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13 **Local indicators for global species: pelagic sharks in the tropical northeast Atlantic, Cabo**  
14 **Verde islands region.**

15

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17 Pedro G. Lino<sup>1</sup>, Daniela Rosa<sup>1,2</sup>, Catarina C. Santos<sup>1,2</sup>, Pascal Bach<sup>5</sup>, Hilario Murua<sup>6,7</sup>, Pablo  
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30

31

32 **Abstract**

33 Pelagic sharks are an important bycatch in pelagic fisheries, especially for drifting longlines  
34 targeting swordfish. In the Cabo Verde Archipelago (tropical NE Atlantic), pelagic shark catches  
35 can reach a significant proportion of the total catches. Due to the increased concern on the  
36 status of pelagic shark species, this study was developed to enhance the current knowledge of  
37 those sharks in the Cabo Verde region in comparison to the adjacent areas, especially  
38 associated with European Union (EU) pelagic longline fishing activity. Stock status indicators for  
39 the two main species, blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*), were  
40 developed, based on fisheries data from logbooks and onboard scientific observers, including  
41 analysis of size frequency distributions and standardized catch-per-unit-of-effort (CPUE)  
42 indexes over time. The standardized CPUEs have been stable or increasing for both species in  
43 the past 10 years, indicating no signs of local depletion. In terms of sizes, the blue shark catch is  
44 composed mainly of adults, which can be a sign of a stable population. On the contrary, the  
45 catch of shortfin mako is composed mainly of juveniles, which in conjunction of a decrease of  
46 mean size might be a cause of concern, highlighting possible overfishing on the species in the  
47 region. Thirty satellite tags, 25 archival miniPATs and 5 SPOT GPS, were deployed in the Cabo  
48 Verde Exclusive Economic Zone (EEZ), showing that those species are highly mobile. The  
49 biomass and size distributions were modeled with spatial and seasonal models (GAMs)  
50 identifying locations where juveniles are predominantly concentrated and that should be  
51 prioritized for conservation. This work presents new information on the status of pelagic sharks  
52 in the Cabo Verde region in the context of those highly migratory species, and can now be used  
53 to promote more sustainable fisheries in the region.

54

55 **Key-words:**

56 Indices of abundance; longline fisheries; pelagic sharks; population trends; satellite tagging;  
57 spatial models.

58

59

## 60 **1. Introduction**

61 Pelagic sharks are an important component in pelagic fisheries catches, especially for drifting  
62 longliners targeting swordfish and tunas (Mejuto et al., 2009; Coelho et al., 2018). Depending  
63 on the fisheries, areas and seasons, pelagic sharks can be significant in the overall catch. Blue  
64 shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) are the two main shark species in  
65 those fisheries, and can in some areas and season represent more than 50% of the total  
66 longline catch and 90% of the total elasmobranch catch (Coelho et al., 2012). In the Cabo Verde  
67 Archipelago (tropical NE Atlantic), pelagic shark catches can also be important for pelagic  
68 fisheries (Fernandez-Carvalho et al., 2015a); however, the local status of those populations is  
69 not currently assessed. Cabo Verde has a large Exclusive Economic Zone (EEZ) of 734,000 km<sup>2</sup>  
70 and, thus, its future sustainability will be largely based on activities related to the use and  
71 exploitation of the sea and coastal resources (de Carvalho, 2013). Overall for the Atlantic  
72 Ocean, total pelagic fish catches reported to the International Commission for the  
73 Conservation of the Atlantic Tunas (ICCAT) in the last few years (2014-2017) were  
74 approximately 745,000 t per year. Of those, approximately 76,000 t per year (around 10% of  
75 the total catch) represented pelagic sharks, mostly blue shark (approximately 65,000 t per year)  
76 followed by shortfin mako (around 6,000 t per year) (ICCAT, 2018).

77 The blue shark is one of the widest ranging of all sharks, found throughout tropical and  
78 temperate seas from latitudes of about 60°N to 50°S. It is a pelagic species mainly distributed  
79 from the sea surface to depths of about 350 m, even though deeper dives of up to 1000 m  
80 have been recorded (Campana et al., 2011). Blue shark is a highly migratory oceanic species,  
81 with complex movement patterns and spatial structure probably related to the reproduction  
82 cycles and prey distribution (Montealegre-Quijano and Vooren, 2010; Tavares et al., 2012;  
83 Coelho et al., 2018). Tagging studies have shown extensive movements with numerous trans-  
84 Atlantic migrations probably accomplished by using the major oceanic current systems  
85 (Stevens, 1976; Stevens 1990; Queiroz et al., 2005; Silva et al., 2010; Campana et al., 2011). For  
86 the north Atlantic, data on the distribution, movements and reproductive behavior suggests a  
87 complex reproductive cycle, involving major oceanic migrations associated with mating areas in  
88 the north-western Atlantic and pupping areas in the north-eastern Atlantic (Pratt, 1979;  
89 Stevens, 1990).

90 The shortfin mako is also a widespread pelagic shark species, occurring in temperate and  
91 tropical waters of all oceans from about 60°N to 50°S. It occurs from the surface to at least 500  
92 m depth, and is occasionally found close to inshore waters where the continental shelf is

93 narrow (Compagno, 2001). Tagging studies in the northwest Atlantic have shown that shortfin  
94 makos can make extensive migrations of more than 3,000 km (Casey and Kohler, 1992), even  
95 though it has been suggested that trans-Atlantic migrations are not as common as in the blue  
96 shark. In the Atlantic, Casey and Kohler (1992) suggests that shortfin mako core distribution in  
97 the northwest Atlantic is between 20° to 40°N, bordered by the Gulf Stream in the west and  
98 the mid-Atlantic ridge in the east. In the northeast Atlantic it is presumed that the Strait of  
99 Gibraltar might be a nursery ground (Buencuerpo et al., 1998 and Tudela et al., 2005). The area  
100 between 17° to 35°S off the coast of Brazil seems to be an area of birth, growth and mating in  
101 the southwest Atlantic (Amorim et al., 1998).

102 The blue shark is currently listed as Near Threatened by IUCN, the International Union for the  
103 Conservation of Nature (Stevens, 2009), while the shortfin mako is currently listed as  
104 Endangered Rigby et al., 2019). In the Ecological Risk Assessments (ERAs) carried out for pelagic  
105 sharks in the Atlantic in 2010 and 2012 (Cortés et al., 2010; Cortés et al., 2015), blue shark was  
106 shown to have an overall intermediate vulnerability, because it is the most productive of all  
107 pelagic shark species. On the contrary the shortfin mako was one of the most vulnerable of all  
108 species analyzed, due to its relatively low productivity and high susceptibility.

109 The latest blue shark stock assessments in the Atlantic were carried out by ICCAT in 2015  
110 (Anon., 2015). For the North Atlantic the stock was unlikely to be overfished and subject to  
111 overfishing, even though there were very high levels of model uncertainty reported (Anon.,  
112 2015). For the shortfin mako the latest stock assessments were carried out by ICCAT in 2017  
113 (Anon., 2017). The results for the North Atlantic indicated that stock abundance was either  
114 below or very close to  $B_{MSY}$ , but that fishing mortality was overwhelmingly above  $F_{MSY}$ , with a  
115 combined 90% probability of the stock being in an overfished state and experiencing  
116 overfishing (Anon, 2017). Although the current biomass of the stock was still not very strongly  
117 depleted, current fishing mortality levels are unsustainable and can lead to strong population  
118 declines in the near future.

119 Due to the increased concern on the status of pelagic shark species and lack of specific  
120 knowledge for the region around the Cabo Verde islands in the tropical NE Atlantic and how  
121 local shark components are related to the managed population, this study was developed to  
122 enhance the current knowledge of the two main pelagic sharks captured in longline fisheries in  
123 the Cabo Verde region, especially associated with European Union (EU) pelagic longline fishing  
124 activity. Specifically, the main objectives of this study were to: 1) analyze potential local  
125 depletion of sharks in the region, specifically by analyzing trends in the catch composition,

126 catch rates (CPUEs: catch per unit effort) and size distribution for the main species and; 2)  
127 identify possible biological and ecological sensitive areas in the region by modeling the spatial  
128 distribution of catches of the main species in the region and using the analysis of satellite  
129 telemetry tagging data.

130

## 131 **2. Materials and Methods**

### 132 **2.1. Study area and fisheries data collection**

133 The study focused on the Cabo Verde region in the tropical NE Atlantic. Two areas were  
134 defined, specifically: i) the Cabo Verde EEZ, and ii) a buffer of 300 nm adjacent to the EEZ  
135 (**Figure S1** - Supplemental electronic material).

