Updated Ecological Risk Assessment (ERA) for shark species caught in fisheries managed by the Indian Ocean Tuna Commission (IOTC)

by

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ABSTRACT

Ecological risk assessment (ERA), and specifically Productivity-Susceptibility Analysis (PSA), is a useful methodology for assisting the management of fisheries from an ecosystem perspective in a data poor situation. Indian Ocean tuna and tuna-like fisheries, managed by the Indian Ocean Tuna Commission (IOTC), are economically important both at local and international scales and interact with several non-target or bycatch species.

A PSA for shark caught in various longline fleets, purse seiner fleet and gillnet fleet operating in the Indian Ocean was carried out. We follow the methodology proposed by Cortés *et al.* (2010), which allows ranking the vulnerability of the species based on its productivity and susceptibility to the fishing gear. We estimate the species productivity parameters based on Leslie matrices analysis, in which the value of Lambda (λ), population finite growth rate, was calculated (Caswell 2001). The susceptibility analysis was carried out comparing the horizontal overlap between fisheries and stock distribution, the vertical overlap between the species and fishing gear, the gear selectivity, and post-capture mortality.

The species with the least productivity values are the pelagic thresher (*Alopias pelagicus*) and the crocodile shark species (*Pseudocarcharias kamoharai*), followed by several Lamniformes (*Alopias superciliosus, Alopias vulpinus, Isurus paucus,* and *Lamna nasus*). However, for *Isurus paucus* little biological information is available and most information is from the Atlantic. As had been previously observed for other Oceans, such as the Atlantic (ICCAT, 2012), the blue shark (*Prionace glauca*) seems to be the pelagic shark species with the higher values of biological productivity.

The species more susceptible for the longline fishing fleets are the blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrhinchus*) followed by silky shark (*Carcharhinus falciformis*), porbeagle (*Lamna nasus*), bigeye thresher, great hammerhead and longfin mako. Then oceanic whitetip (*Carcharhinus longimanus*), common and pelagic threshers and smooth hammerhead (*Sphyrna zygaena*) are ranked in lower levels of susceptibility and the susceptibility of the rest of species is even lower. Overall, it was estimated that the most vulnerable species are the shortfin mako, silky shark, porbeagle and bigeye thresher, followed by blue shark, longfin mako, great hammerhead and oceanic whitetip. Common and pelagic threshers are rank with lower vulnerability because lower post-capture mortality after the entry in force of Resolution 12/09 on threshers.

The species more susceptible for the purse seine fishing fleets are the crocodile shark and pelagic thresher followed by longfin mako, particularly due to estimated selectivity and post-capture mortality, which are caught in low quantities in PS. The rest of species are ranked in much lower levels of susceptibility. The coastal shark species are less susceptible for the purse seiner fleets. Overall, and according to our analysis, for the purse seiner fleets the most vulnerable species are the crocodile shark, pelagic thresher, longfin mako, and silky shark. The most vulnerable species estimated in 2012, the oceanic white-tip and silky shark, were rank in much lower level of vulnerability in this exercise because their lower post-capture mortality after the implementation of safe release best practices in the purse seiner fleet in 2014. The rest of species are ranked in much lower levels of vulnerability.

The species more susceptible for the gillnet fishing fleets were the most coastal shark species such as smooth hammerhead, the crocodile shark and pelagic thresher followed by silky shark, scalloped hammerhead and longfin mako. Overall, for the gillnet fleets the most vulnerable species are the coastal crocodile shark, smooth hammerhead, pelagic thresher, silky shark and scalloped hammerhead. The rest of species are ranked in similar levels of vulnerability except blue shark and porbeagle with lower vulnerability.

The current PSA study does not evaluate the status of the stocks because it does not estimate the fishing mortality neither the biomass in relation to their biological reference points. Thus, from the result it cannot be inferred the stock status (eg overfishing/overfished) of the species of high vulnerability. Nevertheless, it is a step to identify the species which may be most vulnerable to different gears and for which more attention should be paid (e.g. data collection, surveys, assessment, etc…).

INTRODUCTION

While shark fisheries still account for a limited share of world fishing production, they have experienced rapid growth since the mid-1980s. This trend has been driven by an increased demand for shark products (fins in particular, but also meat, skin, cartilage, etc) and encouragement of full utilization of carcasses (to avoid finning), especially in Asian market and has been sustained by a number of factors, including improvements in fishing technology, processing and consumer marketing and declines in other fish stocks. All these elements contributed to make sharks a more valuable fishery, it has been estimated an average declared value of total world shark fin imports at USD377.9 million and USD239.9 million for shark meat for the period between 2000 and 2011 (FAO, 2015). Between 1984 and 2004, world catches of sharks grew from 600,000 to over 810,000 metric tons (Lack and Sant, 2011). Afterwards, according to the Food and Agriculture Organization of the United Nations (FAO) global production database, the world shark catches showed a slight decrease and catches fluctuated between 798,000 and 734,000 tonnes during the last decades. Sharks are particularly vulnerable to overexploitation because of their biological characteristics of maturing late, low reproductive capacity and being long-lived. This results in these species having a limited capacity to recover from periods of over fishing or other negative impacts.

Despite the growing concern about vulnerability and overexploitation of sharks, lack of accurate, species-specific harvest data often hampers quantitative stock assessment and, thus, effective international shark management and conservation. Action on sharks by United Nations Food and Agriculture Organisation (FAO), international treaties such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the Sharks Memorandum of Understanding on the Conservation of Migratory Shark (CMS Shark MoU), Regional Fisheries Management Organizations (RFMOs) and shark catching countries and entities has been prompted by increasing international concern about shark stocks as a result of a growing body of evidence that many shark species are threatened and continuing to decline because of fishing activity. As such FAO developed International Plan of Action for

Conservation and Management of Sharks (IPOA Sharks) to ensure the conservation and management of sharks and their long-term sustainable use.

In response to the increasing concerns, most of the tuna Regional Fisheries Management Organizations (tRFMOs) have also adopted conservation and management measures to mitigate the effect and bycatch of shark in tuna fisheries for ensuring their sustainability. Moreover, shark population status has led tuna RFMOs to agree on several actions to improve shark data collection, assessment and management. For example, IOTC has adopted *Resolution 17/05 On the conservation of sharks caught in association with fisheries managed by IOTC* and *Resolution 13/06 On a scientific and management framework on the conservation of shark species caught in association with IOTC managed fisheries*, where the CPCs are requested to improve their data collections system on shark and to submit data on shark catch and interaction of their fisheries to IOTC. Moreover, the Scientific Committee is requested to develop the management advice on shark based on most recent fishery data, stock assessment including Ecological Risks Assessment. In this regard, the IOTC Working Party on Ecosystem and Bycatch (WPEB) included in its 2018 workplan an update of the shark ERA carried out in 2012.

The Ecological Risk Assessment (ERA) for the effects of fishing framework involves a hierarchical approach that moves from a comprehensive but largely qualitative analysis of risk (level 1), through a more focused and semi-quantitative approach (level 2), to a highly focused and fully quantitative approach (level 3, (Hobday *et al.*, 2006)). Level 1 (Scale, Intensity, Consequence Analysis) evaluation of the risk is mostly based on perception from interaction with stakeholders, while a semi-quantitative approach which relies on good scientific investigation forms the basis of level two (Productivity Susceptibility Analsis, PSA), and level 3 is fully quantitative (full stock assessment and analysis of uncertainty).

There have been some ERA applications to tuna and tuna like fisheries. For instance, a PSA analysis for species caught in WCPO tuna fisheries was conducted by Kirby (2006). Cortés *et al.* (2010) conducted a PSA analysis first for eleven species of pelagic elasmobranchs and later expanded to sixteen species (Cortés *et al*., 2015) to assess their vulnerability to pelagic longline fisheries in the Atlantic Ocean. Similarly, a PSA was conducted for 17 shark species caught in the IOTC by longline and purse seine fleets (Murua *et al*., 2012). Also, the seabird assessment conducted within the ICCAT Sub-Committee on Ecosystems and Bycatch, included an initial PSA analysis that allowed the identification of seabird species most at risk, and those for which a level 3 risk assessment might be pursued (Anon., 2008). A similar Productivity–Susceptibility Analysis (PSA). analysis was also conducted as well as a PSA analysis for seabird in the WCPFC (Waugh et al., 2012). It was also applied to bycatch species caught in the Atlantic (Arrizabalaga *et al*., 2011), Indian (Murua *et al.*, 2009) and Eastern Pacific (Olson, 2011) Oceans. There have been also other initiatives to apply an Ecological Risk Assessment to turtles in IOTC (Nel et al., 2013; Williams et al., 2018).

The purpose of this paper is to update and extend previously conducted PSA, i.e. level 2 of an ERA analysis, for shark species caught in various fisheries targeting tuna and tuna-like species in the Indian Ocean (Murua *et al.*, 2012) to evaluate the vulnerability of sharks to longline, purse seiner, baitboat and gillnet fisheries operating in the Indian Ocean. The present document develops Productivity and Susceptibility Analysis for the major fishing fleets operating in the Indian Ocean and includes the following changes with respect to 2012 ERA IOTC: i) new fishery data including last year records and ii) besides longline and purse seine fleets, gillnet fleet is also added to the analysis. ERA could assist the Commission to identify, in the first instance, the key shark species considered to have the highest vulnerability to different gears so as to determine the shark species to be assessed and to prioritize research on these species more vulnerable to IOTC fishing gears as requested in Resolution 13/06.

MATERIAL AND METHODS

The Productivity and Susceptibility Analysis was first developed to rank bycatch sustainability in the Australian prawn fishery (Milton, 2001; Stobutzki *et al.*, 2001) by contrasting the productivity (*p*) of the bycatch species and their susceptibility (*s*) to the fishery. Different methodology has been used since then to estimate productivity and susceptibility (Milton, 2001; Braccini *et al.*, 2006; Hobday *et al.*, 2007; Patrick *et al.*, 2010; Cortés *et al.*, 2010) which use qualitatively (Patrick *et al.*, 2010) or semi-quantitative (Cortes *et al.*, 2010; 2015) approach. The productivity and susceptibility scores are displayed graphically on an x-y scatter plot to visualize species with high productivity and low susceptibility, which are considered at low risk or vulnerability, and low productivity and high susceptibility or those at high risk. The PSA figure allows to estimate directly an overall vulnerability score (*v*), a measure of the resilience of the species to the impact of the fishery (Stobutzki *et al.*, 2002; Cortés *et al.*, 2010; 2015), as the Euclidean distance from the origin of x-y xcatter plot (r = 1, s = 1) or

$$v = \sqrt{(p-1)^2 + (s-1)^2}$$

Productivity

Productivity parameters were estimated based on Leslie matrices analysis, in which the value of Lambda (λ), population finite growth rate, is calculated (Caswell 2001). All models considered were of the pre-breeding survey type, in which reproduction and natality take place first and only then is the survivorship considered. The elements in the first row of the matrices were, therefore, calculated as the products of the number of female offspring produced annually by each mature female of age x (mx) and the first-year survivorship (s0): Fx = s0.mx.

