*Supplementary materials:* **Elasmobranch bycatch distributions and mortality: the case of the European tropical tuna purse-seine fishery**

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**Appendix S1:**

**Table S1.** Number of individuals caught and percentage of these individuals measured and sexed by ocean for the main species caught as bycatch by the purse-seine fishery in the Atlantic and Indian Oceans

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Atlantic Ocean | | | Indian Ocean | | |
| Scientific name (FAO code) | Number of individuals | % measured | % sexed | Number of individuals | % measured | % sexed |
| *Prionace glauca* (BSH) | 531 | 64.0 | 90.9 | 35 | 45.7 | 68.7 |
| *Mobula mobular* (RMM) | 343 | 77.8 | 70.4 | 88 | 56.8 | 52.00 |
| *Manta birostris* (RMB) | 79 | 87.3 | 65.2 | 111 | 54.1 | 56.7 |
| *Sphyrna mokarran* (SPK) | 212 | 95.7 | 79.8 | - | - | - |
| *Carcharhinus longimanus* (OCS) | 119 | 87.4 | 93.3 | 706 | 50.4 | 66.3 |
| *Pteroplatytrygon violaeca* (PLS) | 298 | 77.2 | 41.7 | 258 | 62.8 | 55.5 |
| *Sphyrna lewini* (SPL) | 1491 | 67.5 | 90.2 | 3 | 66.7 | 0.00 |
| *Isurus oxyrinchus* (SMA) | 110 | 86.4 | 93.7 | 11 | 63.6 | 71.4 |
| *Carcharhinus falciformis* (FAL) | 14722 | 58.7 | 89.3 | 31332 | 66.3 | 87.9 |
| *Sphyrna zygaena* (SPZ) | 979 | 52.1 | 94.7 | - | - | - |

**Table S2.** Maturity range in centimeter of each elasmobranch observed in catch and size maturity shift used (TL for shark and WD for ray). Species presenting more than 120 individuals caught, and therefore studied in more detail, are highlighted in bold.

|  |  |  |
| --- | --- | --- |
| **Scientif name** | **L50 (cm)** | **references** |
| *Aetobatus narinari* | 110 – 120 (99.8) | [White et al., 2006](#White_et_al_2006) |
| *Alopias pelagicus* | 260 – 292 (276) | [Weigmann, 2016](#Weigmann_2016) |
| *Alopias superciliosus* | 154 – 341 (250) | [Cervigón et al., 1992](#Cervigon_et_al_1992) |
| *Alopias vulpinus* | 226 – 400 (303) | [Weigmann, 2016](#Weigmann_2016) |
| ***Carcharhinus falciformis*** | 202 – 260 (225) | [Compagno and Niem, 1998](#Compagno_and_Niem_1998) |
| ***Carcharhinus longimanus*** | 180 - 200 (190) | [Compagno et al., 1995](#Compagno_et_al_1995); [Bacchet et al., 2006](#Bacchet_et_al_2006) |
| *Carcharhinus obscurus* | 220 – 300 (235) | [Compagno et al., 1989](#Compagno_et_al_1989); [Sanches, 1991](#SAnches_1991) |
| *Carcharhinus plumbeus* | 126 – 183 (150) | [Frimodt, 1995](#Frimodt_1995); [Murdy et al., 1997](#Murdy_et_al_1997) |
| *Galeocerdo Cuvier* | 210 – 350 (300) | [Schneider, 1990](#Scneider_1990); [Vidthayanon, 2005](#Vidthayanon_2005) |
| ***Isurus oxyrinchus*** | 275 – 285 (280) | [Cervigón et al., 1992](#Cervigon_et_al_1992); [Weigmann, 2016](#Weigmann_2016) |
| *Lamna nasus* | 170- 219 (237) | [Muus and Dahlström, 1978](#Muus_and_Dahlström_1978); [Scott and Scott, 1988](#Scott_and_Scott_1988) |
| *Manta alfredi* | 370 – 390 (380) | [Marshall et al., 2009](#Marshall_et_al_2009) |
| ***Manta birostris*** | 380 – 460 (420) | [Stehmann, 1981](#Stehmann_1981); [White et al., 2006](#White_et_al_2006) |
| *Megachasma pelagios* | 540 - ¿ (540) | [Dulvy et al., 2008](#Dulvy_et_al_2008) |
| ***Mobula mobular*** | UNK (200) | [McEachran and Seret, 1990](#McEachran_and_Séret_1990) |
| *Mobula tarapacana* | UNK (200) | [White et al., 2006](#White_et_al_2006) |
| *Mobula thurstoni* | 150 – 154 (152) | [Eschmeyer et al., 1983](#eschmeyer_et_al_1983); [McEachran and Notarbartolo di Sciara, 1995](#McEachran_and_Notarbartolo_1995) |
| ***Pteroplatytrygon violaeca*** | 40 – 50 (45) | [Ebert, 2003](#Ebert_2003); [McEachran, 1995](#McEachran_1995) |
| ***Prionace glauca*** | 170 – 221 (221) | [Cervigón et al., 1992](#Cervigon_et_al_1992); [Muus and Nielsen, 1999](#Muus_and_Nielsen_1999) |
| ***Sphyrna lewini*** | 140 – 273 (230) | [Smith, 1997](#Smith_1997); [Compagno, 1998](#Compagno_1998) |
| ***Sphyrna mokarran*** | 210 – 300 (275) | [Compagno, 1984](#Compagno_1984); [Compagno, 1998](#Compagno_1998) |
| ***Sphyrna zygaena*** | 265 - ¿ (265) | [Compagno, 1998](#Compagno_1998); [Muus and Nielsen, 1999](#Muus_and_Nielsen_1999) |