136 The data collected and analyzed included EU (Portugal and Spain) pelagic longline fleets fishery  
137 logbook and scientific fishery observer data. Those data were compiled and used to provide  
138 analysis on the sharks catch composition, catch rate trends and size distributions in the region.  
139 Data were available and analyzed between 2006 and 2015, with the exception of 2008 that was  
140 not included due to issues related with a switch in database format, which did not allow linking  
141 the catch, effort and location (Vessel Monitoring System, VMS) data for that year. All fisheries  
142 parameters and indicators were compared between the Cabo Verde EEZ and the neighboring  
143 300 nm buffer area, according to the study areas previously defined.

144

### 145 **2.2. Satellite tagging**

146 A total of 30 satellite tags were deployed within this study, specifically 25 miniPATs and 5  
147 Fastloc GPS SPOT tags, both models from Wildlife Computers Inc. One of the GPS SPOT tagged  
148 specimens was recaptured after 77 days, and that tag was redeployed on another specimens.  
149 As such, of the available tags, 20 miniPATs and 6 GPS SPOTs (5 GPS SPOTs with 1 deployed  
150 twice) were deployed in blue sharks and 5 miniPATs were deployed in shortfin makos, all inside  
151 the Cabo Verde EEZ during 2016 (**Table S1** - Supplemental electronic material).

152 For the tagging operations, the sharks were restrained alongside the vessel and handled  
153 carefully, with those in the best condition selected for tagging in order to maximize post-  
154 release survivorship. Each tagged shark was measured, and the sex and maturity stage  
155 determined (juvenile vs. adult, see section 2.3.2 with the used sex specific maturity ogives

156 available in the literature, Anon., 2014). Additional data recorded for each tagged specimen  
157 included tagging location (latitude and longitude), date and time.

158 The miniPATs were rigged with monofilament leaders secured with stainless steel crimps and  
159 encased in plastic tubing. Umbrella-type nylon darts (Domeier et al., 2005) were used to attach  
160 the tags to the shark dorsal musculature below the first dorsal fin, using the methodology  
161 described by Howey-Jordan et al. (2013). For the SPOT tags, the tags were attached with a  
162 plastic fin mount system placed in the first dorsal fin provided by the tag manufacturer.

163 The miniPAT tags archive detailed depth and temperature time-series data and use the light-  
164 based information for geo-locations. On the contrary, the Fastloc GPS SPOT tags use GPS based  
165 geo-locations that are much faster and provide more precise estimates, but do not record  
166 depth or temperature profiles. As such, both tags were used to provide complementary  
167 information on the sharks' habitat use and movements.

168 For estimating geographical daily positions, the Fastloc GPS signals are processed by the tags,  
169 compressed and then transmitted over the ARGOS satellite system. For the miniPATs, the daily  
170 locations were calculated based on the light levels recorded and using state-space statistical  
171 models (GPE3 software, processed through the tag manufacturer web portal). The miniPATs  
172 provide observations on twilight, sea surface temperature and dive depth, and the state-space  
173 modeling approach uses those observations and the corresponding reference data, along with  
174 a simple diffusion based movement model, to generate time-discrete gridded probability  
175 surfaces throughout the deployment. The corresponding oceanographic reference data used  
176 was that from NOAA Optimum Interpolation SST V2 High Resolution for the sea surface  
177 temperature, and from NOAA ETOP01 global relief model, Bedrock version, for bathymetry,  
178 respectively. The grids used were 0.25\*0.25 degrees of latitude\*longitude. From those  
179 probability surfaces, the most likely animal locations for a given day/time were derived.

180

## 181 **2.3. Analysis of local shark indicators**

### 182 *2.3.1. Catch composition*

183 The relative catch composition of sharks, defined as the species specific shark species in  
184 relation to the total shark catches, was calculated and analyzed for the general Cabo Verde EEZ,  
185 as well as for the 300 nm neighboring area.

186



187 *2.3.2. Size distribution*

188 The annual trends in the size frequency distributions and mean sizes for the main shark species  
189 were analyzed and plotted by area, sex and quarter of the year. Size data were tested for  
190 normality with Kolmogorov-Smirnov normality tests with Lilliefors correction (Lilliefors, 1967),  
191 and for homogeneity of variances with Levene tests (Levene, 1960). Specimen sizes were  
192 compared between regions (Cabo Verde EEZ and 300nm adjacent area), sexes and quarters of  
193 the year using non-parametric k-sample permutation tests (Manly, 2007).

194 The mean size at first maturity ( $L_{50}$ ) used to define immature and mature specimens were  
195 based on the ICCAT Sharks Working Group report (Anon., 2014) for the North Atlantic shark  
196 stocks, as follows:

- 197 • Blue shark (males): mean = 200.1 cm Fork Length (FL);
- 198 • Blue shark (females): mean = 185.1 cm FL;
- 199 • Shortfin mako (males): mean = 182.5 cm FL; range = 180 - 185 cm FL;
- 200 • Shortfin mako (females): mean = 286.5 cm FL; range = 275 - 298 cm FL.

201

202 *2.3.3. CPUE trends and standardization*

203 The time series of catch per unit effort (CPUE) were plotted for blue and shortfin mako sharks,  
204 which allowed following the trends over time and assessing seasonality effects in the catch  
205 rates. The CPUE time series were standardized in order to remove the fishery-dependent  
206 effects (i.e., spatial, seasonal and targeting effects) and estimate relative indexes of abundance  
207 that can be used as population status indicators. For the standardization process, the response  
208 variable considered was CPUE measured in biomass of live fish (kg) per 1000 hooks deployed.  
209 The standardized CPUEs were estimated with statistical models using Generalized Linear  
210 Models (GLMs) and Generalized Linear Mixed Models (GLMMs).

211 Blue shark and shortfin mako data had different characteristics, especially with regards to the  
212 percentage of zeros in the datasets. Specifically, the blue shark is relatively common in the  
213 catches and has a low percentage of fishing sets with zero catches, while the shortfin mako is  
214 rarer in the catches and had a much higher percentage of fishing sets with zero catches. The  
215 presence of fishing sets with zero catches results in a response variable of  $CPUE=0$ , that can  
216 cause mathematical problems for fitting the models, and as such different approaches were  
217 tested and applied in each case.

218 Four different modeling methodologies were initially tested and compared, specifically  
219 tweedie, gamma, lognormal and delta lognormal models. For the tweedie models the nominal  
220 CPUE was used directly, as the response variable, given that this distribution can handle a  
221 certain proportion of zeros (mass) and a continuous distribution for the non-zeros. For the  
222 gamma and lognormal models the response variable was defined as the nominal CPUE +  
223 constant (c), with c set to 10% of the overall mean catch rate. The value of c=10% of the mean  
224 has been recommended by Campbell (2004), as it seems to minimize the bias for this type of  
225 adjustments. Further, and in a comparative study, Shono (2008) showed that when the  
226 percentage of zeros in the dataset is low (<10%), the method of adding a constant to the  
227 response variable performs relatively well. The final tested approach was a delta-lognormal  
228 model that uses and combines two different models, specifically a binomial model for the  
229 proportion of positive catches and a lognormal model for the expected CPUEs in the positive  
230 sets.

231 The covariates considered and tested in the models were:

- 232 • Year: analyzed between 2006 and 2015;
- 233 • Seasonal effects (quarters of the year, 4 categories): 1 = January to March, 2 = April  
234 to June, 3 = July to September, 4 = October to December;
- 235 • Spatial/area effects: tested as 5\*5 or 10\*10 degree grids;
- 236 • Targeting effects: based on the SWO/SWO+BSH ratio of captures.

237 Interactions between pairs of variables were considered and tested in the analysis and used in  
238 the final models, if significant. Specifically, interactions not involving the year factor were  
239 considered as fixed factors in GLM type models, while interactions involving the year factor  
240 were considered as random variables within GLMM models.

241 The significance of the explanatory variables, as well as the interactions, were assessed with  
242 likelihood ratio tests (LRT) comparing each univariate model to the null model (considering a  
243 significance level of 5%), and by analyzing the deviance explained by each covariate. Goodness-  
244 of-fit and model comparison was carried out with the Akaike Information Criteria (AIC) and the  
245 pseudo coefficient of determination ( $R^2$ ). Model validation was carried out with a residual  
246 analysis. The final estimated indexes of abundance were calculated by least square means  
247 (LSMeans or Marginal Means), that for comparison purposes were scaled by the mean  
248 standardized CPUE in the time series.