For all species analyzed, a 1:1 male to female ratio in the offspring was considered. Following the methods described in Cortes *et al.* (2010; 2015), and due to the lack of maturity ogives for most species, the proportion of mature females was assumed to be 0 for the ages younger than the age-at-maturity, 0.5 for the age-at-maturity reported in the literature, and 1 for the older age classes. A time lapse delay was added to each species to account for the delay between a specimen achieving maturity and effectively contributing with offspring to the population. This time lapse delay corresponded to duration (in years) of the reproductive cycle reported in the literature. The matrices first rows were further corrected to take into consideration the species-specific reproductive cycles (i.e. biannual, annual, biennial or triennial), as reported in the literature.

The annual survivorship input parameters for the matrices were estimated based on several indirect life history equations, specifically Pauly (1980), Hoenig (1983), Jensen (1996), Peterson and Wroblewski (1984), Chen and Watanabe (1989). For details on the application of these methods see Cortés (2002, 2004), Simpfendorfer *et al.* (2004). This analysis was carried out only for the species for which sufficient data specific to the Indian Ocean is available from the literature (Table 1). However, for most species analyzed in this paper, no information specific to the Indian Ocean is available and, thus, life history parameters previously reported for the Atlantic and/or Pacific Ocean were used (Table 1). In comparison to the previous ERA (Murua et al. 2012), biological information for each species was updated except for silky shark (*Carcharhinus falciformis*), tiger shark (*Galeocerdo cuvier*), whale shark (*Rhincodon typus*) and stingray (*Pteroplatytrygon violacea*) for which no studies/information were available after the previous 2012 ERA. For thresher sharks (genus *Alopias*), since reproductive cycle periodicity is still uncertain, two scenarios were analyzed taking into account different reproductive cycle periodicities (1 and 2-year reproductive cycle). Although information for whale shark is presented in Table 1, there was not sufficient information to estimate survivorship and, thus, to apply Leslie matrix for productivity analysis.

Uncertainty in the analysis was introduced in the survivorship and fecundity parameters. Uncertainty in the survivorship parameters was introduced by using a linearly increasing distribution with support defined between the minimum and maximum ranges of the estimated survivorship values. This method is similar, for example, to what previously applied by Cortes *et al.* (2010) for the Atlantic, and was used to simulate a compensatory density-dependent response from the species. Uncertainty in the reproductive parameters was introduced for the fecundity using a Normal distribution defined by the mean and with SD set to 25% of the mean. This approach to set the SD was chosen because of the general lack of information on the variability of the fecundity parameters for most species, and was based on personal observations from the authors.

Monte-Carlo simulation was used to introduce uncertainties in the analysis, with 10,000 matrices constructed for each species, based on the previously assumed distributions for the survivorship and fecundity parameters. The resulting 10,000 Leslie matrices were analyzed, and the distributions of the output parameters summarized as the mean λ values and the corresponding 95% confidence intervals (0.025 and 0.975 quantiles). This analysis was conducted using the R Project for Statistical Computing version 3.3.3. (R Development Core Team, 2017).

Susceptibility

Following Walker (2004) and Cortés *et al.* (2010), susceptibility, defined as the potential effect of the fisheries in the stock, can be assessed as the product of four parameters: availability, encounterability, selectivity and post-capture mortality. Availability is the proportion of the species habitat area harvested by a given fleet or the probability that the stock will be available for a given fleet on the horizontal plane; for example, a population that entirely lays in the fishing fleet range has a high availability equal to 1 whereas a population that distributes beyond fishing fleet range has low availability. Encounterability is the probability to encounter the available stock by one unit of fishing gear. Selectivity is the proportion of the individuals captured by the fishing gear provided that they are encountered. And post-capture mortality, is the proportion of animals that die as a result of the interaction with the gear (for more details see Walker (2004) or Cortés *et al.* (2010)).

Availability was estimated as the proportion of horizontal spatial overlap between the stock and the fleet. Spatial effort distribution for pelagic longline, purse seiner and gillnet fleets, as total number of hooks or days/hours, were available from IOTC database for a various IOTC fishing fleets for different periods since 1950 (IOTC Task II data - http://www.iotc.org/data/datasets). The period of 2011-2017 for catch and effort spatial distribution was used. Species distributions shapefiles were obtained from the International Union for the Conservation of Nature (IUCN; Global marine species assessment distribution maps). IOTC fisheries effort, compiled in 5º by 5º squares for LL and 1º by 1º squared for PS, were overlap with species distribution shapefiles to estimate the proportion of overlap between fishery and species spatial distribution using the package "sp" in R. For gillnets, the same approach of Williams et al. (2018) was used, where gillnet shapefile was produced to estimate gillnet spatial fishing effort distribution (for more details see Williams et al., 2018); which was then overlap with species distribution.

Encounterability was estimated as the proportion of vertical overlap between the population vertical distribution and the vertical distribution of the gear. Information of species vertical distribution was obtained from literature and web based libraries (www.fishbase.org, www.sealifebase.org, www.iucn.org, www.searoundus.org, http://www.flmnh.ufl.edu/fish/), while information of gear depth distribution was provided by the observer programs of various fleet analysed in the study. Since the information of vertical preferences of sharks is scarce and the vertical distribution of the gear is very variable depending various factors, such as target species and/or gear configuration, a value of 1 was assigned when depth distribution of population and fishing gear overlaps. Selectivity was estimated as the proportion of overlap between the size distributions of the animals caught by the fishery from the scientific observer programs and the length distributions obtained from the Leslie matrix (see the productivity analysis). The latter was obtained transforming the stable-age distribution output of the Leslie matrix into length distributions using Von Bertalanffy growth curve parameters for each species. Post-capture mortality was estimated as the proportion of dead animals (retained plus discarded dead for longline and discarded dead for purse seiner) from the scientific observer programs analysed.

Data and analysis

First, we identified all the shark by-catch species from the observed data for some of the fleets of LL, PS, and GN considered. In several cases only the genera or family is specified (no full species name is available) and, thus, to avoid potential duplication, we worked only with records with full species names. Then, we used web based libraries (www.fishbase.org, www.sealifebase.org, www.iucn.org, www.searoundus.org, http://www.flmnh.ufl.edu/fish/), as well as published documents in IOTC or elsewhere in relation to shark biology, to obtain biological and life history characteristic information about the shark species caught in IOTC fisheries. Based on observer records, we include 17 species 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), pelagic thresher (*Alopias pelagicus*; PTH), oceanic whitetip (*Carcharhinus longimanus*; OCS), silky (*Carcharhinus falciformis*; FAL), porbeagle (*Lamna nasus*; POR), scalloped hammerhead (*Sphyrna lewini*; SPL), smooth hammerhead (*Sphyrna zygaena*; SPZ), great hammerhead (*Sphyrna mokarran*; SPM), tiger (*Galeocerdo cuvier*; GAC) and crocodile sharks (*Pseudocarcharias kamoharai*) and the pelagic stingray (*Pteroplatytrygon violacea*; PLS). We did not include great white shark (*Carcharodon Carcharias*) and whale shark (*Rhincodon typus*) because the biological information to conduct a Leslie matrix analysis or information to estimate susceptibility was not available. The biological information obtained specifically for Indian Ocean was scarce and, thus, in those cases information available for other Oceans was used.

The susceptibility analysis for the effects of fishing on sharks was carried for the combined longline fleet, including longline targeting swordfish (ELL), longline Fresh (FLL), frozen longline (LL), exploratory longline (LLEX) and longline targeting sharks (SLL). Information from LL observer programs was available from Portuguese longline, Japanese longline, Chinese longline, and Maldivian LL. The combined Purse seiner fleet included industrial purse seiners (PS), small purse seiners (PSS), ring net (RIN) and ring net offshore (RNOF) and observer data was available for EU purse seiners. For gillnet (GN) different fleet segments as included in the IOTC catch and effort database were used. As such, the effort distribution for each combined fleet for the period 2011-2017 was combined to compare to the species distribution in order to estimate availability. The values of selectivity for different species were obtained from the observer length frequency distributions gathered by the Portuguese, Japanese, and Chinese longline observer program for the longline fleet and from the European Union observer program for the purse seiner fleet. No information on observer programs neither for gillnet was available. The post-capture mortality for different species was obtained from the Portuguese (Coelho *et al.*, 2011a; 2011b) and Japanese observer program data for the longline fleet and from the European Union observer program for the purse seine fleet.

RESULTS AND DISCUSSION

Fisheries information

Although several countries have not collected shark fishery statistics in the early years of the time series, the shark nominal reported catches in IOTC convention area increased continuously from 1950 onwards but especially from around the beginning of the 90s (Figure 1) to reach the historic highest catch levels of the time series in 1999 with around 120,000 tonnes of sharks. Since then, the total nominal reported catches have slightly decreased, and it was around 80,000 tonnes in 2008. Afterwards, shark catches increased again, and since 2015 catches have been over 100,000 tonnes. The Commission adopted Resolution 15/01, 15/02 and 17/05 which make mandatory the reporting of shark catch data for various shark species; however, the collection and reporting of shark catches in IOTC fisheries has been very irregular over time but have improved in the most recent years (Herrera and Pierre, 2012). Thus, the information on shark catch and bycatch available in the IOTC database is thought to be very incomplete. In this sense, it is considered that not all shark catches are reported and, if they are reported, they are not usually reported by species and they represent the catches of these species that are retained on board (or nominal catches) dressed with no indication on the type of processing that the different specimens underwent; which make very difficult the estimation of total shark catches by species (Herrera and Pierre, 2012). Herrera and Pierre (2012) also showed that most of the shark catches corresponds to pelagic sharks (around 60 %) while the coastal sharks corresponds to around 30 % of the total shark catches.