**Table S3.** Total number of individuals caught in the Atlantic and Indian Oceans. Species presenting more than 120 individuals caught, and therefore studied in more detail, are highlighted in bold

|  |  |  |  |
| --- | --- | --- | --- |
| **Scientific name** | **IUCN status (✝)** | **Atlantic Ocean** | **Indian Ocean** |
| *Aetobatus narinari* | NT | 0 | 1 |
| *Alopias pelagicus* | VU | 1 | 0 |
| *Alopias superciliosus* | VU | 6 | 0 |
| *Alopias vulpinus* | VU | 1 | 0 |
| ***Carcharhinus falciformis*** | NT | 14722 | 31332 |
| ***Carcharhinus longimanus*** | VU | 119 | 706 |
| *Carcharhinus obscurus* |  | 0 | 1 |
| *Carcharhinus plumbeus* | VU | 1 | 0 |
| *Galeocerdo cuvier* | NT | 2 | 6 |
| ***Isurus oxyrinchus*** | VU | 110 | 11 |
| *Lamna nasus* | VU | 2 | 1 |
| ***Manta birostris*** | VU | 79 | 113 |
| ***Mobula mobular*** | EN | 343 | 88 |
| *Mobula tarapacana* | VU | 55 | 13 |
| *Mobula thurstoni* | NT | 1 | 0 |
| ***Pteroplatytrygon violaeca*** | LC | 298 | 258 |
| ***Prionace glauca*** | NT | 531 | 35 |
| ***Sphyrna lewini*** | EN | 1491 | 3 |
| ***Sphyrna mokarran*** | EN | 212 | 0 |
| ***Sphyrna zygaena*** | VU | 979 | 0 |

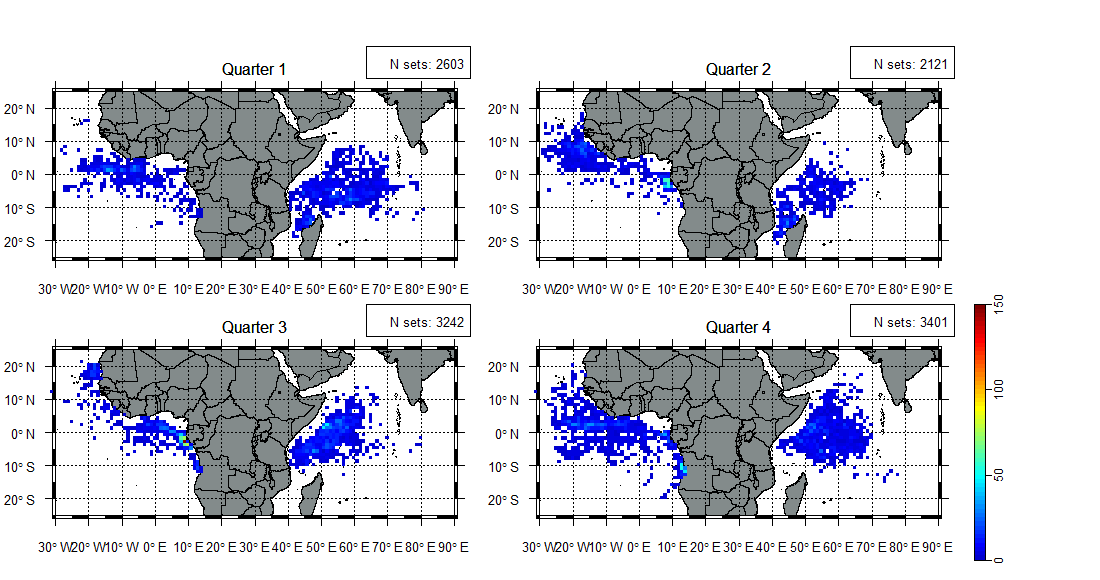
✝IUCN classification: EX = Extinct, EW = Extinct in the Wild, CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern, DD = Data Deficient, NE = Not Evaluated

