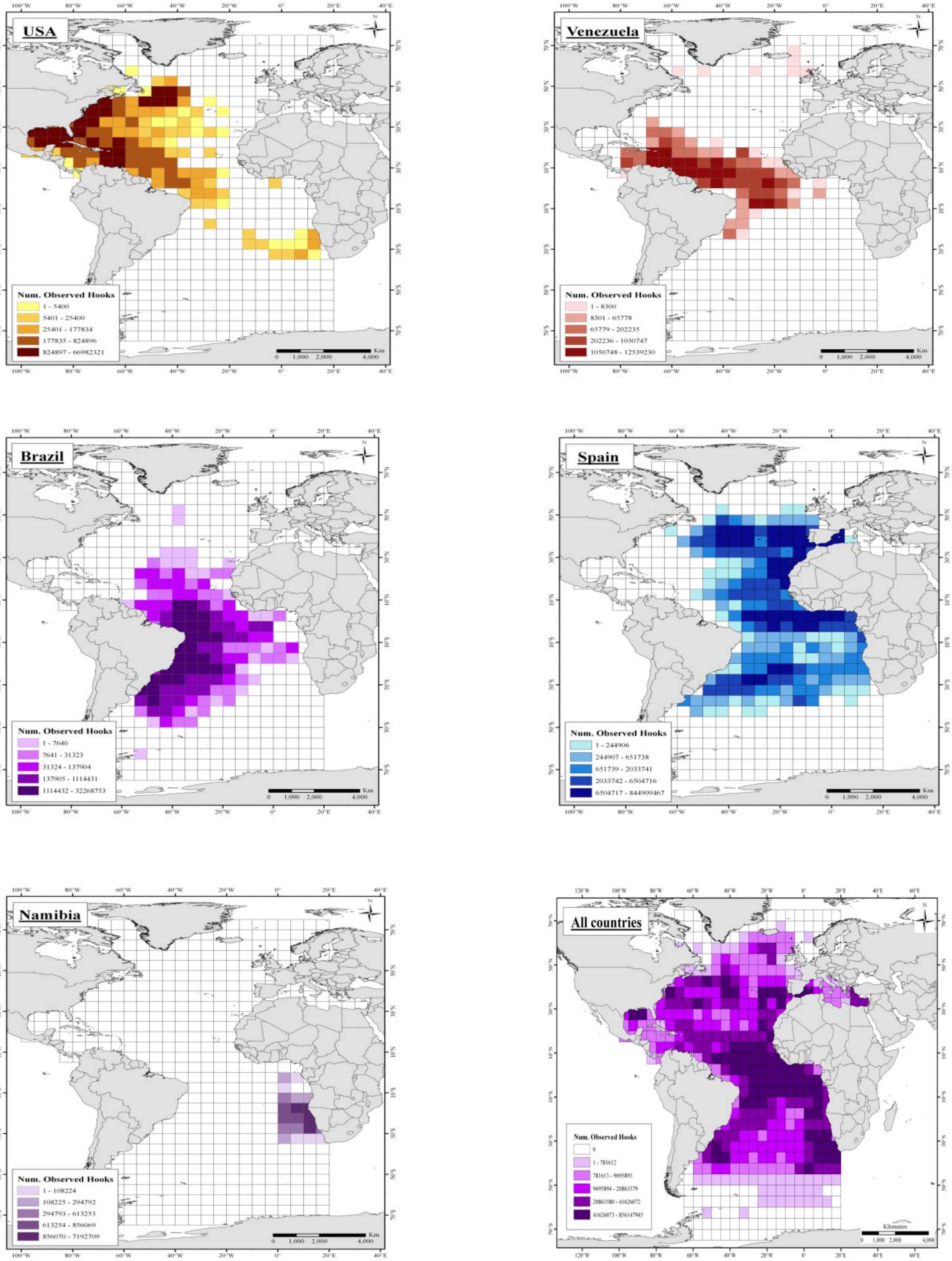

Figure 1. Effort (number of observed hooks) distribution for the USA, Venezuela, Brazil, Spain, Namibia, and all fleets combined