249

## 250 **2.4. Spatial models for prediction of catch rates and sizes**

251 Generalized Additive Models (GAM) were used to predict the expected blue shark and shortfin  
252 mako shark catch rates (CPUEs) and size distribution as a function of location (latitude and  
253 longitude) and quarter of the year. The models used were lognormal GAMs for modeling the  
254 CPUEs and Gaussian with identity link for modeling the sizes.

255 The predictors in the models were given by the smooth functions of latitude and longitude plus  
256 a parametric component for the quarters of the year. The smooth terms for the location  
257 covariates were estimated by maximum likelihood with thin plate regression splines (Wood,  
258 2003). The significance of the model parameters was tested with LRT comparing nested  
259 models, including the significance of the interactions between latitude, longitude and quarter  
260 of the year. Goodness-of-fit was assessed with the Akaike Information Criterion (AIC; Akaike,  
261 1973) and with the final deviance explained. A residual analysis was carried out for model  
262 validation. The expected mean catch rates and sizes were mapped along the study area and for  
263 each quarter of the year.

264 All analysis in this study was carried out using the R language for statistical computing v3.4.0 (R  
265 Core Team, 2017), with the following additional libraries: "car" (Fox and Weisberg, 2011),  
266 "ggplot2" (Wickham, 2009), "gmodels" (Warnes et al., 2013), "KernSmooth" (Wand, 2015),  
267 "lme4" (Bates et al., 2013), "lsmmeans" (Lenth, 2014), "maps" (Becker et al., 2013), "mgcv"  
268 (Wood, 2006, 2011), "perm" (Fay and Shaw, 2010), "plyr" (Wickham, 2011), "raster" (Hijmans,  
269 2016) and "tweedie" (Dunn, 2013).

270

## 271 **3. Results**

### 272 **3.1. Local shark indicators**

#### 273 *3.1.1. Catch composition*

274 The catch composition of elasmobranchs in the study area is largely dominated by blue shark  
275 (BSH) followed by shortfin mako (SMA) (**Table 1**). Other less frequent elasmobranch species  
276 occasionally captured in the region include the bigeye thresher (BTH) (*Alopias superciliosus*),  
277 silky shark (FAL) (*Carcharhinus falciformis*), longfin mako (LMA) (*Isurus paucus*), oceanic  
278 whitetip (OCS) (*Carcharhinus longimanus*), crocodile shark (PSK) (*Pseudocarcharias kamoharai*)  
279 and smooth hammerhead (SPZ) (*Sphyrna zygaena*) (**Table 1**). Most of those other species are

280 either no-retention species in ICCAT and/or listed in CITES, and therefore are mostly released or  
 281 discarded.

282

283 **Table 1.** Catch composition (percentage, in weight) of major shark species captured in the Cabo  
 284 Verde EEZ and adjacent waters of the tropical NE Atlantic.

FAO code	Species	Species composition (%)		
		EEZ	300 nm	Combined
BSH	Blue shark	93.4	94.5	94.1
SMA	Shortfin mako	4.7	3.3	3.8
SPZ	Smooth hammerhead	0.2	0.3	0.3
FAL	Silky shark	0.3	0.3	0.3
OCS	Oceanic whitetip	0.1	0.1	0.1
BTH	Bigeye thresher	<0.1	<0.1	<0.1
SKH	Other elasmobranchs	1.2	1.4	1.3

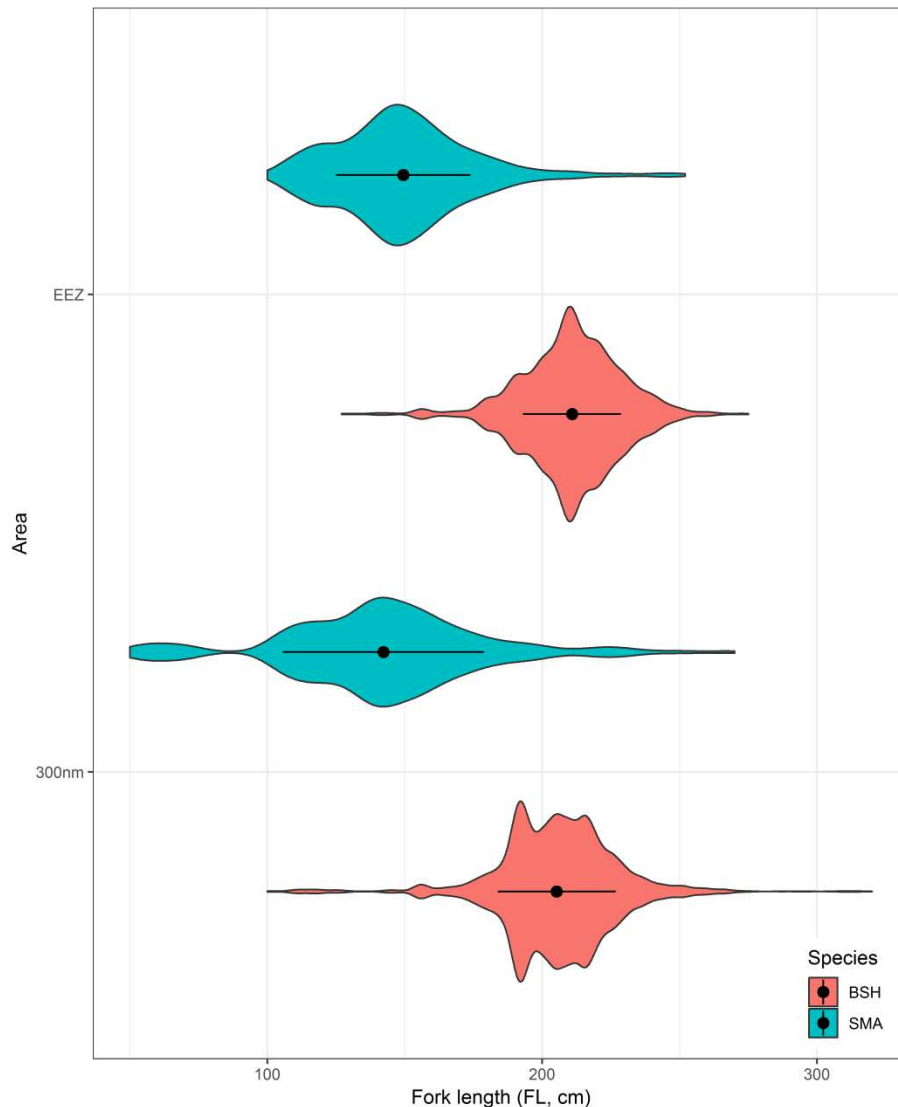
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### 286 3.1.2. Size distribution of the major shark species

287 In terms of size distribution, blue sharks caught in the Cabo Verde region are relatively large  
 288 specimens with mean sizes of 210.9 cm FL (SD=17.9) inside the Cabo Verde EEZ and 205.3 cm  
 289 FL (SD=21.5) in the 300 nm adjacent waters (**Figure 1**). Those differences observed in the mean  
 290 sizes in the two areas were significant (K-Sample Asymptotic Permutation Test: Chi2 = 88.9, df =  
 291 1, p-value < 0.001), meaning that in the Cabo Verde EEZ the blue sharks are significantly larger  
 292 than in the adjacent waters. Considering that the estimated blue shark mean size at first  
 293 maturity for the North Atlantic is 185 cm FL for females and 200.1 cm FL for males (Anon.,  
 294 2014), the catch of blue sharks in the Cabo Verde EEZ and neighboring waters is likely  
 295 composed mainly by adults. The size distribution is also narrower in the EEZ.

296 For the shortfin mako the mean sizes were 149.4 cm FL (SD=24.5) inside the Cabo Verde EEZ  
 297 and 142.2 cm FL (SD=36.6) in the adjacent waters. In this species the observed differences  
 298 between areas were also statistically significant (K-Sample Asymptotic Permutation Test: Chi2 =  
 299 13.4, df = 1, p-value < 0.001), meaning that in the Cabo Verde EEZ shortfin makos are also  
 300 significantly larger than in the adjacent waters (**Figure 1**). Considering that the estimated  
 301 shortfin mako mean size at first maturity for the North Atlantic is 275-298 cm FL for females

302 and 180-185 cm FL for males (Anon., 2014), the catch of shortfin makos in both regions is likely  
303 composed mainly by juveniles. Again for shortfin mako the size distribution of the catches  
304 showed a wider distribution outside the EEZ of Cabo Verde.