**Table S4.** Percentage of sets with at least one individual elasmobranch caught by season (Atlantic Ocean by quarter: 1= January–March; 2= April–June; 3= July–September and 4= October–December and Indian Ocean by monsoon: 1= December–March; 2= April–May; 3= June–September; 4 = October–November). Fishing modes: FAD= Fish Aggregating Devices; FSC=free-swimming tuna schools

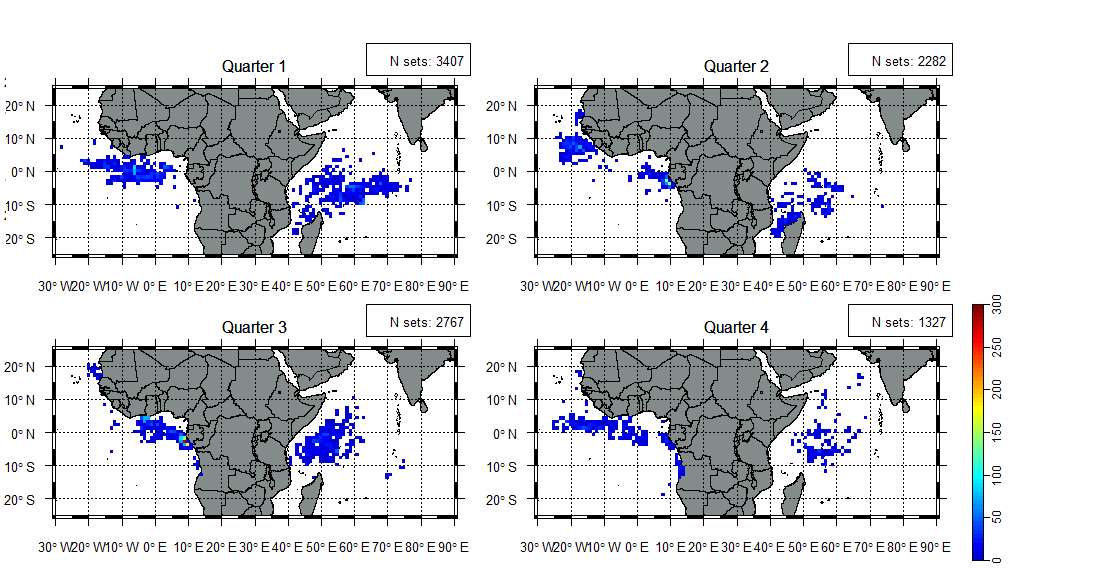
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Atlantic Ocean | | Indian Ocean | |
| Season | FAD | FSC | FAD | FSC |
| 1 | 21.5 | 4.0 | 67.5 | 12.9 |
| 2 | 46.9 | 26.6 | 68.0 | 17.0 |
| 3 | 50.2 | 25.7 | 68.4 | 11.7 |
| 4 | 34.8 | 12.1 | 67.3 | 9.1 |

**Table S5.** Percentage of juveniles, females, and apparent mortality rates by species and ocean for the main species captured as bycatch by the purse-seine fishery in the Atlantic and Indian Oceans.