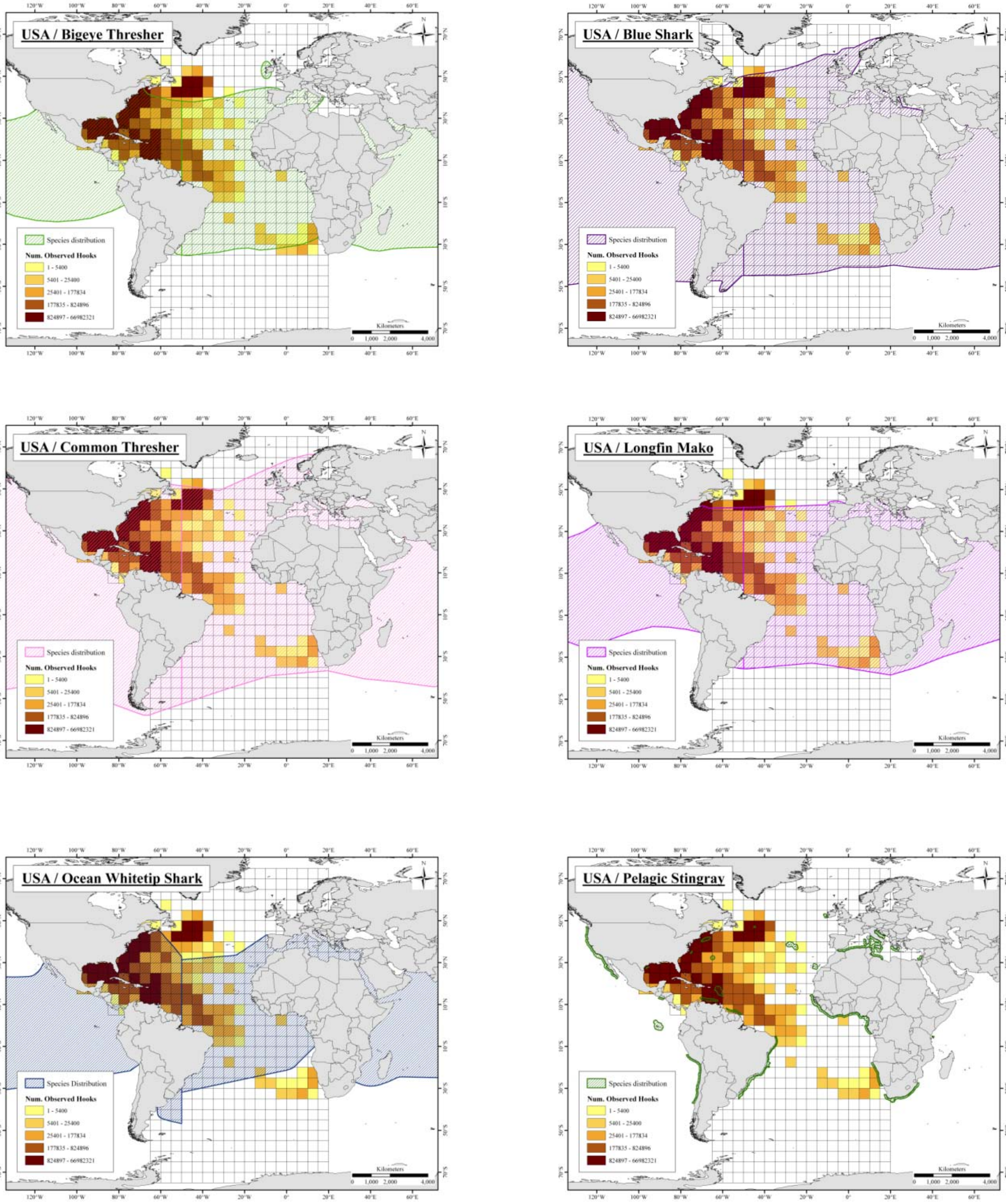

Figure 2. Spatial distribution of the 11 species of pelagic elasmobranchs included in the analysis (BTH, BSH, ALV, LMA, OCS, PST, POR, SPL, SMA, FAL, SPZ) and the crocodile shark superimposed on the effort distribution of the USA pelagic longline fleet.