305

306 **Figure 1.** Size frequency distributions of the main shark species (BSH - blue shark and SMA -  
307 shortfin mako) in the Cabo Verde EEZ and 300 nm adjacent waters. The point and lines inside  
308 the plots represent the mean  $\pm$  standard deviations. (*Note do editor: Color figure provided for*  
309 *the online version of the paper and a grayscale version is provided for the print version- this*  
310 *applies to all figures in the manuscript*).

311

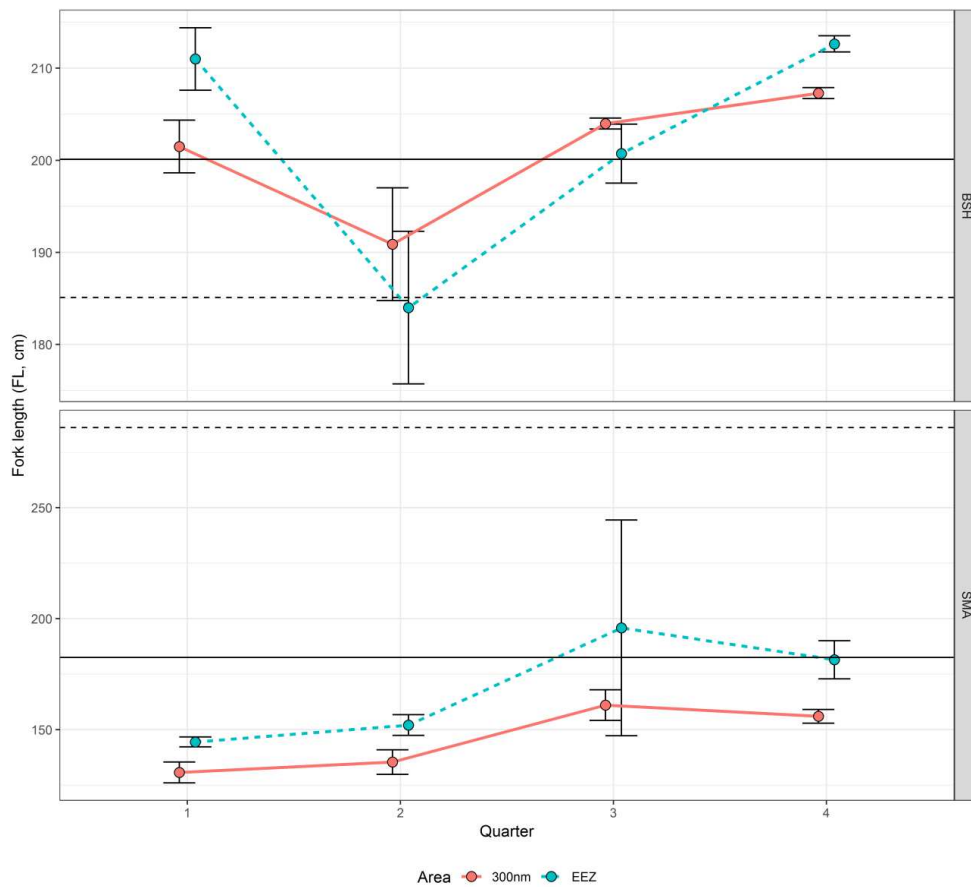
312 In terms of seasonality, larger blue sharks were captured in the 1st, 3rd and 4th quarters of the  
313 year, while smaller specimens were caught mainly in the 2nd quarter (**Figure 2**), with those

314 seasonal differences being statistically significant (K-Sample Asymptotic Permutation Test: Chi2  
315 = 180.1, df = 3, p-value < 0.001).

316 For the shortfin mako the smaller size specimens were captured in the 1st and 2nd quarters),  
317 while larger specimens are captured later in the year, in the 3rd and 4th quarters (**Figure 2**).

318 Those differences were also statistically significant (K-Sample Asymptotic Permutation Test: Chi2  
319 = 113.9, df = 3, p-value < 0.001).

320



321

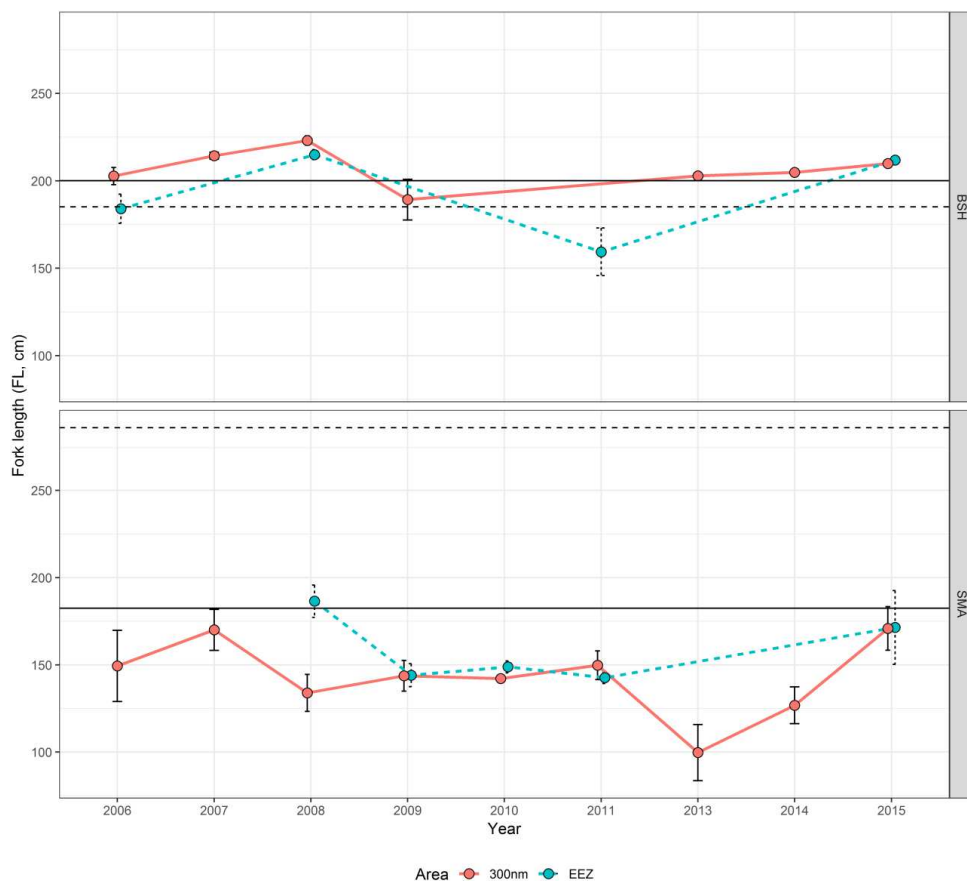
322 **Figure 2.** Seasonal mean sizes of the main shark species (BSH - blue shark and SMA - shortfin  
323 mako) in the Cabo Verde EEZ and 300 nm adjacent waters. The error bars refer to the 95%  
324 confidence intervals (CI). Mean sizes at first maturity ( $L_{50}$ ) of each species are indicated for  
325 males (horizontal solid lines) and females (horizontal dashed lines) (Anon., 2014).

326

327 In terms of trends in the size distribution, blue shark mean size was relatively stable along the  
328 time series (**Figure 3**) in both areas, even though those relatively small differences were

329 significant (K-Sample Asymptotic Permutation Test:  $\text{Chi}^2 = 573.3$ ,  $\text{df} = 7$ ,  $p\text{-value} < 0.001$ ). By  
 330 contrast, there was a general decreasing trend in the mean size of shortfin mako during the  
 331 study period, especially in the 300 nm adjacent waters, except in the most recent years (2014-  
 332 2015) when mean sizes increased to similar levels of the initial years (**Figure 3**). The mean  
 333 annual differences in the shortfin mako sizes were also statistically significant (K-Sample  
 334 Asymptotic Permutation Test:  $\text{Chi}^2 = 136.4$ ,  $\text{df} = 8$ ,  $p\text{-value} < 0.001$ ).