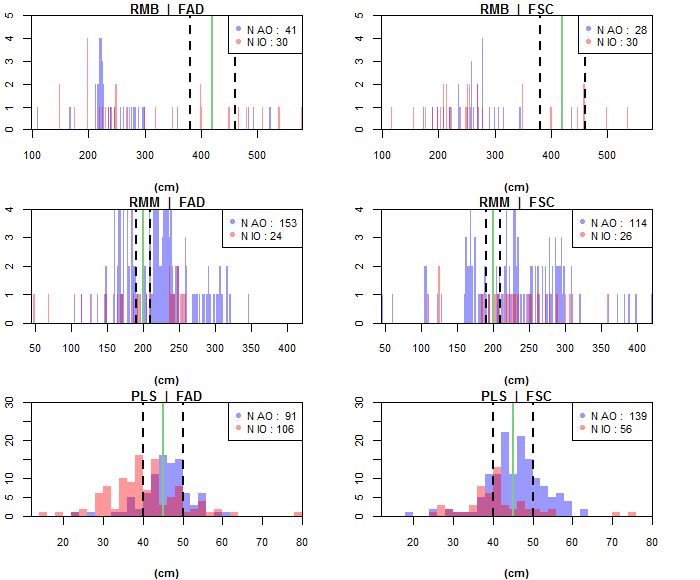
|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Atlantic Ocean** | | | | **Indian Ocean** | | | |
| **Scientific name (FAO code)** | **N caught** | **% juvenile** | **% female** | **Mortality rate** | **N caught** | **% juvenile** | **% female** | **Mortality rate** |
| *Prionace glauca* (BSH) | 531 | 50.00 | 13.27 | 34.83 | 35 | 62.50 | 36.36 | 57.14 |
| *Mobula mobular* (RMM) | 343 | 30.71 | 50.53 | 46.94 | 88 | 36.00 | 57.69 | 30.68 |
| *Manta birostris* (RMB) | 79 | 94.20 | 66.67 | 43.03 | 111 | 80.00 | 35.29 | 24.32 |
| *Sphyrna mokarran* (SPK) | 212 | 98.52 | 41.13 | 58.96 | - | - | - | - |
| *Carcharhinus longimanus* (OCS) | 119 | 54.81 | 56.70 | 41.17 | 706 | 83.15 | 57.20 | 27.19 |
| *Pteroplatytrygon violaeca* (PLS) | 298 | 37.39 | 48.96 | 33.22 | 258 | 37.78 | 73.46 | 63.95 |
| *Sphyrna lewini* (SPL) | 1491 | 71.27 | 57.99 | 45.20 | 3 | 0.00 | 0.00 | 33.33 |
| *Isurus oxyrinchus* (SMA) | 110 | 100 | 61.79 | 60.00 | 11 | 100.00 | 60.00 | 63.63 |
| *Carcharhinus falciformis* (FAL) | 14722 | 93.11 | 51.26 | 51.73 | 31332 | 99.50 | 51.93 | 59.98 |
| *Sphyrna zygaena* (SPZ) | 979 | 97.65 | 63.77 | 60.36 | - | - | - | - |