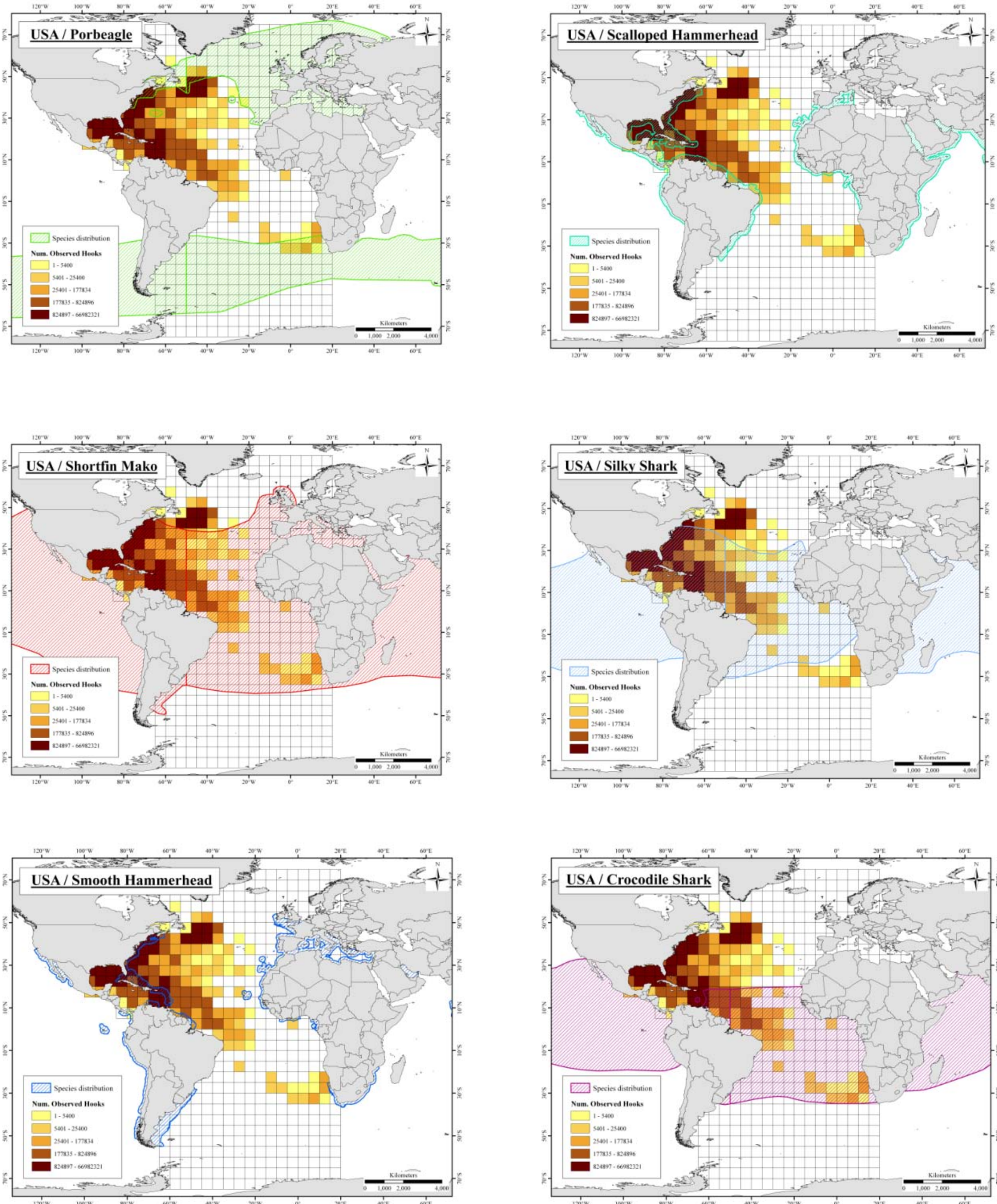

Figure 2. (continued).

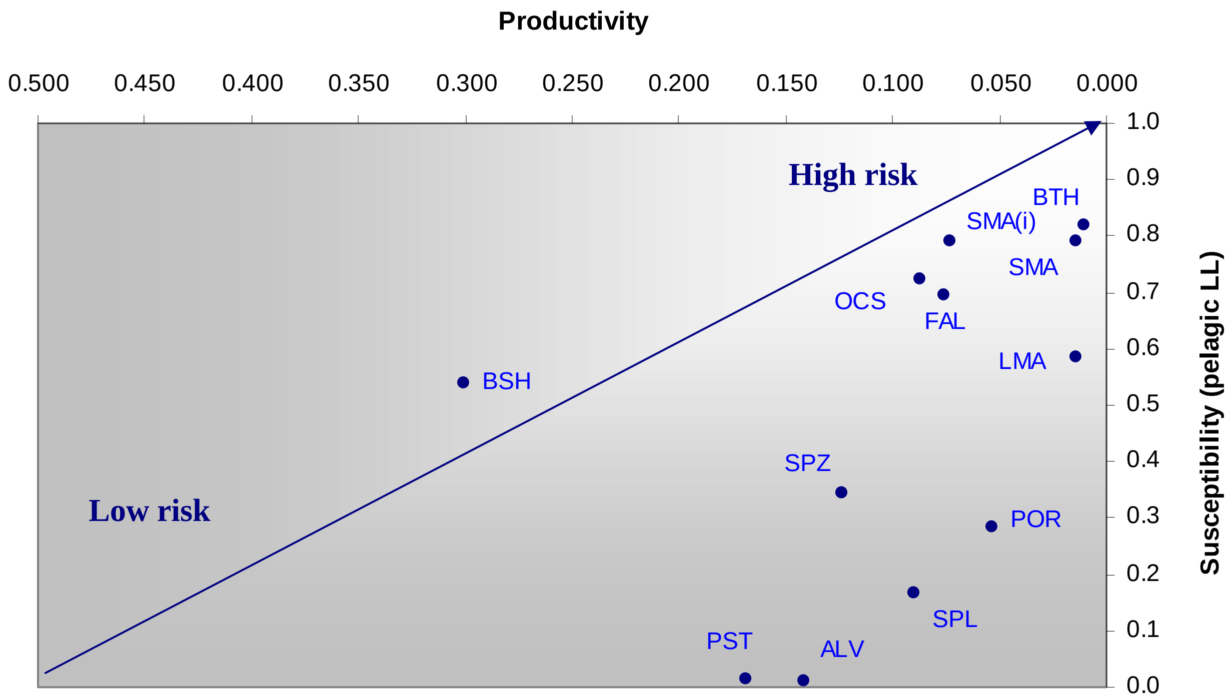

Figure 3. Productivity and susceptibility plot for 11 species of Atlantic pelagic elasmobranchs. Productivity is expressed as r (intrinsic rate of increase of the population) and susceptibility as the product of availability, encounterability, selectivity and post-capture mortality (see text for details).