The contribution of each gear to total IOTC shark catches is shown in Figure 2. It can be observed that while the gillnet fishery contributed with 29 % of the total IOTC species its contribution increased up to a 56 % of the total shark catches being the main gear catching sharks. The gillnet fishery is followed by the line with 22 % (around 13 % of the total IOTC species) and longline with 14 % (around 22 % of the total IOTC species) of the total shark contribution. Purse seine contributes with 8 % (24 % of the total IOTC species) for which around 97% are caught by small purse seiners and ring nets; and other fleets and baitboat with 0 % (4% and 8 % of total IOTC species, respectively). The contribution of the different species in each fleet showed that most of the shark catches are reported as a group without identifying the species, except for longliners (Figure 3). For example, in the gillnet fishery most of the shark are reported as shark group (89 % SKH), whereas the main sharks reported by species are silky shark (5 %), blue shark (3%), and milk shark (2%). In the line fleet 71 % of the catch is reported as generic groups (sharks 47 %, thresher sharks 9 %, bonnethead and hammerhead sharks 8 %, mako sharks 4 %, and hammerhead sharks 3 %), whereas the main sharks reported by species are blue shark (28 %) and silky shark (1 %). Similarly, in purse seine 91 % is reported as shark groups (mostly reported as sharks by the small purse seiners) and by species silky sharks (7 %) and blue shark (2 %) are the most common reported species by the ring net. In others fleets and baitboat reported shark group catch is 100 % and 65 % (the other 35 % correspond to giant manta), respectively. However, in the longline around 28 % is reported as sharks in general (26 % sharks and 2 % mako sharks) and 71 % as species being blue shark (43 %) the main shark caught, followed by silky shark (17 %) and shortfin mako (8 %) and various species (3 % of the total catch) (Figure 3).

Biological and observer information

According to the observer data, in all fleets combined 26 shark and ray species were recorded. However, in several cases only the genera or family was specified (no full species name is available) and, thus, it was difficult to identify fully the number of shark species recorded. For the most common shark species present in the fleets analysed, the biological information compiled for the estimation of productivity is showed in Table 1. It can be observed that little biological information is available for most of the species specifically for the Indian Ocean. In fact, the complete set of biological information needed to run the Leslie matrix is only available specifically for the Indian Ocean for pelagic thresher, crocodile, tiger, silky and white great sharks. For the rest of the species, although some information is specific to Indian Ocean, most of the values of biological parameters were obtained from other Oceans (mainly from the Atlantic Ocean).

For the susceptibility analysis, Table 2 shows the data available to estimate the different parameters such as availability, encounterability, selectivity and post-capture mortality for the longline fleet. Although data to estimate availability and encounterability is available for all fleets, it should be mentioned that species distribution maps from IUCN are in constant process of improvement and, thus, update maps (e.g. for pelagic stingray) will affect in some extent the values of availability. Moreover, the values of selectivity and post-capture mortality are not widely collected by different observer programs which, in turn, affect the precision of the susceptibility analysis. For example, in our case, most of the data for post-capture mortality was obtained from Portugal fleet as more detailed information was available, except for common (ALV), pelagic thresher (PTH), and pelagic stringray (PLS) for which data from Japanese observer program was available but not from Portuguese fleet. For smooth hammerhead a post-capture mortality of 100 % was used as observer information was not available. Moreover, in some species the length frequencies used to estimate selectivity and the post-capture mortality values are estimated using a small sample which will have great impact in the final estimation. In this case, no data for great hammerhead was available and the value from 2012 for selectivity was used.

In the case of the purse seine fleet, most of the data available to estimate the different parameters of susceptibility was available. For some species, as the level of bycatch was very low there were not size frequency data available and, thus, in those cases the selectivity of the fleet was considered 1 (e.g. *Lamna nasus, Sphyrna mokarran, Isurus paucus, Alopias pelagicus, Galeocerdo cuvier, Pseudocarcharias kamoharai and Sphyrna lewini*). The same can be applied to the estimation of post-capture mortality; which due to very low number of bycatch individuals was not well recorded in the observer program. Nevertheless, in those cases the post-capture mortality was assigned the highest value of 1 (e.g. *Isurus paucus, Pseudocarcharias kamoharai* and *Pteroplatytrygon violacea*).

For gillnet fisheries no information on size/selectivity and post-capture mortality was available and, thus, for gillnet a size selectivity covering the whole selectivity estimated by the leslie matrix and 100 % post-capture mortality was assumed. This, of course, are large assumptions that could affect the results and should be taken into account. For the three fleets, the post-capture mortality should be considered as minimum values as there is no information of the survivorship of the animals release alive both in the longline and the purse seiner fleet.

Productivity Analysis

A summary of the species productivity, with the respective point estimates and 95% confidence intervals, is presented in Table 3. Monte-Carlo simulation on the Lambda estimates from the matrices by species are presented in Figure 4 and a comparison between species are shown in Figure 5. The species with the least productivity values are the pelagic thresher (PTH) and the crocodile coastal shark species (PSK), followed by several Lamniformes (bigeye-BTH and common-ALV threshers, longfin mako-LMA, and Porbeagle-POR). Specifically, the Lamniformes species with the lower productivity estimated were the species in the genus *Alopias* (PTH, BTH and ALV), when considering a 2-year reproductive cycle. By the contrary, the smooth hammerhead shark (SPZ) and the pelagic stingray (PLS) had relatively high productivity, which is consistent with the results from the previous ERA (Murua et al. 2012). The blue shark (BSH), as has been observed for other Oceans, such as in the Atlantic (ICCAT, 2012), seems to be the pelagic shark species among the highest values of biological productivity.

Susceptibility Analysis

The susceptibility analysed for the longline fleet is presented in Table 4. The species more susceptible for the longline fishing fleets are the blue shark (0.889) and shortfin mako (0.867) followed by silky shark, porbeagle, bigeye thresher, great hammerhead and longfin mako. Then oceanic whitetip, common and pelagic threshers and smooth hammerhead are ranked in lower levels of susceptibility and the susceptibility of the rest of species is even lower. Pelagic and common thresher are ranked lower in susceptibility than in 2012 as the retention of these species is forbidden by Resolution 12/09 and, thus, the values of post-capture mortality are lower than in 2012. Coastal shark species are less susceptible for the longline fleets. The overlap between shark species spatial distribution and the spatial distribution of the longline fleet can be observed in Figure 6. According to our results, availability is high for most of the species with values greater than 85 % in all cases with the exception of more coastal sharks such as great and smooth hammerheads and tiger shark for which an availability was between 65 and 75%. Availability for pelagic stingray was estimated very low because the IUCN distribution map restricts its distribution to very coastal waters, however, based on expert knowledge suggestion a much broader distribution (Domingo et al., in preparation) a larger value was used (as in 2012 analysis). The estimated selectivity was also large for most of the species with the exception of smooth/great hammerheads, tiger shark and crocodile shark. In most of the cases this value, with the exception of blue shark and shortfin mako, was estimated with few samples and, thus, this has a great impact on the final estimation of susceptibility (and hence vulnerability). The post-capture mortality varied from very low values of pelagic stringray (5%), crocodile shark (19 %), common (44 %) and pelagic (30%) threshers, and Oceanic whitetip shark (55%) to values larger than 70 % for the rest of the species. The post-capture mortality was estimated to be 100 % for great hammerhead because data was not available.

The susceptibility analysis for the purse seine fleet is presented in Table 5. The species more susceptible for the purse seine fishing fleets are the crocodile shark (0.442) and pelagic thresher (0.376) followed by longfin mako (0.364). The rest of species are ranked in much lower levels of susceptibility. The coastal shark species are less susceptible for the purse seiner fleets. The overlap between shark species spatial distribution and the spatial distribution of the purse seiner fleet can be observed in Figure 7. According to our results, availability is intermediate and low for most of the species whereas is very low for some species such as porbeagle, scalloped and smooth hammerhead and, in a lesser extent, for blue shark and common thresher. In any case, the availability estimated for the purse seiner fishery is much lower than the one estimated for longline as the latter is covering a larger area in the Indian Ocean. The estimated selectivity varied between around 0 % for smooth hammerhead and to 100 % for silky and oceanic white tip sharks. In most of the cases this value, with the exception of silky shark and oceanic white tip shark, was estimated with few samples and, thus, as this has a great impact on the final estimation of susceptibility (and hence vulnerability), it should be revisited once better length distribution form observer program are made available. The post-capture mortality varies from 20-25 % for bigeye thresher and blue shark, to values of around of 30 % for oceanic whitetip shark and of 55 % for silky and shortfin mako sharks. These values of post-capture mortality are much lower than previous ERA carried out in 2012 as the European purse seiner fleet (from which data is available) implemented the best practices for shark safe release in all its vessels since 2014. When data was not available, the post-capture mortality was assumed to be 100 % for that particular species, however, it should be taken into account that in most cases only few specimens of these species are caught.

The susceptibility analysis for the gillnet fleet are presented in Table 6. The species more susceptible for the gillnet fishing fleets were the most coastal shark species such as smooth hammerhead (0.447), the crocodile shark (0.447) and pelagic thresher (0.404) followed by silky shark (0.398), scalloped hammerhead (0.394) and longfin mako (0.384). The rest of species are ranked in similar levels of susceptibility except the blue shark and porbeagle. The overlap between shark species spatial distribution and the spatial distribution of the gillnet fleet can be observed in Figure 8. According to our results, availability is intermediate and low for most of the species whereas is very low for some species such as blue shark and porbeagle. Encounterability, selectivity and post-capture mortality was assumed to be 1 because no information was available for gillnet fisheries, as such the vulnerability was driven by the availability. Thus, as this has a great impact on the final estimation of susceptibility (and hence vulnerability), it should be revisited once better information form observer program are made available.

Vulnerability

According to our analysis, for the longline fleet the most vulnerable species are the shortfin mako, silky shark followed by porbeagle, bigeye thresher, blue shark, longfin mako and great hammerhead (Table 4 and Figure 9). The first four vulnerable species are characterized by relatively low productivity and high susceptibility; while blue shark is showing largest productivity but also the largest susceptibility. Longfin mako and great hammerhead are showing low productivity but also lower susceptibility. The rest of the species show variable productivity (from lowest to intermediate levels) but lower susceptibility values for the fishery and, thus, they have a lower overall vulnerability corresponding to lower rank of vulnerability (Table 4). For example, crocodile shark and pelagic/common thresher with the lowest productivity are ranked low in vulnerability because they are showing less susceptibility (particularly lower selectivity and post-capture mortality). Therefore, a priority should be given to those species which may request more attention from a biological point of view but also from stock assessment point of view in order to develop best possible management advice.