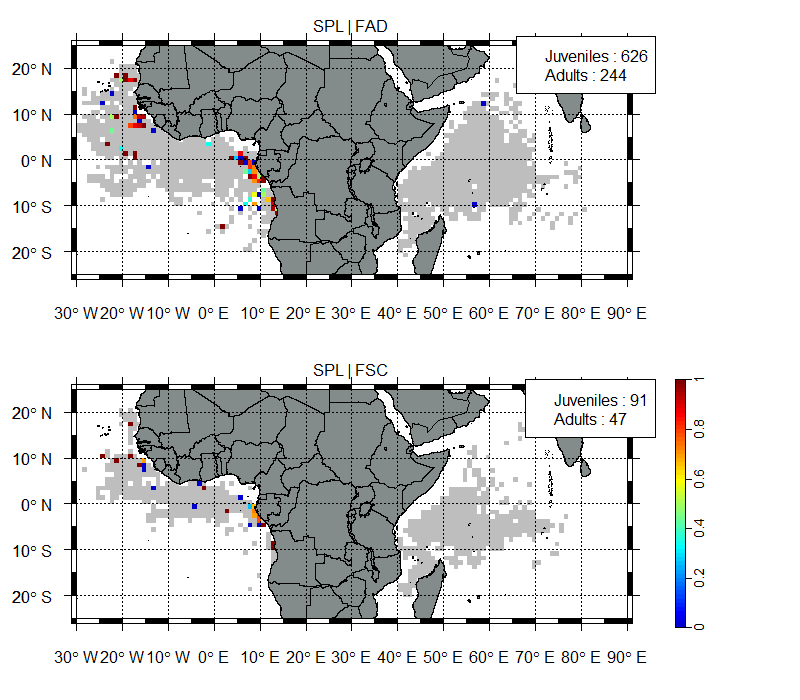


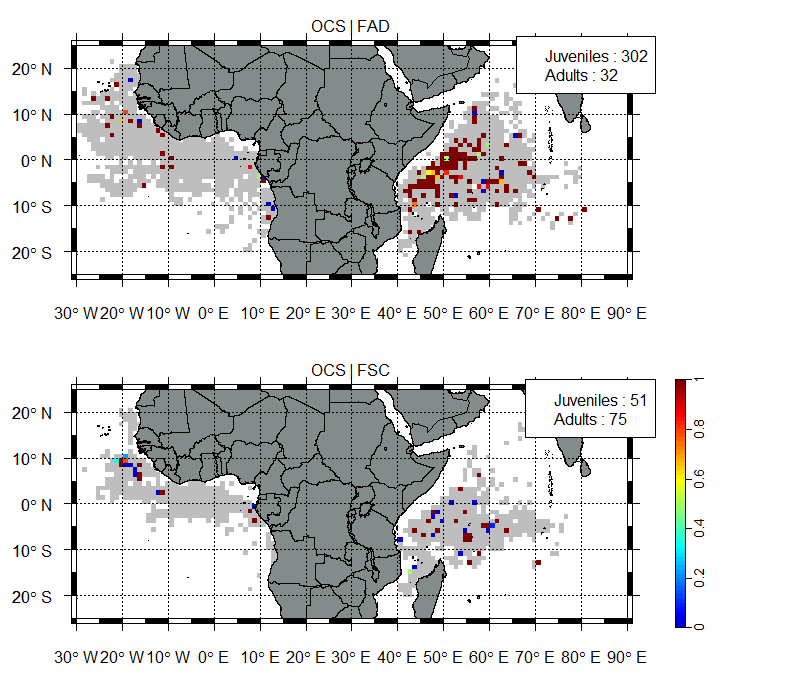
**Figure S1.** Quarterly distribution of fishing effort (i.e. number of fishing sets) on Fish Aggregating Devices (FAD) sets per 1° square. N sets is the number of sets. Each quarter correspond to a trimestral division in the Atlantic Oceans and to monsoon and inter-monsoon seasons in the Indian Ocean.



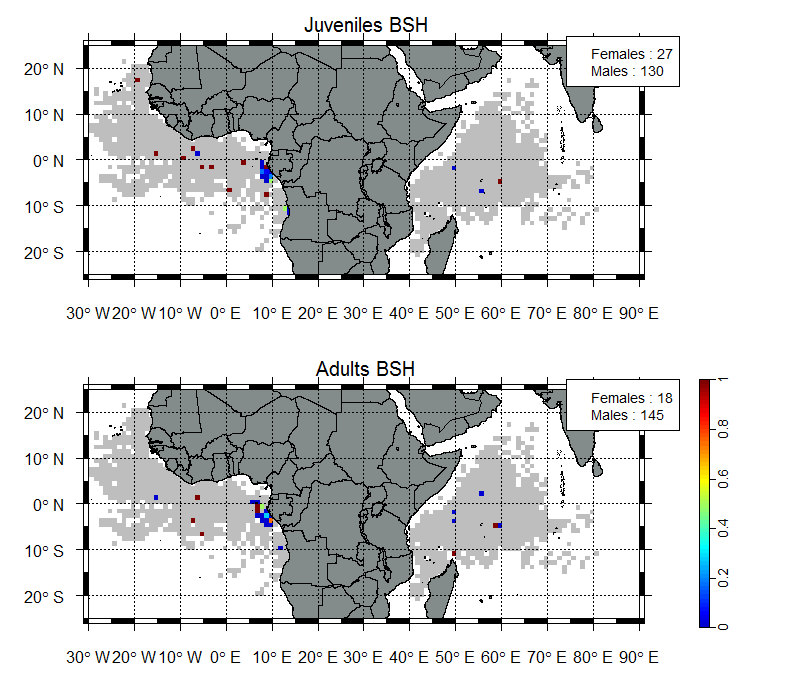
**Figure S2.** Quarterly distribution of fishing effort (i.e. number of fishing sets) on free-swimming tuna schools (FSC) sets per 1° square. N sets is the number of sets. Each quarter correspond to a trimestral division in the Atlantic Oceans and to monsoon and inter-monsoon seasons in the Indian Ocean each quarter.