335



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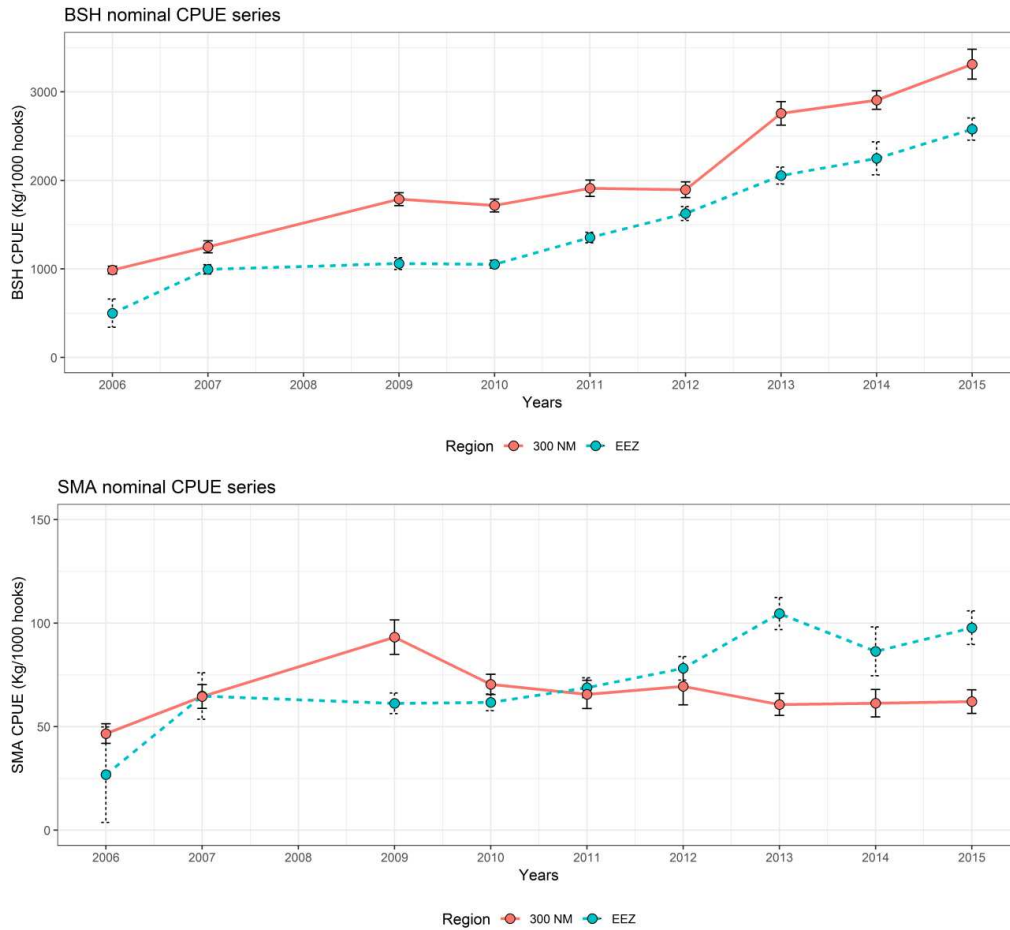
337 **Figure 3.** Time series trends of the mean sizes of the main shark species (BSH - blue shark and  
 338 SMA - shortfin mako) in the Cabo Verde EEZ and 300 nm adjacent waters. The error bars refer  
 339 to the 95% confidence intervals (CI). Mean sizes at first maturity ( $L_{50}$ ) values are indicated for  
 340 males (solid line) and females (dashed line) of each species (Anon., 2014).

341

### 342 3.1.3. Nominal catch per unit of effort (CPUE) distribution and trends

343 General increasing CPUE trends for both blue shark and shortfin mako were observed along the  
 344 study period in both areas. More specifically, for blue shark there was a progressive increase

345 between 2006 and 2015, while for shortfin mako there was an increase mainly in the earlier  
 346 years, between 2006 and 2009, and then a more stable period between 2009 and 2015 (**Figure**  
 347 **4**).



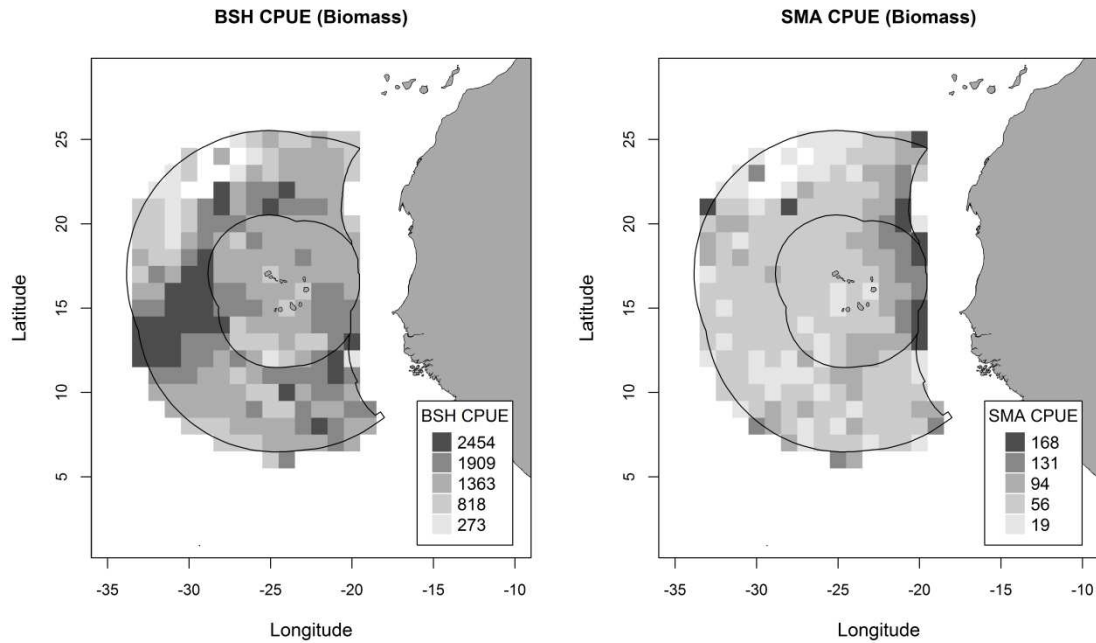
348

349 **Figure 4.** Time series of nominal catch per unit of effort (CPUE, biomass in Kg/1000 hooks) for  
 350 blue shark (above) and shortfin mako (below) in each of the study areas, Cabo Verde EEZ and  
 351 the 300 nm adjacent waters. The error bars refer to the 95% confidence intervals (CI).

352

353 In terms of the spatial CPUE distribution, higher blue shark catch rates occurred mainly outside  
 354 the Cabo Verde EEZ, in the 300 nm adjacent waters, especially in the western area (**Figure 5**).  
 355 For shortfin mako, higher CPUEs were also observed in the limits and outside the Cabo Verde  
 356 EEZ, but mainly in the eastern areas towards the African western coast (**Figure 5**).





357

358 **Figure 5.** Spatial distribution (by 1°\*1° squares) of catch per unit of effort (CPUE, biomass in  
 359 kg/1000 hooks) in the Cabo Verde EEZ and 300 nm adjacent waters, for blue shark (left plot)  
 360 and shortfin mako (right plot). Data was combined for the period 2006-2015.

361

### 362 3.1.4. CPUE standardization of blue shark

363 The percentage of fishing sets with zero catches of blue shark was low (2.9%). There was a  
 364 slight decrease in the sets with zero catches in the earlier period until 2011, followed by a slight  
 365 increase in the more recent years (**Figure S2** - Supplemental electronic material). In terms of  
 366 data distribution, the nominal blue shark CPUEs were highly skewed to the right and became  
 367 more normal distributed in the log-transformed scale (**Figure S3** - Supplemental electronic  
 368 material).

369 Of the various models tested, the best fit was obtained with a lognormal GLMM model. All the  
 370 explanatory variables tested for the CPUE standardization were significant and contributed  
 371 significantly for explaining part of the model deviance, including the effects for year, quarter,  
 372 area and targeting (**Table S2** - Supplemental electronic material). The interactions of quarter  
 373 with targeting were also significant and included in the model as a fixed variable, as well as the  
 374 interaction between year and quarter included as a random effect. On the final fitted model,  
 375 the factors that contributed most for the deviance explanation were targeting, followed by  
 376 year, quarter and area (**Table S2** - Supplemental electronic material). In terms of model

377 validation, the residual analysis, including the residuals distribution along the fitted values, the  
378 QQ plots and the residuals histograms, showed a good model fit without major outliers or  
379 trends in the residuals (**Figure S4** - Supplemental electronic material).