According to our analysis, for the purse seiner fleets the most vulnerable species are the crocodile shark, pelagic thresher, longfin mako, and silky shark being oceanic whitetip shark rank in 11th position. Crocodile shark, pelagic thresher and longfin mako are particularly vulnerable due to estimated selectivity and post-capture mortality, but are caught in lower quantity than silky shark. The most PS vulnerable species in 2012, silky and oceanic whitetip shark, were rank in lower vulnerability due to lower post-capture mortality after the implementation of safe release best practices in the purse seiner fleet in 2014. The rest of species are ranked in much lower levels of vulnerability. In the purse seiner fleet, the vulnerability is in a large extent defined by the susceptibility of the species to the gear rather than for the productivity of the species (Table 5 and Figure 9). Irrespective of the productivity, and in lesser extent availability, the vulnerability is driven by selectivity and post-capture mortality, which values were assumed to be 1 for the most vulnerable species. The three most vulnerable species are characterized by low productivity and high susceptibility. The rest of the species show variable productivity (from lowest to intermediate levels) but lower susceptibility values for the fishery and, thus, they have a lower overall vulnerability corresponding to lower rank of vulnerability (Table 5). Therefore, research and stock assessment priority should be given to those species ranked high.

According to our analysis, for the gillnet fleets the most vulnerable species are the coastal crocodile shark, smooth hammerhead, pelagic thresher, silky shark and scalloped hammerhead. The rest of species are ranked in similar levels of vulnerability except blue shark and porbeagle with lower vulnerability. In the gillnet fleet, the vulnerability is in a large extent defined by the susceptibility (availability) of the species to the gear rather than for the productivity of the species (Table 6 and Figure 9).

CONCLUSIONS

The present expanded Productivity and Susceptibility analysis was carried out for the three major fishing fleets operating in the Indian Ocean, i.e., g longline, gillnet and purse seiner fishery. In this sense, present document constitutes a significant step forward with respect to 2012 ERA, as including gillnet fleet, the major fleet catching pelagic and coastal shark species are now assessed. However, and despite noted data improvements, the study showed that there is a lack of biological parameters information specific for the Indian Ocean for those sharks caught in longline/purse seiner and gillnet fisheries as well as there is a limited length frequency and post-capture mortality data from observes for some longline/purse seiner fleets but being absent for gillnetters. Moreover, the post-capture mortality should be considered as minimum values as there is no information of the survivorship of the animals release alive both in the longline and the purse seiner fleet. Therefore, it is strongly recommended that shark biological information specific to the Indian Ocean as well as observer data compilation (size dat, post-release mortality studies, etc…) are collected to improve the analysis as data becomes available.

The PSA analysis carried out in this study can be considered quantitative but restricted to species caught by longline, gillnet and purse seiner fleets. This kind of global analysis, followed by more concentrated analyses could correspond to different levels within the ERA framework (Hobday *et al.*, 2006), can be regarded as a way to triage or rapidly assess different numbers of species to identify potentially vulnerable species that can then be subject to more detailed and rigorous analyses (Dulvy *et al.*, 2004) as well as data gaps that needs to be filled for research priorities. In this sense, the present study contributes to rank the vulnerability or relative risk to overexploitation of different shark species harvested by the longline, gillnet and purse seiner fleet in the Indian Ocean. In summary, for the longline fleet it was estimated that the most vulnerable species are the shortfin mako, silky shark, porbeagle and bigeye thresher, followed by blue shark, longfin mako, great hammerhead and oceanic whitetip. Common and pelagic threshers are rank with lower vulnerability because lower post-capture mortality after the entry in force of Resolution 12/09 on threshers. The first four vulnerable species are characterized by relatively low productivity and high susceptibility; while blue shark is showing largest productivity but also the largest susceptibility. Longfin mako and great hammerhead are showing low productivity but also lower susceptibility. The rest of the species show variable productivity (from lowest to intermediate levels) but lower susceptibility values for the fishery and, thus, lower overall vulnerability.

For the purse seiner fleet it was estimated that the most vulnerable species are the crocodile shark, pelagic thresher, longfin mako, and silky shark being oceanic whitetip shark rank in 11th position. It must be noted that for this fishery the whale shark was not considered in the analysis because there was not sufficient information to estimate survivorship and, thus, to apply Leslie matrix to estimate its productivity. The most vulnerable species estimated in 2012, the oceanic white-tip and silky shark, were rank in much lower level of vulnerability in this exercise because their lower post-capture mortality after the implementation of safe release best practices in the purse seiner fleet in 2014. The rest of species are ranked in much lower levels of vulnerability. For the gillnet fleet the most vulnerable species are the coastal crocodile shark, smooth hammerhead, pelagic thresher, silky shark and scalloped hammerhead. The rest of species are ranked in similar levels of vulnerability except blue shark and porbeagle with lower vulnerability.

Although it is difficult to compare the PSA analysis of different fleets, it is clearly observed from the tables and figures that having the same productivity most of the species the values of vulnerability are larger for the longline fleet in comparison with the purse seiner and gillnet fleet (Figure 9). In the longline fleet, more species are considered at higher vulnerability due to higher susceptibility to the gear in comparison to the purse seiner and gillnet gear that is showing a lower susceptibility for sharks. This is mainly because longline fleet shows a broader effort distribution covering almost the entire Indian Ocean (i.e. larger availability). However, this comparison should be refined taking into consideration the total catch and effort of different fleets in different areas and periods.

The current PSA study does not evaluate the status of the stocks because it does not estimate the fishing mortality neither the biomass in relation to their biological reference points. Thus, from the result it cannot be inferred the stock status (eg overfishing/overfished) of the species of high vulnerability. Nevertheless, it is a step to identify the species which may be most vulnerable to different gears and for which more attention should be paid (e.g. data collection, surveys, assessment, etc…).

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TABLES

Table 1.- Biological data inputs for the productivity component of the ERA analysis. In black: data specific to the Indian Ocean; In red: data from the Atlantic (ICCAT North Atlantic shark stocks); In green: data from the Pacific Ocean.

Species	Common name	Source region of biological data	Mean litter (n)	Reproductive periodicity (yr)	Female K (yr-1)	L∞ (cm FL)	t0	Median age at maturity (yr)	Female longevity (yr)	S0 (yr-1)
Alopias superciliosus (BTH)	Bigeye thresher	N Atlantic	3	1/2	0.06	284	109*	13	25	0.88
Alopias pelagicus (PTH)	Pelagic thresher	Indian Ocean	2	1/2	0.12	328.1[1]	140*	13	28	0.89
Alopias vulpinus (ALV)	Common thresher	N Atlantic	4	1/2	0.09	275.4	96.6*	12	24	0.82
Carcharhinus falciformis (FAL)	Silky shark	Indian Ocean	7.2	2	0.057	320.4[1]	81.1*	15	35	0.88
Carcharhinus longimanus (OCS)	Oceanic whitetip shark	Pacific Ocean	6	2	0.085	309.4[1]	64*	9	25	0.82
Pseudocarcharias kamoharai (PSK)	Crocodile shark	N Atlantic	4	2	0.137	129.2[1]	-3.9	5	13	0.72
Galeocerdo cuvier (TIG)	Tiger shark	Indian Ocean	55	2	0.202	301[1]	-1.11	11	29	0.77
Isurus oxyrinchus (SMA)	Shortfin mako	N/S Atlantic	15	2	0.04	407.56	-7.8	18	32	0.87
*Isurus paucus (LMA)***	Longfin mako	N/S Atlantic	4	2	0.04	407.56	-7.8	14	32	0.87
Lamna nasus (POR)	Porbeagle	Pacific Ocean	4	1	0.085	210.9	-6.10	15	32	0.88
Prionace glauca (BSH)	Blue shark	Indian Ocean	38	1	0.13	283	44*	6	25	0.71
Pteroplatytrygon violacea (PLS)	Pelagic stingray	N Atlantic	6	0.5	0.2	116[1]	17*	3	12	0.64
Sphyrna lewini (SPL)	Scalloped hammerhead	N Atlantic	25	2	0.09	233.1	-2.22	15	31	0.84
Sphyrna mokarran (SPK)	Great hammerhead	N Atlantic	24	2	0.11	307.8	-2.86	6	44	0.89
Sphyrna zygaena (SPZ)	Smooth hammerhead	N Atlantic	33	1	0.09	293.9	52.7*	9	24	0.85
Rhincodon typus (RHN)	Whale shark	Indian Ocean	55	-	0.032	1496	0.85	30 yr (males)	1900 cm	-
Carcharodon carcharias (WSH)	Great white shark	Indian Ocean	10	2	0.03	583.53	-7.86	30	38	0.80

* L0 (cm): FL for BTH, ALV, BSH and SPZ; DW for PLS; TL for PTH, FAL and OCS; [1] L∞ (cm): TL for PTH, FAL, OCS and PSK; PCL for TIG; DW for PLS.

Table 2.- Available data to estimate susceptibility parameters in the longline fleet.

			Susceptivility			
FAO Code	**Species/Stock**	**Common name**	**Availability**	**Encounterability**	**Selectivity**	**Post-capture mortality**
PSK	*Pseudocarcharias kamoharai*	Cocrodile shark	All	All	Portugal	
LMA	*Isurus paucus*	Longfin mako	All	All	Portugal/Japan	Portugal
BTH	*Alopias superciliosus*	Bigeye thresher	All	All	Portugal/Japan	Portugal
POR	*Lamna nasus*	Porbeagle	All	All	Japan	Portugal
SMA	*Isurus oxyrinchus*	Shortfin mako	All	All	Portugal/Japan	Portugal
SPL	*Sphyrna lewini*	Scalloped hammerhead	All	All	Portugal/Japan)	Portugal
FAL	*Carcharhinus falciformis*	Silky shark	All	All	Portugal/Japan	Portugal/
PTH	*Alopias pelagicus*	Pelagic thresher	All	All	Japan	Japan
SPM	*Sphyrna mokarran*	Great hammerhead	All	All	n/a	n/a
WSH	*Carcharodon carcharias*	Great white shark	All	All	n/a	Portugal
GAC	*Galeocerdo cuvier*	Tiger shark	All	All	Portugal/Japan	Portugal
ALV	*Alopias vulpinus*	Common thresher	All	All	Japan	Japan
OCS	*Carcharhinus longimanus*	Oceanic whitetip shark	All	All	Portugal/Japan	Portugal
PLS	*Pteroplatytrygon violacea*	Pelagic stingray	All	All	Japan	Japan
SPZ	*Sphyrna zygaena*	Smooth hammerhead	All	All	Portugal/Japan	Portugal
BSH	*Prionace glauca*	Blue shark	All	All	Portugal/Japan/China	Portugal

Table 3.- Productivity parameters for shark species captured and impacted in pelagic fisheries in the Indian Ocean in the IOTC area. The species list is sorted from lower to higher biological productivity. * Reproductive cycle (periodicity): 1-year; ** Reproductive cycle (periodicity): 2-year.