 **Figure S3.** Size distribution of the *Manta birostris* (RMB), *Mobula mobular* (RMM) and *Pteroplatytrygon violacea* (PLS) in Fish Aggregating Devices (FAD) sets versus Free school (FSC) sets in the Atlantic Ocean (AO; blue distribution) and in the Indian Ocean (IO; red distribution). N AO and N IO correspond to the number of individuals caught in the Atlantic and Indian Oceans, respectively. The green line corresponds to L50 sexual maturity length and black dashed line corresponds to the range of first and last length of sexual maturity

**Figure S4.** Juvenile proportion of scalloped hammerhead (SPL) in function of fishing mode (Fish Aggregating Devices (FAD) and free-swimming tuna schools (FSC)) per 1° square. Color gradient correspond to the juvenile proportion. Number of juveniles and adults caught are mentioned in the up-right corner of the Figure. Grey cells correspond to fishing effort distribution.

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**Figure S5**. Juvenile percentage of *Carcharhinus longimanus* (OCS) as a function of fishing mode per 1° square. Color gradient corresponds to the juvenile percentage (0 = 0% juvenile, 1=100% juvenile), grey cells correspond to fishing effort distribution

**Figure S6.** Sex-ratio distribution of *Prionace glauca* (BSH) as a function of life stage per square of 1°. Color gradient corresponds to the percentage of females (0 = 0% and 1 = 100%), grey cells correspond to fishing effort distribution

**Appendix S2: Biodiversity indices**

In this study, elasmobranch assemblages were studied using complementary diversity indices: i) species Richness Per Unit of Effort (RPUE) computed such as CPUE (see Materials and method of the article) from the number of elasmobranch species caught, ii) unbiased Simpson's diversity, also known as Probability of Interspecific Encounter ([Hurlbert, 1971](#Hurlbert_1971)) and iii) Simpson's equitability ([Smith and Wilson, 1996](#Smith_and_Wilson_1996)). Contrarily to species richness, Simpson’s diversity has been shown being relatively stable to sample size variation (here number of sets) ([Lande, 1996](#Lande_1996)), as observed for the studied data set during preliminary analyses. Thus, the initial value of this index was considered (i.e. not adjusted by number of sets).

Indices were computed as follows:

* **Simpson diversity: (*N*/*N*-1) x 1-*D***

**With *D* = , with *pi=ni/N; n****i* : number of individuals for each species *i*; *N* : total number of individual of elasmobranch, *Nsp* the total number of species

* Species Richness Per Unit of Effort: *RPUE* = *Nsp* / *Nse*t

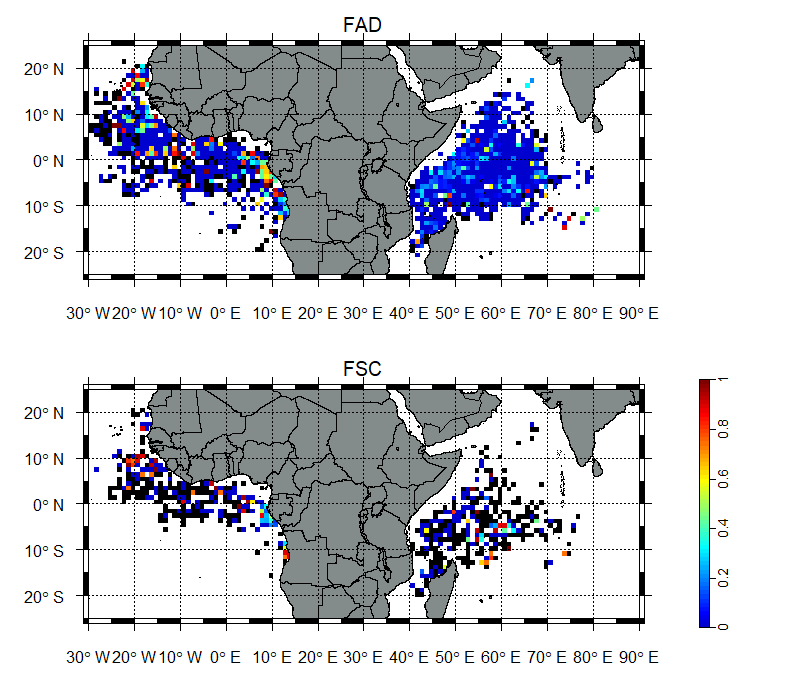
With *Nset*the sets number.