380 The final standardized index of abundance for the blue shark in the Cabo Verde EEZ between  
381 2006 and 2015 shows an overall increase along the entire time series period, similar to what is  
382 observed in the nominal CPUE series (**Figure 6**).

383

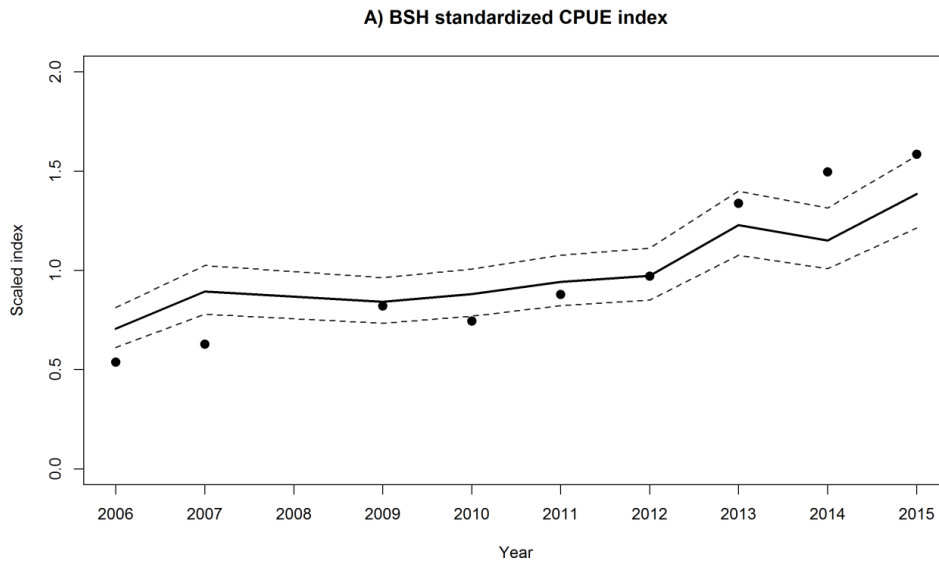
#### 384 *3.1.5. CPUE standardization of shortfin mako*

385 The overall percentage of fishing sets with zero catches of shortfin mako was 37.7%. Higher  
386 proportion of sets with zero shortfin mako catches were observed in the earlier years, and a  
387 progressive decrease for the most recent years (**Figure S5** - Supplemental electronic material).

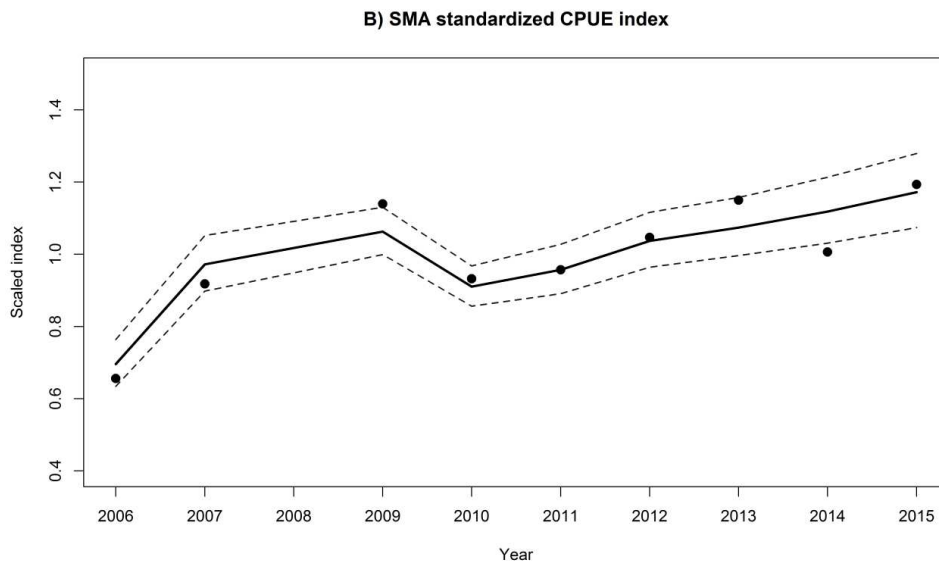
388 The CPUE distribution was also highly skewed to the right and became more normal distributed  
389 in the log-transformed scale (**Figure S6** - Supplemental electronic material).

390 Given the high percentage of zeros in the data and the shape of the distribution, the best fitted  
391 model was a tweedie GLM. All the explanatory variables tested were significant and  
392 contributed significantly for explaining part of the model deviance, including the effects for  
393 year, quarter, area and target (**Table S3** - Supplemental electronic material). The interactions of  
394 quarter with targeting were also significant and included in the model as a fixed effect. On the  
395 final fitted model, the factors that contributed most for the deviance explanation were the  
396 area, followed by quarter, year and targeting (**Table S3** - Supplemental electronic material). In  
397 terms of model validation, the residual analysis, including the residuals distribution along the  
398 fitted values, the QQ plots and the residuals histograms, showed a good model fit without  
399 major outliers or trends in the residuals (**Figure S7** - Supplemental electronic material).

400 The final standardized index of abundance for the shortfin mako shark in the Cabo Verde EEZ  
401 between 2006 and 2015 shows an increase in the earlier years until 2009, followed by a  
402 decrease in 2010, and then a slight increased again in the most recent years until 2015 (**Figure**  
403 **6**).



404



405

406 **Figure 6.** Standardized catch per unit effort (CPUE) series for blue shark (A - top) and shortfin  
 407 mako (B - below) in the in the Cabo Verde region. The solid line represents the standardized  
 408 CPUE, the dashed line represents the 95% confidence intervals of the standardized CPUE, and  
 409 the black dots represent the nominal CPUE. Each series is scaled by the mean standardized  
 410 CPUE

411

412 **3.2. Satellite tagging**

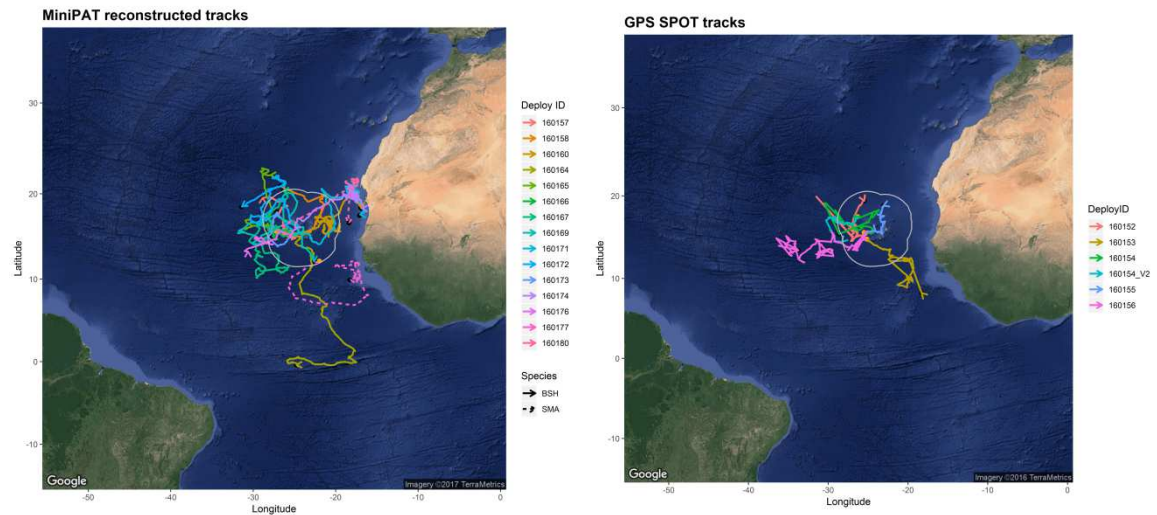
413 The SPOT tags (6 deployments) in blue shark had duration periods between 22 and 88 days,  
 414 with 2 of the tagged specimens fished (recaptured) after 50 and 77 days at liberty. Overall, the

415 deployed SPOT tags recorded data on 328 tracking days for the 6 blue shark specimens (**Table**  
416 **S4** - Supplemental electronic material).