FAO code	Species	λ	95%CI (low)	95%CI (upp)
PTH*	*Alopias pelagicus*	0.923	0.898	0.931
PSK	*Pseudocarcharias kamoharai*	0.932	0.901	0.961
PTH	*Alopias pelagicus*	0.954	0.935	0.971
BTH*	*Alopias superciliosus*	0.988	0.975	0.999
ALV*	*Alopias vulpinus*	0.990	0.979	1.000
CCP	*Carcharhinus plumbeus*	1.001	0.977	1.023
WSH	*Carcharodon carcharias*	1.002	0.993	1.001
DUS	*Carcharhinus obscurus*	1.012	1.000	1.022
LMA	*Isurus paucus*	1.019	1.005	1.033
POR	*Lamna nasus*	1.020	1.009	1.031
FAL	*Carcharhinus falciformis*	1.020	1.005	1.033
BTH	*Alopias superciliosus*	1.033	1.019	1.046
SPL	*Sphyrna lewini*	1.040	1.020	1.058
ALV	*Alopias vulpinus*	1.040	1.027	1.051
OCS	*Carcharhinus longimanus*	1.049	1.028	1.068
SMA	*Isurus oxyrinchus*	1.049	1.036	1.061
TIG	*Galeocerdo cuvier*	1.163	1.130	1.198
SPK	*Sphyrna mokarran*	1.227	1.190	1.260
SPZ	*Sphyrna zygaena*	1.231	1.204	1.257
BSH	*Prionace glauca*	1.349	1.302	1.392
PLS	*Pteroplatytrygon violacea*	1.421	1.289	1.541

Table 4.- Productivity and susceptibility analysis for shark species captured and impacted in pelagic Longline fisheries in the Indian Ocean in the IOTC area. * Reproductive cycle (periodicity): 1-year; ** Reproductive cycle (periodicity): 2-year.

			Productivity	Susceptibility					Vulnerability	
FAO Code	**Species/Stock**	**Common name**	**Lambda**	**Availability**	**Encounterability**	**Selectivity**	**Post-captura mortality**	**Susceptibility**	**Vulnerability**	**RANK**
SMA	Isurus oxyrinchus	Shortfin mako	1.049 (1.036-1.061)	0.889	1.000	1.000	0.975	0.867	0.142	1
FAL	Carcharhinus falciformis	Silky shark	1.02 (1.005-1.033)	0.879	1.000	1.000	0.889	0.781	0.220	2
POR	Lamna nasus	Porbeagle	1.02 (1.009-1.031)	0.959	1.000	0.993	0.731	0.696	0.304	3
BTH**	Alopias superciliosus	Bigeye thresher	0.988 (0.975-0.999)	0.896	1.000	1.000	0.722	0.647	0.353	4
BTH*	Alopias superciliosus	Bigeye thresher	1.033 (1.019-1.046)	0.896	1.000	1.000	0.722	0.647	0.355	5
BSH	Prionace glauca	Blue shark	1.349 (1.302-1.392)	0.912	1.000	1.000	0.975	0.889	0.366	6
LMA	Isurus paucus	Longfin mako	1.019 (1.005-1.033)	0.879	1.000	0.867	0.737	0.561	0.439	7
SPK	Sphyrna mokarran	Great hammerhead	1.227 (1.19-1.26)	0.700	1.000	0.882	1.000	0.617	0.445	8
OCS	Carcharhinus longimanus	Oceanic whitetip shark	1.049 (1.028-1.068)	0.875	1.000	0.967	0.548	0.464	0.538	9
ALV*	Alopias vulpinus	Common thresher	1.04 (1.027-1.051)	0.910	1.000	0.967	0.446	0.392	0.609	10
ALV**	Alopias vulpinus	Common thresher	0.99 (0.979-1)	0.910	1.000	0.933	0.446	0.378	0.622	11
PTH*	Alopias pelagicus	Pelagic thresher	0.954 (0.935-0.971)	0.875	1.000	0.883	0.304	0.235	0.766	12
PTH**	Alopias pelagicus	Pelagic thresher	0.923 (0.898-0.931)	0.875	1.000	0.804	0.304	0.214	0.790	13
SPZ	Sphyrna zygaena	Smooth hammerhead	1.231 (1.204-1.257)	0.769	1.000	0.310	1.000	0.238	0.796	14
TIG	Galeocerdo cuvier	Tiger shark	1.163 (1.13-1.198)	0.643	1.000	0.305	1.000	0.196	0.820	15
PSK	Pseudocarcharias kamohara	Crocodile shark	0.932 (0.901-0.961)	0.871	1.000	0.534	0.189	0.088	0.915	16
SPL	Sphyrna lewini	Scalloped hammerhead	1.04 (1.02-1.058)	0.011	1.000	0.402	1.000	0.004	0.997	17
WSH	Carcharodon carcharias	Great white shark	1.002 (0.993-1.01)	0.903	1.000	0.000	0.000	0.000	1.000	18
PLS	Pteroplatytrygon violacea	Pelagic stingray	1.421 (1.289-1.541)	0.941	1.000	0.931	0.050	0.044	1.045	19

Table 5.- Productivity and susceptibility analysis for shark species captured and impacted in the Purse Seiner fisheries in the Indian Ocean in the IOTC area. * Reproductive cycle (periodicity): 1-year; ** Reproductive cycle (periodicity): 2-year.

			Productivity	Susceptibility					Vulnerability	
FAO Code	Species/Stock	Common name	Lambda	Availability	Encounterability	Selectivity	Post-captura mortality	Susceptibility	Vulnerability	RANK
PSK	Pseudocarcharias kamohara	Crocodile shark	0.932 (0.901-0.961)	0.442	1.000	1.000	1.000	0.442	0.563	1
PTH*	Alopias pelagicus	Pelagic thresher	0.954 (0.935-0.971)	0.376	1.000	1.000	1.000	0.376	0.626	2
PTH**	Alopias pelagicus	Pelagic thresher	0.923 (0.898-0.931)	0.376	1.000	1.000	1.000	0.376	0.629	3
LMA	Isurus paucus	Longfin mako	1.019 (1.005-1.033)	0.364	1.000	1.000	1.000	0.364	0.636	4
FAL	Carcharhinus falciformis	Silky shark	1.02 (1.005-1.033)	0.364	1.000	1.000	0.560	0.204	0.796	5
ALV**	Alopias vulpinus	Common thresher	0.99 (0.979-1)	0.272	1.000	0.667	1.000	0.182	0.818	6
SPK	Sphyrna mokarran	Great hammerhead	1.227 (1.19-1.26)	0.211	1.000	1.000	1.000	0.211	0.821	7
ALV*	Alopias vulpinus	Common thresher	1.04 (1.027-1.051)	0.272	1.000	0.580	1.000	0.158	0.843	8
SMA	Isurus oxyrinchus	Shortfin mako	1.049 (1.036-1.061)	0.304	1.000	0.787	0.540	0.129	0.872	9
PLS	Pteroplatytrygon violacea	Pelagic stingray	1.421 (1.289-1.541)	0.483	1.000	0.459	1.000	0.222	0.885	10
OCS	Carcharhinus longimanus	Oceanic whitetip shark	1.049 (1.028-1.068)	0.348	1.000	1.000	0.310	0.108	0.893	11
SPL	Sphyrna lewini	Scalloped hammerhead	1.04 (1.02-1.058)	0.082	1.000	1.000	1.000	0.082	0.919	12
TIG	Galeocerdo cuvier	Tiger shark	1.163 (1.13-1.198)	0.152	1.000	1.000	0.400	0.061	0.953	13
BTH**	Alopias superciliosus	Bigeye thresher	0.988 (0.975-0.999)	0.304	1.000	0.628	0.200	0.038	0.962	14
BTH*	Alopias superciliosus	Bigeye thresher	1.033 (1.019-1.046)	0.304	1.000	0.533	0.200	0.032	0.968	15
POR	Lamna nasus	Porbeagle	1.02 (1.009-1.031)	0.024	1.000	1.000	1.000	0.024	0.976	16
WSH	Carcharodon carcharias	Great white shark	1.002 (0.993-1.01)	0.267	1.000	0.000	0.000	0.000	1.000	17
SPZ	Sphyrna zygaena	Smooth hammerhead	1.231 (1.204-1.257)	0.085	1.000	0.023	1.000	0.002	1.024	18
BSH	Prionace glauca	Blue shark	1.349 (1.302-1.392)	0.270	1.000	0.372	0.260	0.026	1.034	19

Table 6.- Productivity and susceptibility analysis for shark species captured and impacted in the Gillnet fisheries in the Indian Ocean in the IOTC area. * Reproductive cycle (periodicity): 1-year; ** Reproductive cycle (periodicity): 2-year.