* Simpson’s equitability: *E* = **1-*D* / (1-1/***Nsp***)**

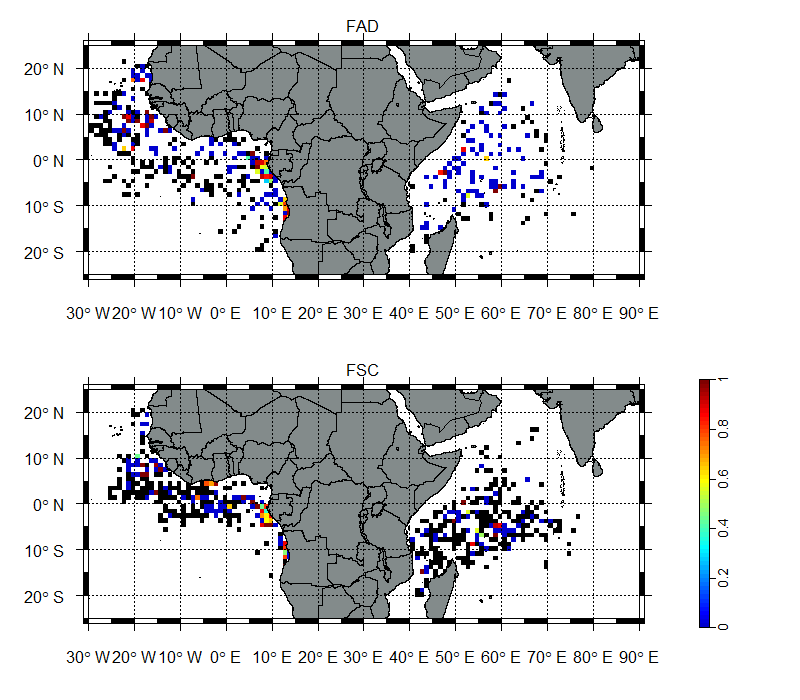
Indices were computed for each 1° grid cell and for each fishing mode separately for juveniles and for adults. Simpson diversity and equitability were highly correlated (adult: r= 0.89; juvenile: r = 0.96). Thus, only Simpson’s equitability was considered for further analyses. Simpson’s equitability appears higher in Gabon, Angola and Mauritania’s coasts for both fishing modes and life stages (**Figures. S7 and 8,** Kruskal Wallis Tests, p<0,05). But juveniles simpson’s equitability appears higher in FSC (**Figure. S9,** Kruskal Wallis Test, p<0,05).

Juveniles RPUE are higher than adults RPUE (i.e. between 0 and 1 for adults, and 0 and 2 for juveniles, **Figures. S9,** Kruskal Wallis Tests, p<0,05). Highest value of RPUE for both life stages are localised in the Atlantic Ocean along the 5°S latitude line (**Figures. S10 and 11**).

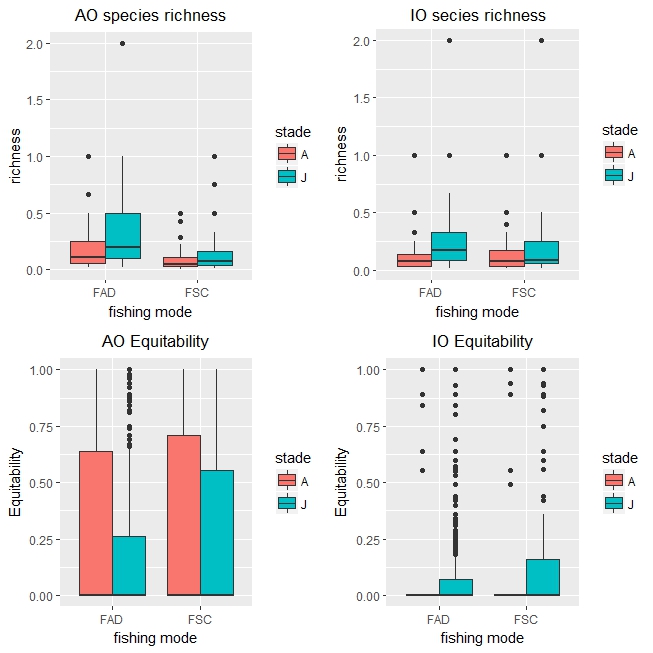
Biodiversity indices are more heterogeneous in the Atlantic Ocean compared to the Indian Ocean, such as for fishing effort or bycatches CPUE.