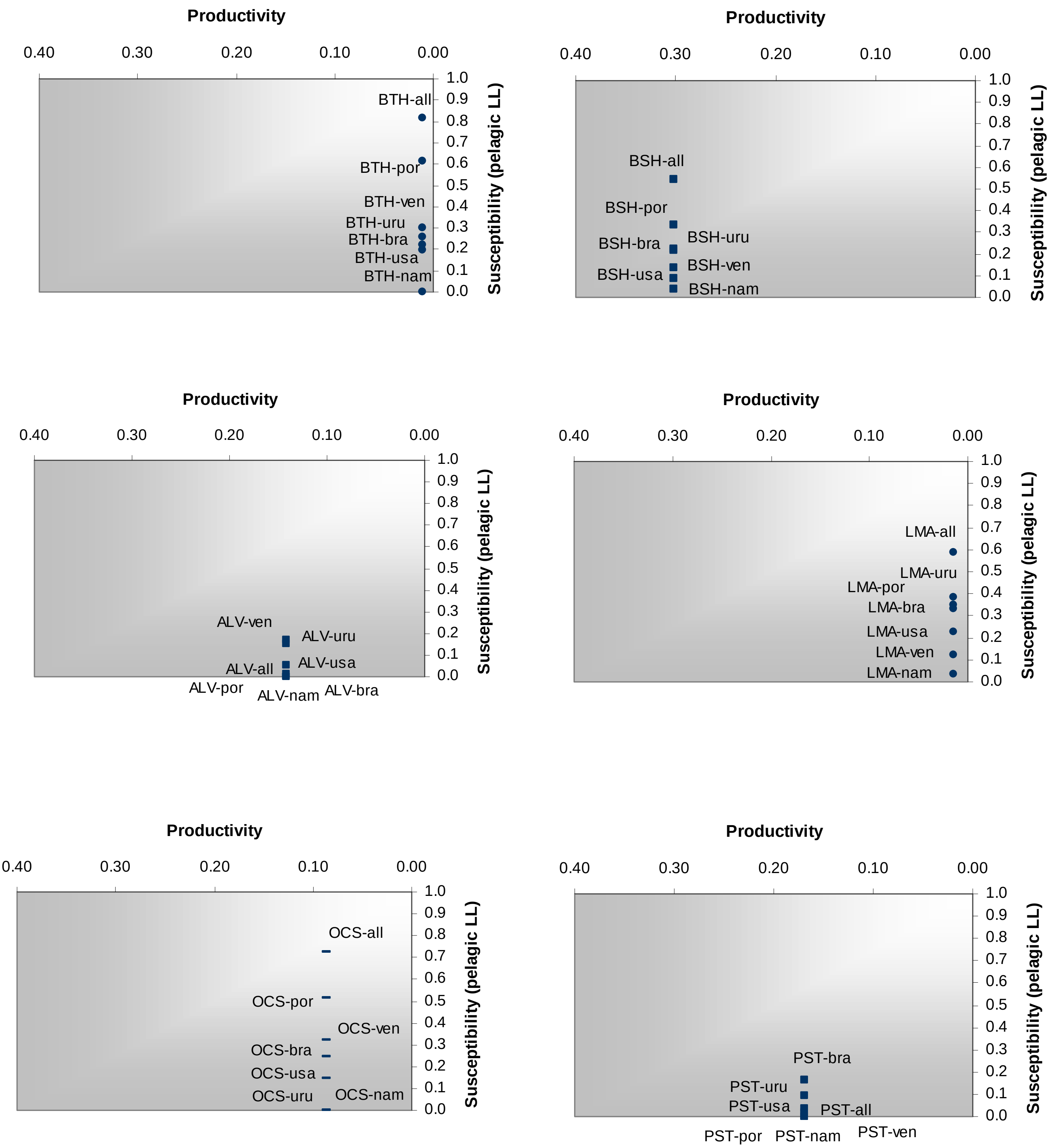

Figure 4. Productivity and susceptibility plots for the 11 species of Atlantic pelagic elasmobranchs by fleet (see text for details).