			Productivity	Susceptibility					Vulnerability	
FAO Code	Species/Stock	Common name	Lambda	Availability	Encounterability	Selectivity	Post-captura mortality	Susceptibility	Vulnerability	RANK
PSK	Pseudocarcharias kamohara	Crocodile shark	0.932 (0.901-0.961)	0.447	1.000	1.000	1.000	0.447	0.557	1
SPZ	Sphyrna zygaena	Smooth hammerhead	1.231 (1.204-1.257)	0.461	1.000	1.000	1.000	0.461	0.587	2
PTH*	Alopias pelagicus	Pelagic thresher	0.954 (0.935-0.971)	0.404	1.000	1.000	1.000	0.404	0.598	3
PTH**	Alopias pelagicus	Pelagic thresher	0.923 (0.898-0.931)	0.404	1.000	1.000	1.000	0.404	0.601	4
FAL	Carcharhinus falciformis	Silky shark	1.02 (1.005-1.033)	0.398	1.000	1.000	1.000	0.398	0.603	5
SPL	Sphyrna lewini	Scalloped hammerhead	1.04 (1.02-1.058)	0.394	1.000	1.000	1.000	0.394	0.607	6
LMA	Isurus paucus	Longfin mako	1.019 (1.005-1.033)	0.384	1.000	1.000	1.000	0.384	0.617	7
OCS	Carcharhinus longimanus	Oceanic whitetip shark	1.049 (1.028-1.068)	0.377	1.000	1.000	1.000	0.377	0.625	8
BTH**	Alopias superciliosus	Bigeye thresher	0.988 (0.975-0.999)	0.332	1.000	1.000	1.000	0.332	0.669	9
BTH*	Alopias superciliosus	Bigeye thresher	1.033 (1.019-1.046)	0.332	1.000	1.000	1.000	0.332	0.669	10
TIG	Galeocerdo cuvier	Tiger shark	1.163 (1.13-1.198)	0.342	1.000	1.000	1.000	0.342	0.678	11
SMA	Isurus oxyrinchus	Shortfin mako	1.049 (1.036-1.061)	0.318	1.000	1.000	1.000	0.318	0.684	12
SPK	Sphyrna mokarran	Great hammerhead	1.227 (1.19-1.26)	0.344	1.000	1.000	1.000	0.344	0.694	13
ALV**	Alopias vulpinus	Common thresher	0.99 (0.979-1)	0.286	1.000	1.000	1.000	0.286	0.714	14
ALV*	Alopias vulpinus	Common thresher	1.04 (1.027-1.051)	0.286	1.000	1.000	1.000	0.286	0.715	15
PLS	Pteroplatytrygon violacea	Pelagic stingray	1.421 (1.289-1.541)	0.342	1.000	1.000	1.000	0.342	0.781	16
BSH	Prionace glauca	Blue shark	1.349 (1.302-1.392)	0.282	1.000	1.000	1.000	0.282	0.798	17
POR	Lamna nasus	Porbeagle	1.02 (1.009-1.031)	0.011	1.000	1.000	1.000	0.011	0.990	18
WSH	Carcharodon carcharias	Great white shark	1.002 (0.993-1.01)	0.285	1.000	1.000	0.000	0.000	1.000	19

FIGURES

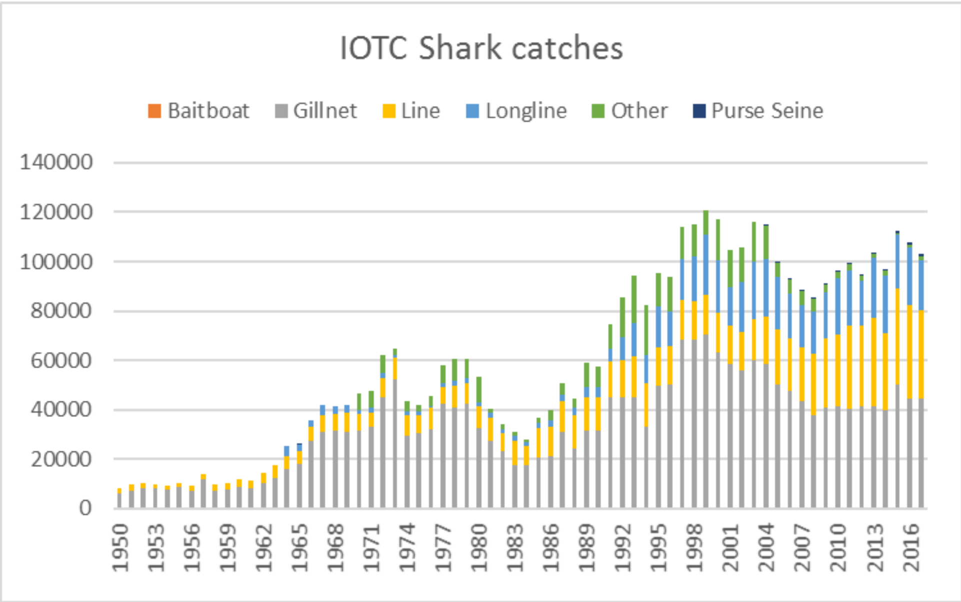

Figure 1.- Total nominal catch of IOTC Shark species by fishing gear for the period 1950-2017.

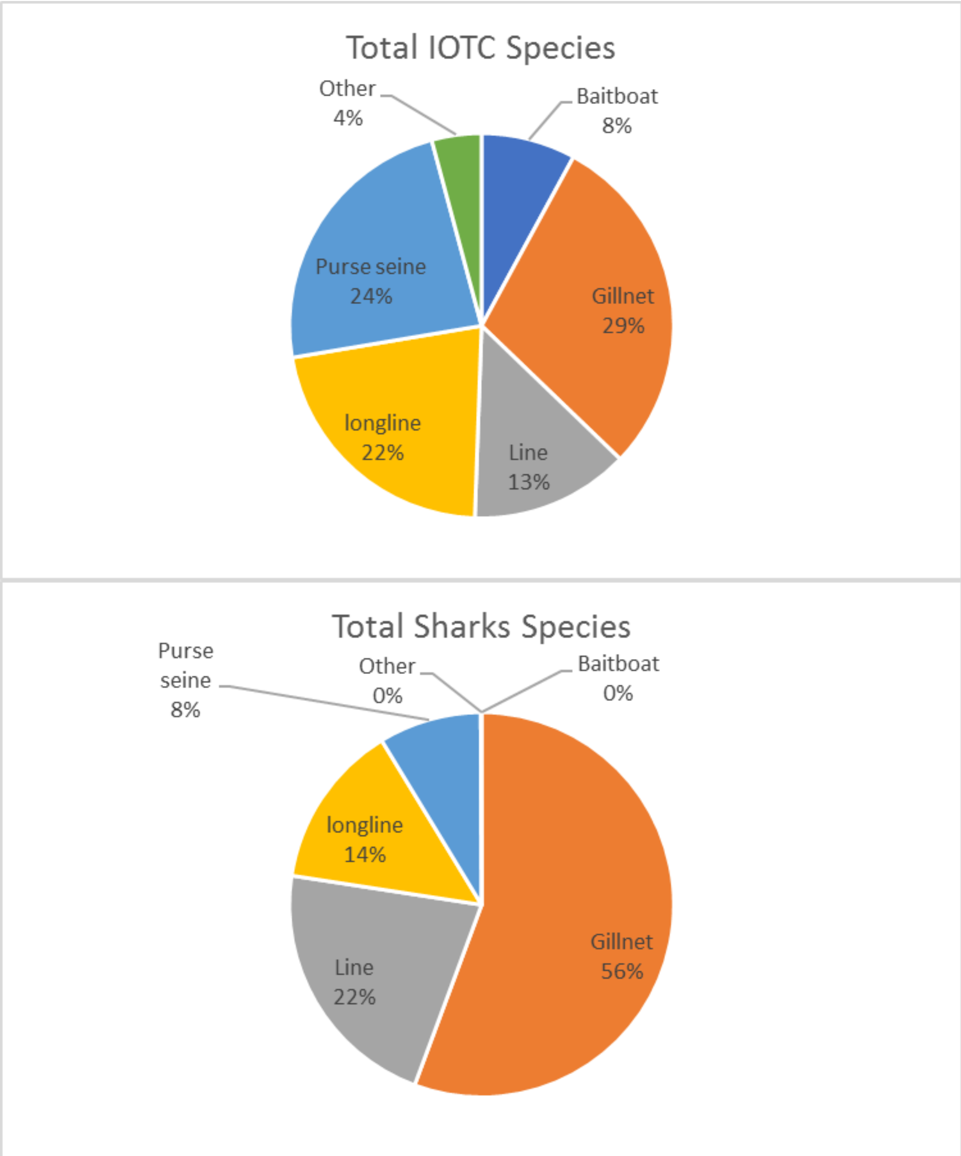

Figure 2.- Relative contribution to total IOTC species catch and total IOTC shark catch by different gears for the period 1950-2017.

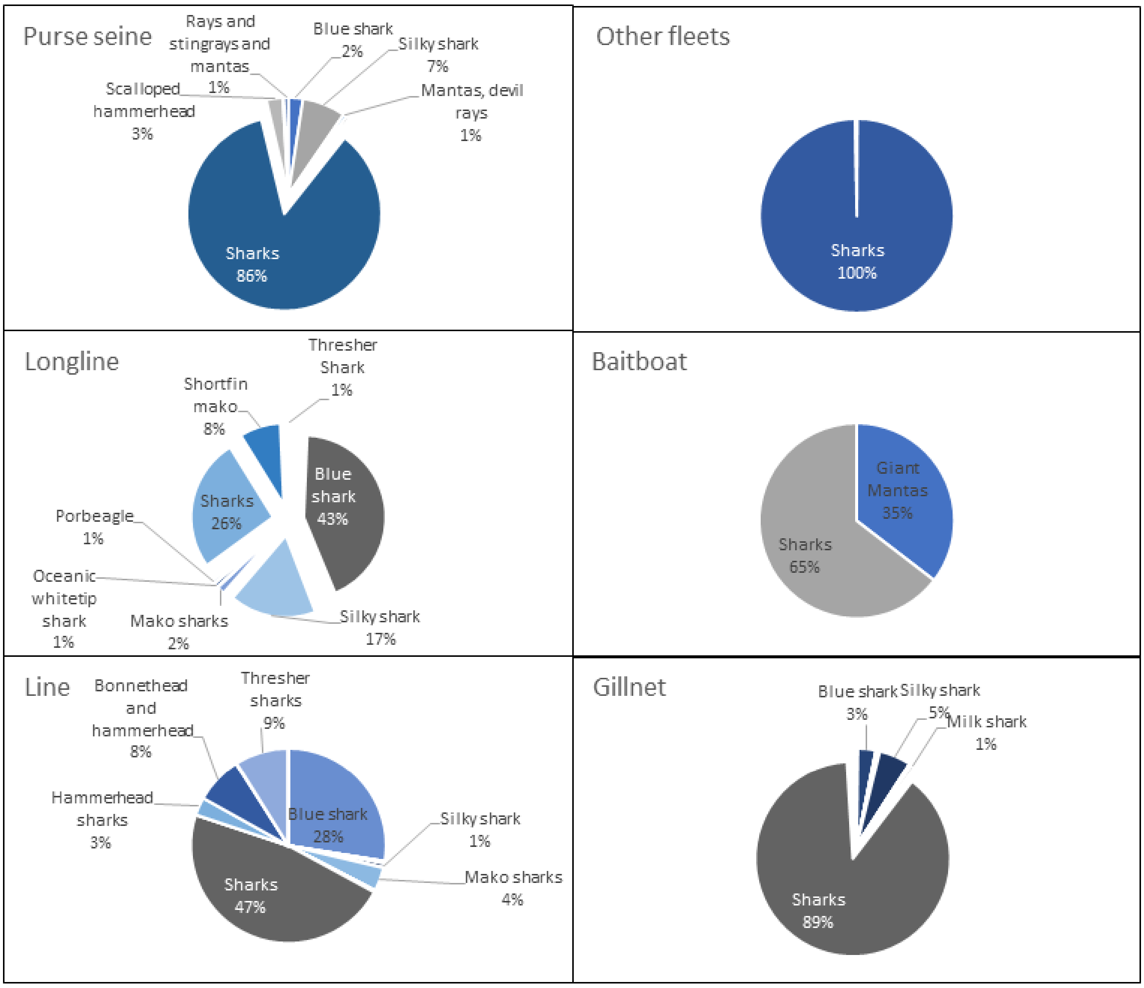

Figure 3.- Relative contribution of different species group and different species to total shark catches by gears for the period 1950-2017.