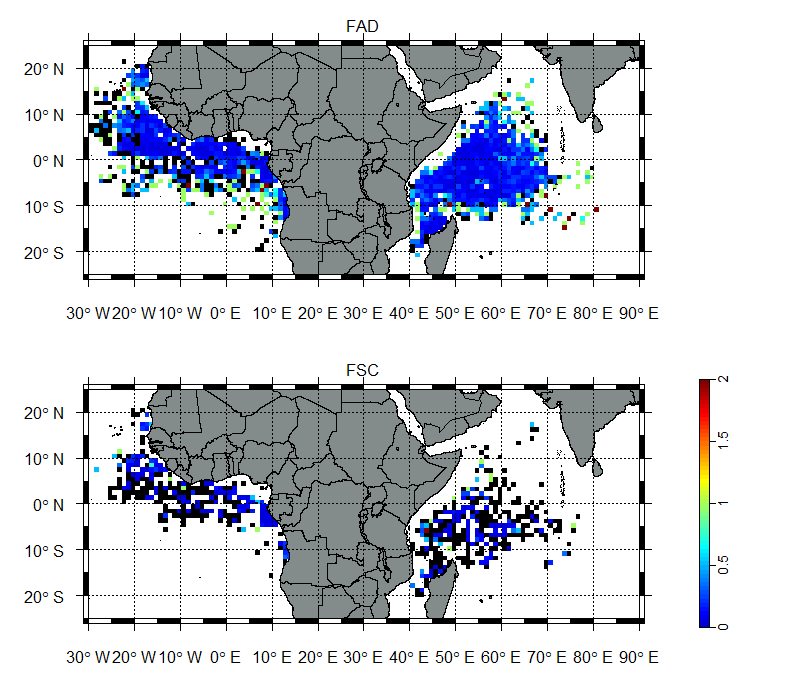
**Figure S7.** Juvenile Simpson’s equitability distribution per fishing mode (Fish Aggregating Devices (FAD) and free-swimming tune schools (FSC)) per 1° square. Black squares correspond to sets without elasmobranches captured, and colour gradient corresponds to values of Simpson’s equitability.



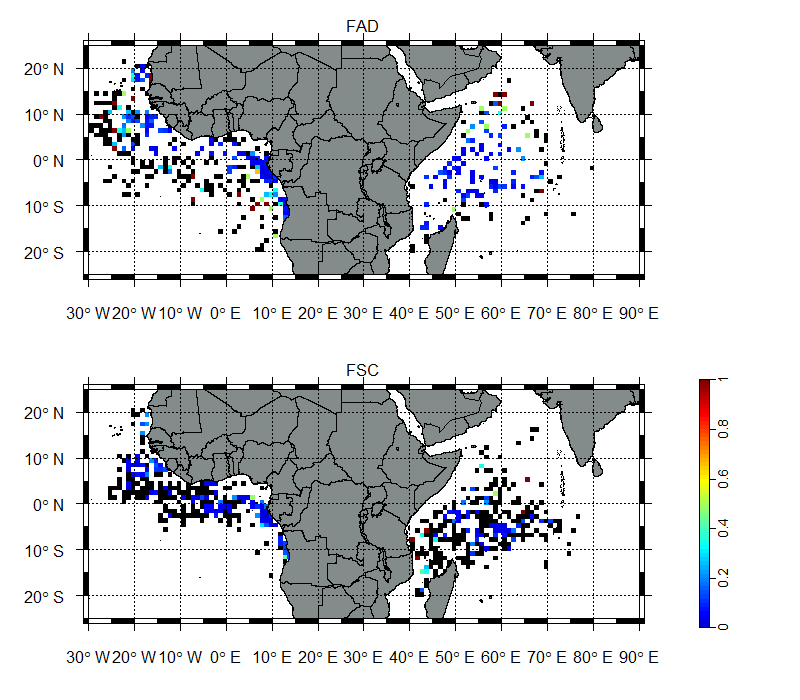
**Figure S8.** Adult Simpson’s equitability distribution per fishing mode (Fish Aggregating Devices (FAD) and free-swimming tune schools (FSC)) per 1° square. Black squares correspond to sets without elasmobranches captured and colour gradient corresponds to values of Simpson’s equitability.



**Figure S9.** Boxplots of Species Richness per Unit of Effort (left column) and Simpson’s equitability (right column) in function life stage (juvenile (J), blue; adult (A), red) in the Atlantic Ocean (AO) and in the Indian Ocean (IO).



**Figure S10.** Juvenile Species Richness Per Unit of Effort distribution per fishing mode (Fish Aggregating Devices (FAD) and free-swimming tune schools (FSC)) per 1° square. Black squares correspond to sets without elasmobranches captured and colour gradient corresponds to RPUE values.



**Figure S11.** Adult Species Richness Per Unit of Effort distribution per fishing mode (Fish Aggregating Devices (FAD) and free-swimming tune schools (FSC)) per 1° square. Black squares correspond to sets without elasmobranches captured and colour gradient corresponds to RPUE values.

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