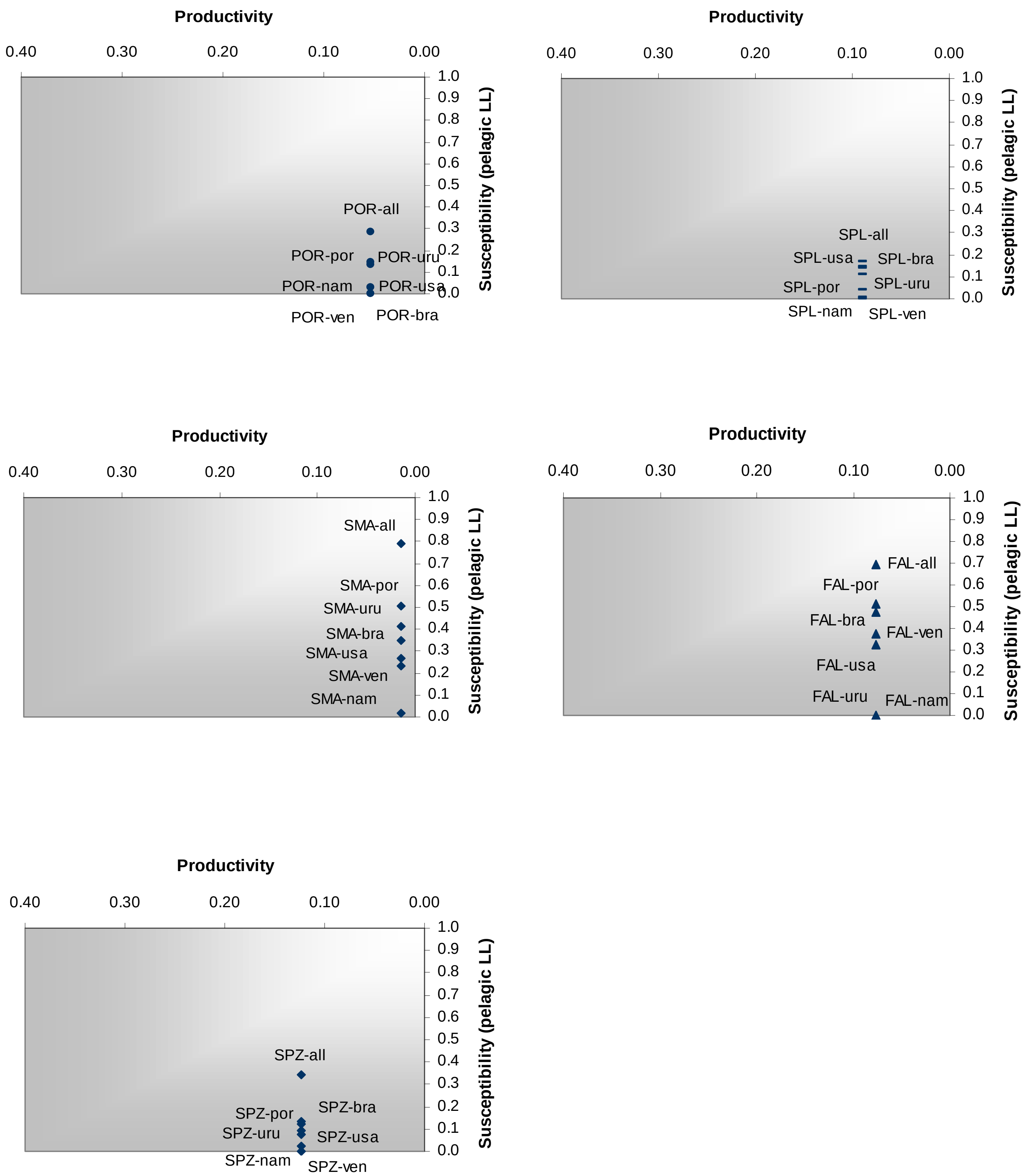

Figure 4. (continued).