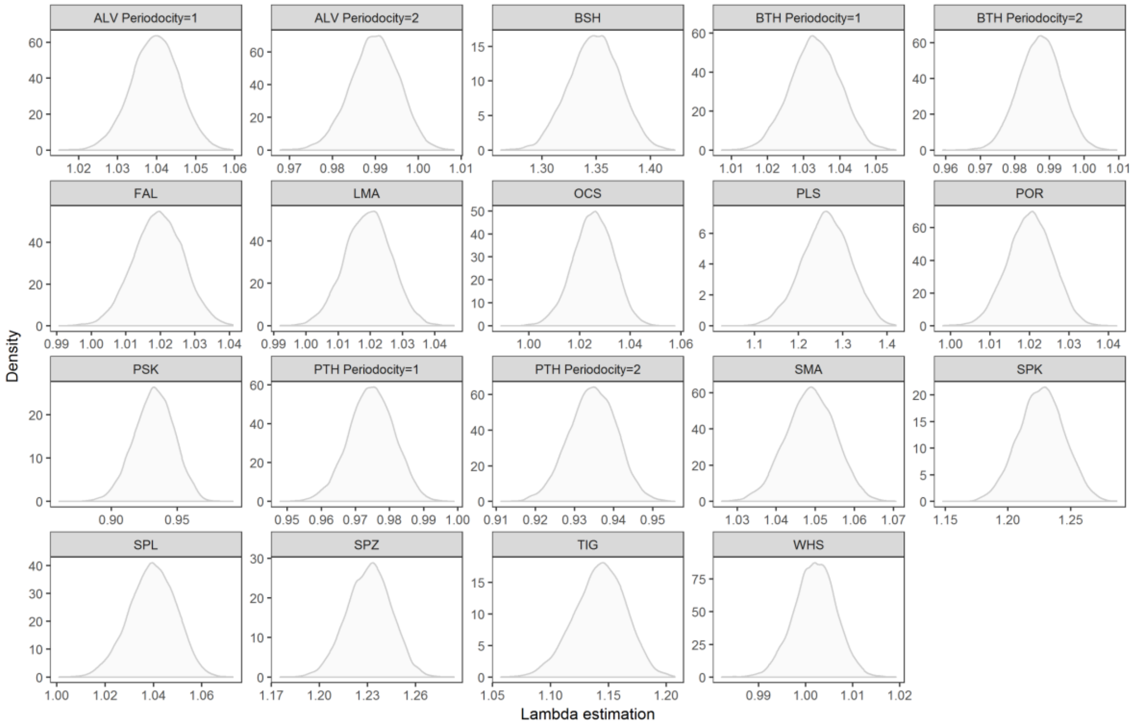

Figure 4.- Frequency distribution of Lambdas estimated by Monte-Carlo simulation (10,000 runs) for all species analyzed.

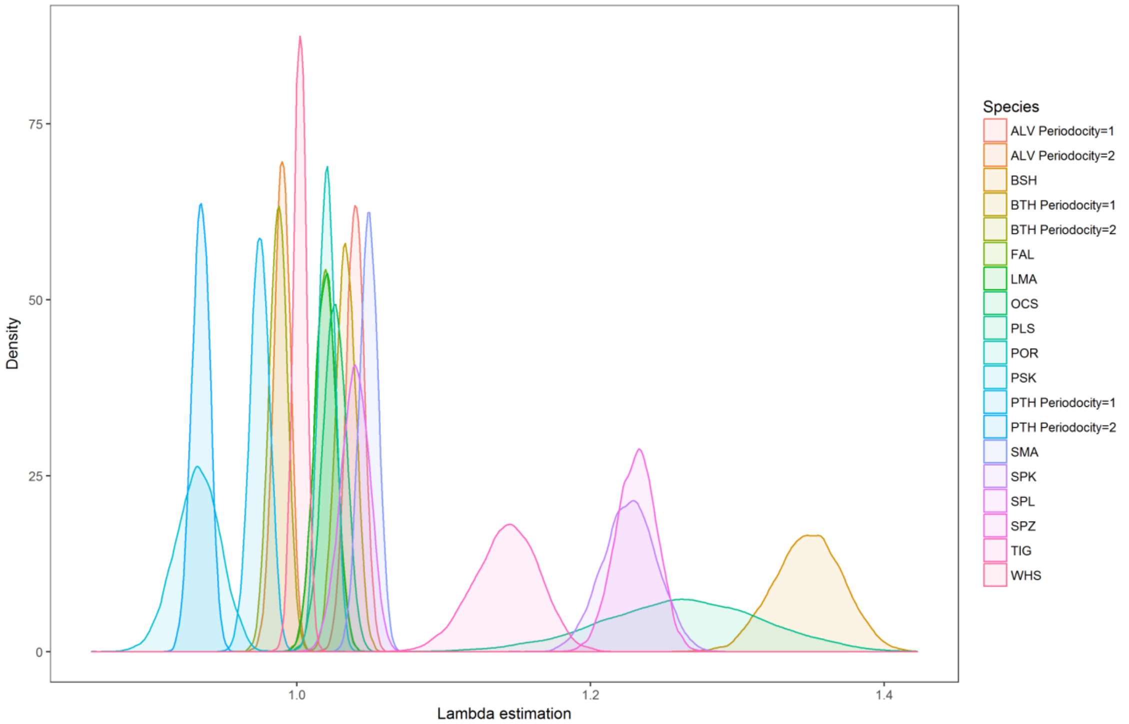

Figure 5.- Comparison of the frequency distribution of Lambdas estimated by Monte-Carlo simulation (10,000 runs) for all species analyzed.

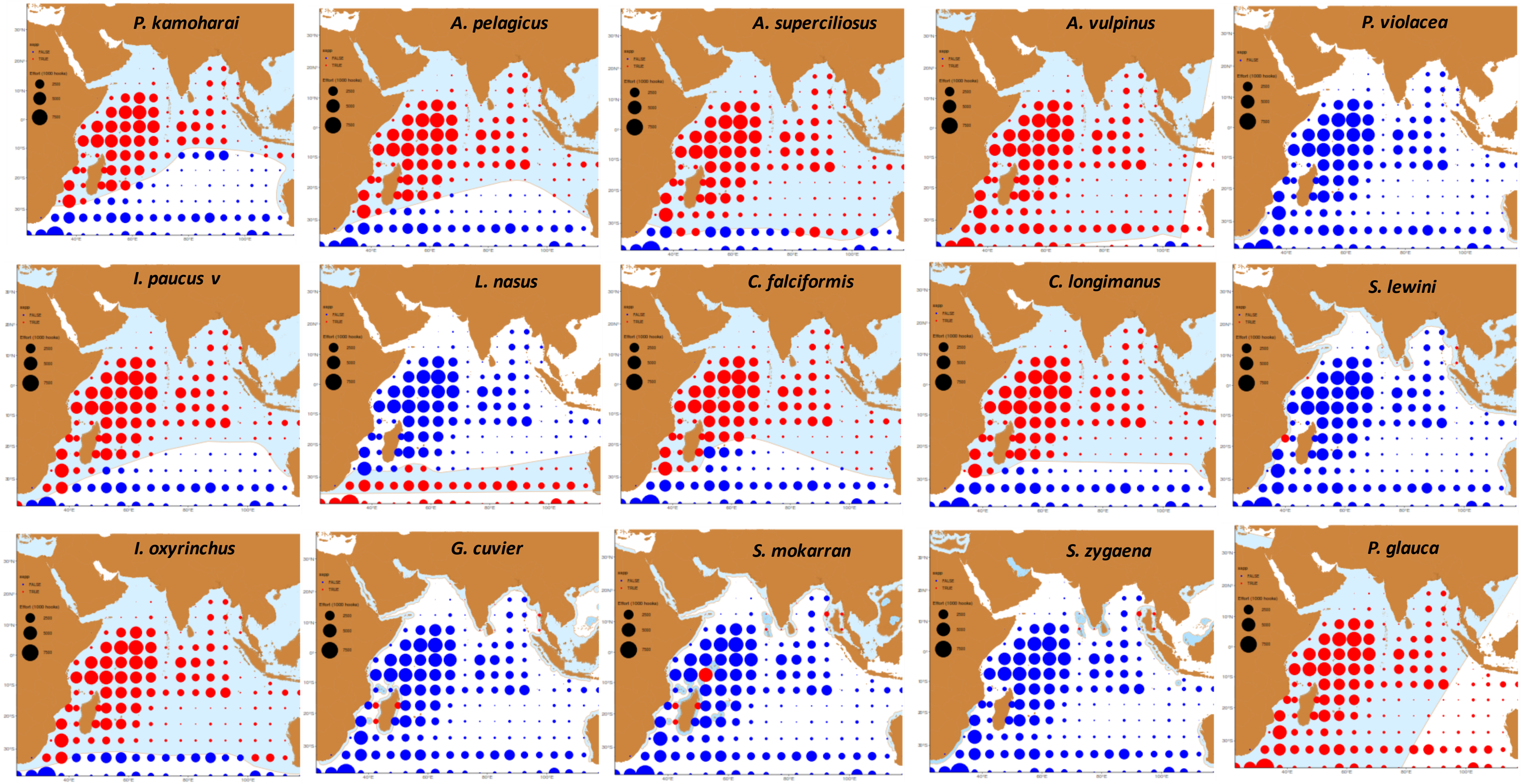

Figure 6.- Overlap between shark species distribution area (blue; source: IUCN SSG GMSA species distribution maps) and Longline total effort (total number of hooks) distribution for the Longline fleet for the period 2011-2017. In red: effort overlapping with species distribution area, in blue: effort outside species distribution area.