417 Of the 25 deployed miniPAT tags (20 on blue shark and 5 on shortfin mako), 10 tags reached  
418 the full deployment period and popped-up on the expected date after 120 days (8 blue sharks  
419 and 2 shortfin makos), 10 specimens suffered post-release mortality (7 blue sharks and 3  
420 shortfin makos) between 1 and 26 days at liberty, 1 blue shark was recaptured by a fishing  
421 vessel after 71 days at liberty, 2 blue sharks dived to the maximum tag depth (~1850m) after 56  
422 and 76 days at liberty and the tags released automatically to avoid damage due to excessive  
423 pressure, 1 tag had premature release (shedding) after 12 days, and 1 tag failed to transmit.  
424 Overall, a total of 1,296 tracking days were recorded for blue sharks and 258 days for shortfin  
425 mako (**Table S4** - Supplemental electronic material).

426 From the miniPAT most likely estimated tracks, it was possible to see that most blue sharks  
427 moved substantial distances, on most cases to areas outside the EEZ (**Figure 7**). There was not  
428 a defined pattern in the movements, as there were cases of sharks moving towards the east,  
429 west, north and south. Particularly noteworthy was a blue shark that was tagged inside the  
430 Cabo Verde EEZ close to the Islands and that moved a significant distance towards the  
431 equatorial waters. Similar patterns were obtained with the GPS SPOT tags, showing blue sharks  
432 also moving outside the Cabo Verde EEZ, in this case mainly towards western and southeastern  
433 areas (**Figure 7**).

434 For the shortfin mako, most specimens also tended to move outside the Cabo Verde EEZ, but in  
435 this case mostly towards areas closer to the western African shelf, east of the Cabo Verde  
436 Islands. One particular specimen that was tagged inside the EEZ southeast of the Islands  
437 moved southeast, towards the region closer to the continental shelf at the latitude of the  
438 Bijagós Islands in Guiné Bissau (**Figure 7**).



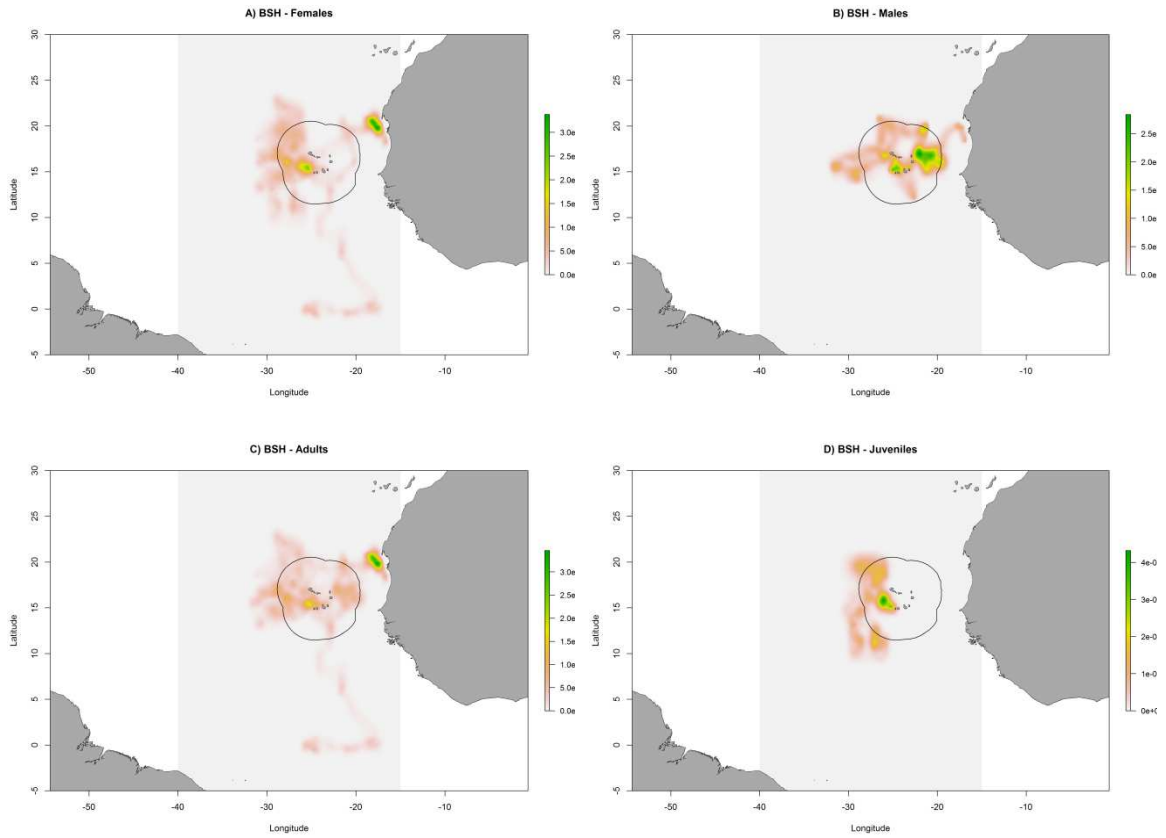
439 **Figure 7.** Reconstructed tracks for miniPAT (left panel) and GPS SPOT tags (right panel) for blue  
 440 shark and shortfin mako. Only tags with tracking days > 26 days are shown, in order to exclude  
 441 specimens that suffered post-release mortality after tagging and/or were fished (recaptured)  
 442 very close to tagging location.

443

444 For blue shark there were differences in the spatial distribution of the satellite tagged sharks,  
 445 when comparing between males and females. In general, males moved less and stayed closer  
 446 to the islands, while females showed wider movement and traveled greater distances to other  
 447 areas (**Figure 8**). When comparing maturity stages, there were also differences, with adults  
 448 travelling greater distances than juveniles (**Figure 8**).

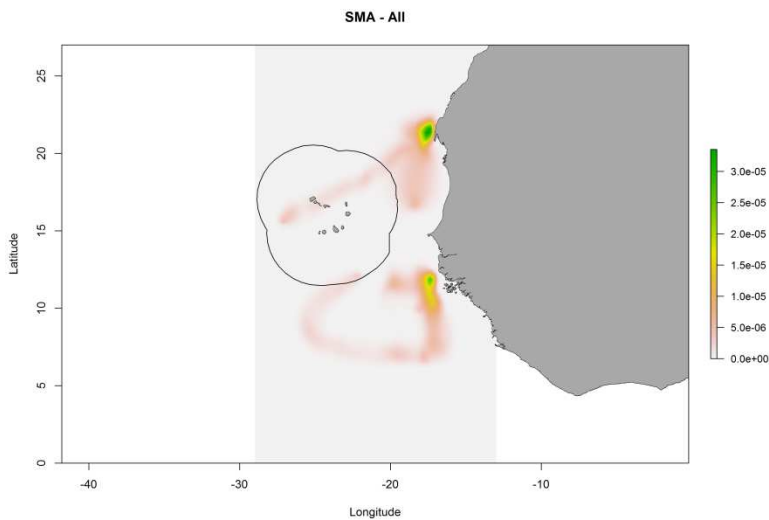
449 For shortfin mako the probability of distributions was closer to the African continental shelf,  
 450 mainly outside the Cabo Verde EEZ (**Figure 9**). For this species, as less specimens were tagged,  
 451 the analysis was made jointly and not separated by sex or maturity stage.

452



453 **Figure 8.** Probability surfaces of the spatial distribution of satellite tagged blue sharks (BSH) in  
 454 the Cabo Verde region, tropical NE Atlantic. The plots represent females (A - top left), males (B  
 455 - top right), adults (C - bottom left) and juveniles (D - bottom right). The colors in the legend  
 456 refer to the distribution of the density of the specimens, ranging from red (lower density) to  
 457 green (higher density).

458



459

460 **Figure 9.** Probability surfaces of the spatial distribution of satellite tagged shortfin mako shark  
461 (SMA) in the Cabo Verde region, tropical NE Atlantic. The colors in the legend refer to the  
462 distribution of the density of the specimens, ranging from red (lower density) to green (higher  
463 density).