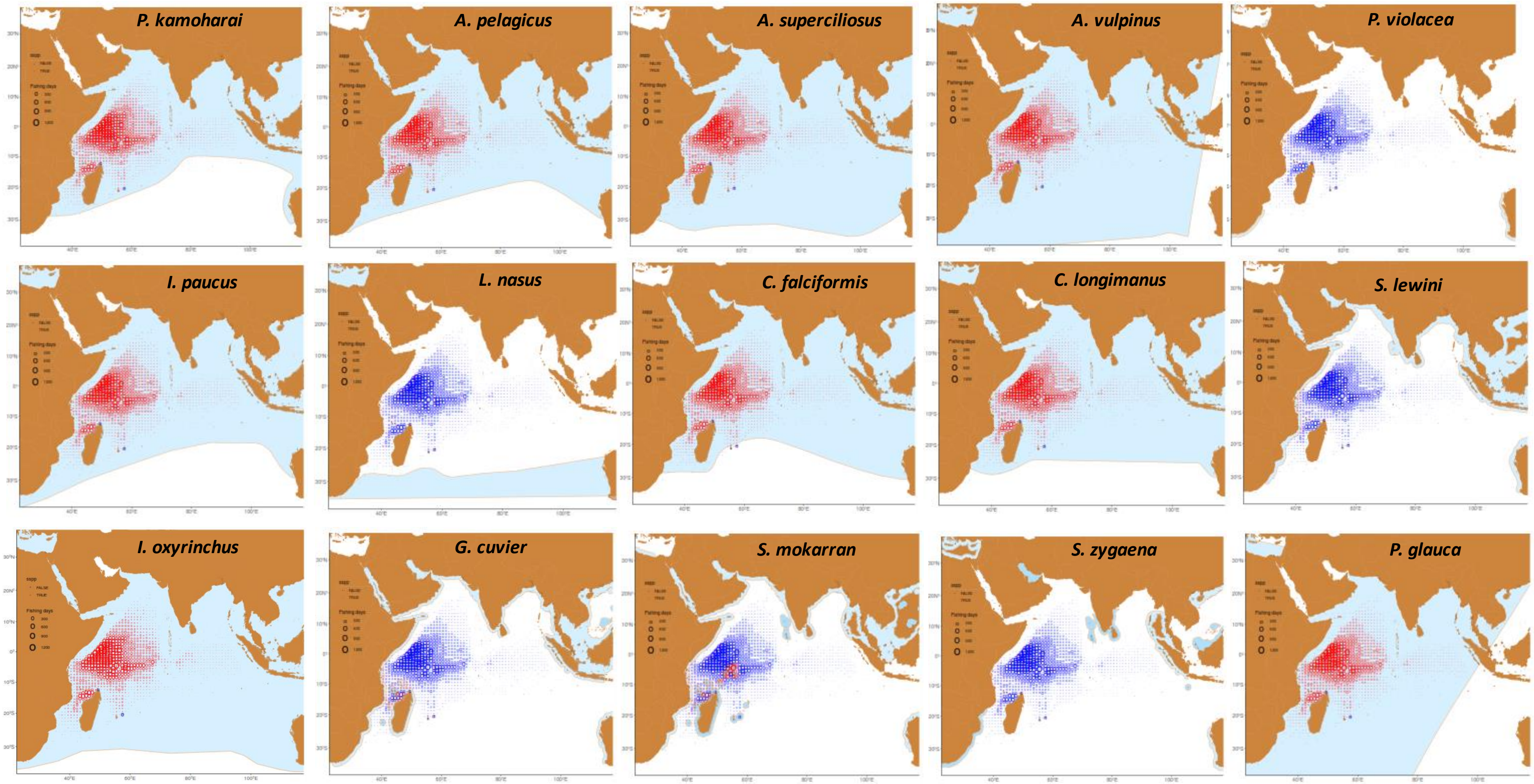

Figure 7.- Overlap between shark species distribution area (source: IUCN SSG GMSA species distribution maps) and purse seiner total effort (total number of days/hours) distribution for the purse seiner fleet for the period 2011-2017. In red: effort overlapping with species distribution area, in blue: effort outside species distribution area.

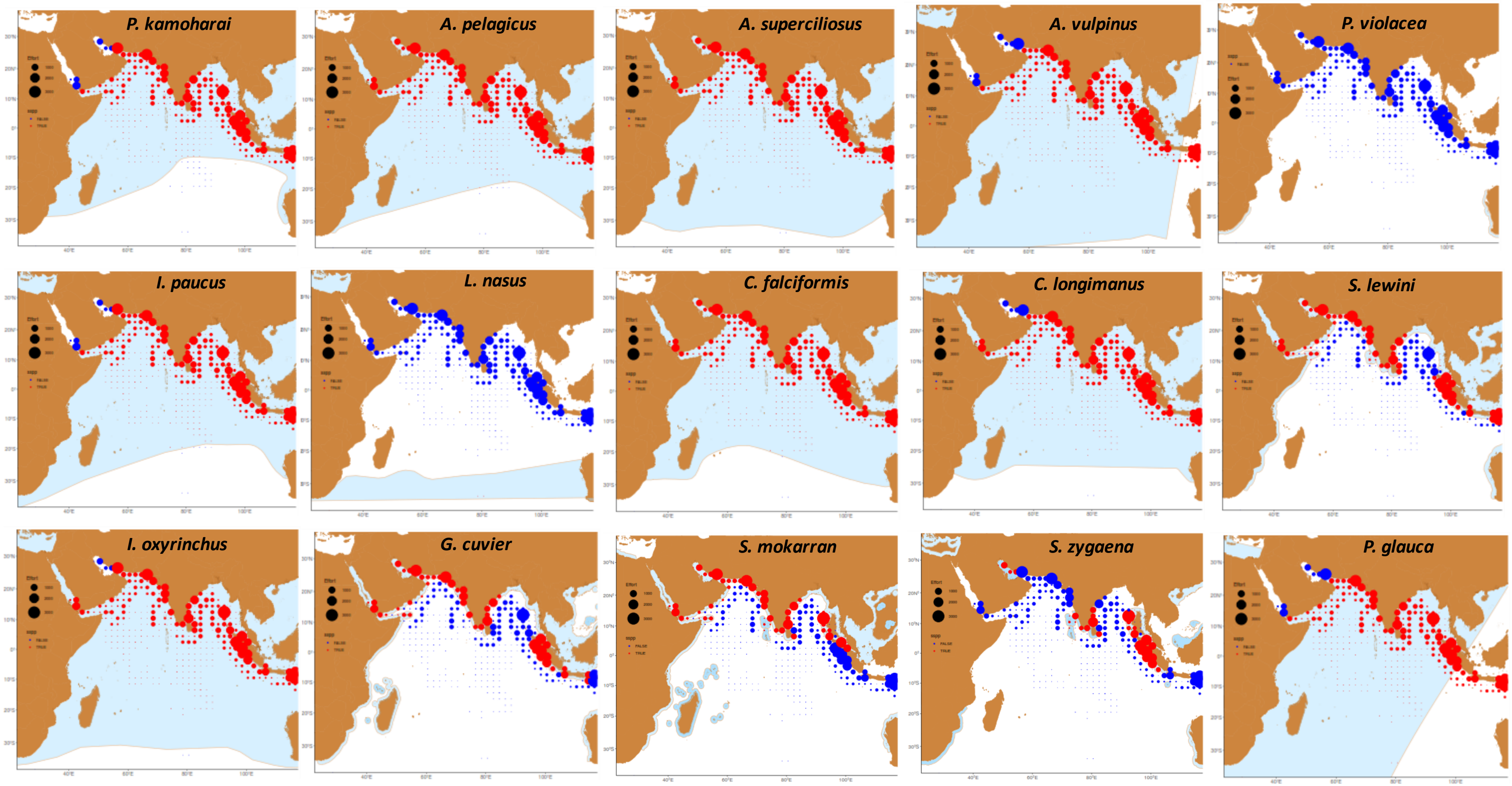

Figure 8.- Overlap between shark species distribution area (source: IUCN SSG GMSA species distribution maps) and GN total effort shape file (from Williams et al, 2018) distribution for the gillnet fleet. In red: effort overlapping with species distribution area, in blue: effort outside species distribution area.

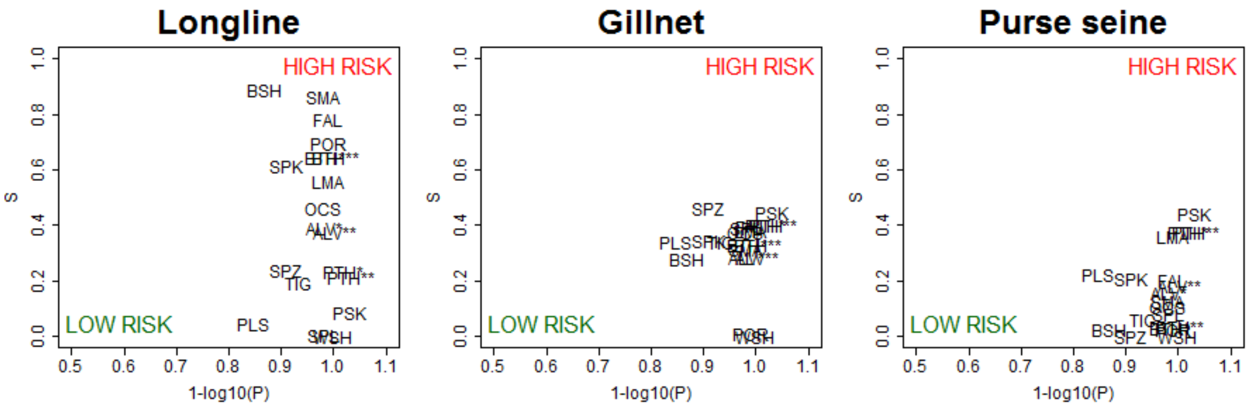

Figure 9.- Productivity susceptibility analysis for species caught by IOTC longline, gillnet and purse seiner fleets. * Reproductive cycle (periodicity): 1-year; ** Reproductive cycle (periodicity): 2-year.