464

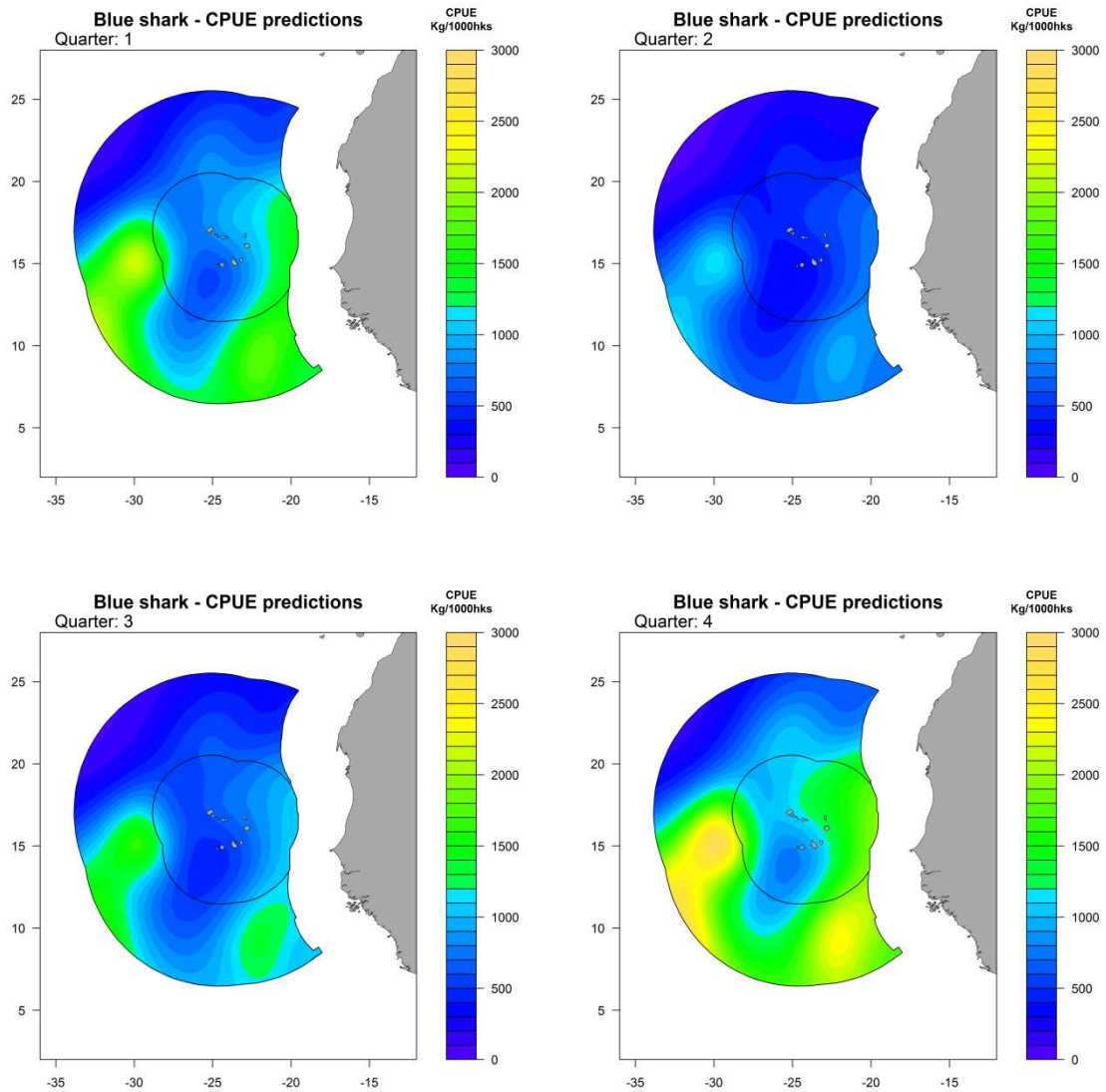
### 465 **3.3. Spatial models**

#### 466 *3.3.1. Modeling and predicting catch rates*

467 There was considerable variability in the expected catch rates (CPUEs) of both blue shark and  
468 shortfin mako in the study area when taking into consideration the location (spatial effects)  
469 and quarter of the year (seasonal effects).

470 For blue shark, overall higher CPUEs were predicted outside the Cabo Verde EEZ, especially in  
471 the south and southwest regions, while lower CPUEs were expected both in the EEZ and also in  
472 the northern areas outside the EEZ (**Figure 10**). Higher CPUEs were predicted during the winter  
473 and autumn (quarters 1 and 4), while much lower overall CPUEs were predicted in late spring  
474 and summer, especially during quarter 2 (**Figure 10**).

475

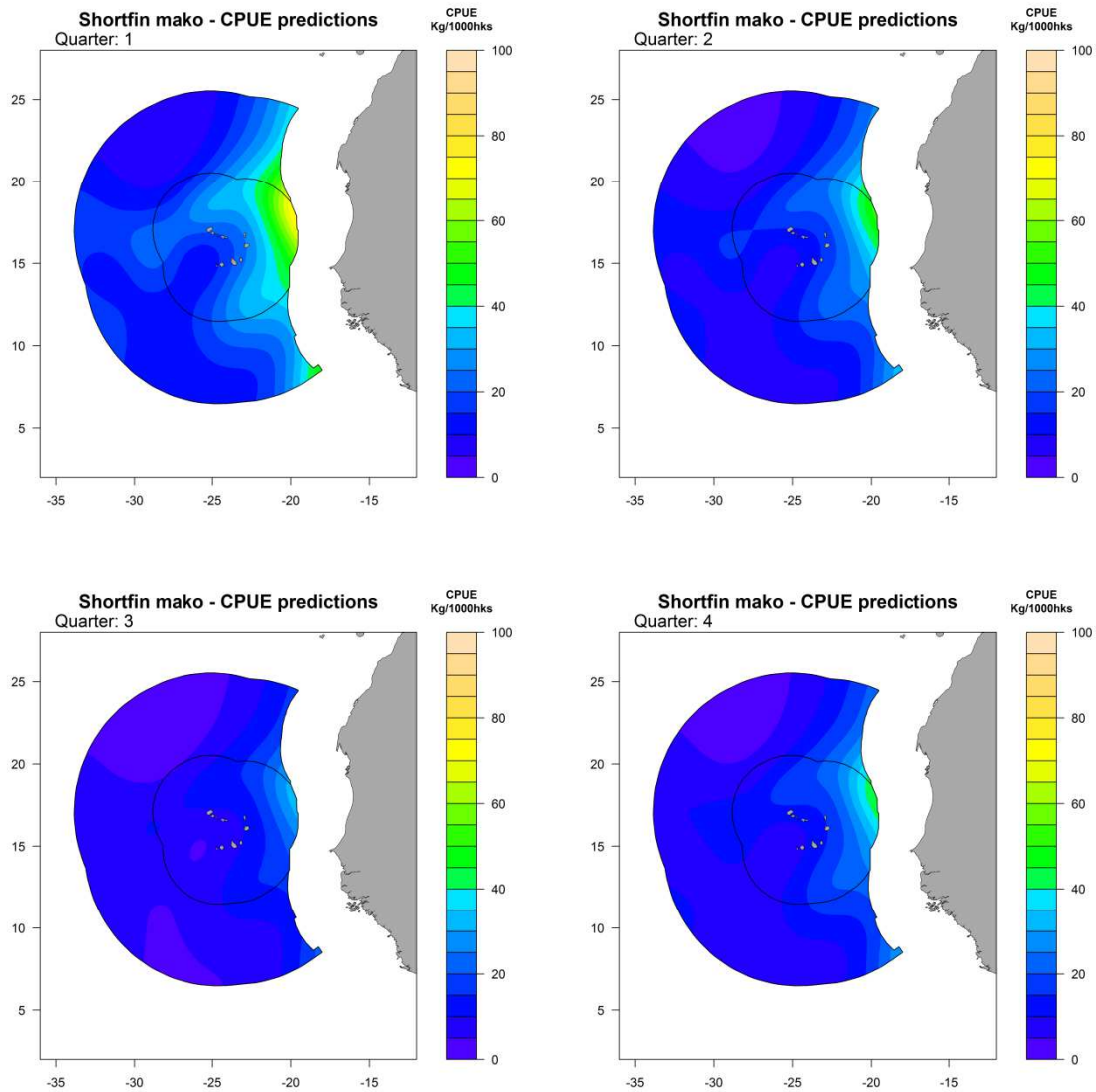


476 **Figure 10.** Seasonal prediction of the catch rates (CPUEs) of blue shark in the Cape Verde EEZ  
 477 and 300nm adjacent waters. The predicted values are the result of a Generalized Additive  
 478 Model (GAM) with lognormal distribution, taking into consideration the smooth terms of catch  
 479 location estimated with thin plate regression splines and the quarter of the year used as a  
 480 parametric term.

481

482 For shortfin mako very low CPUE along most of the study area was predicted, including both  
 483 the Cabo Verde EEZ and most of the adjacent waters. The higher CPUEs for this species were  
 484 predicted in the eastern areas, closer to the African continental shelf waters (**Figure 11**). The  
 485 seasonal effects were not as noticeable as for the blue shark, with the overall trends mostly  
 486 constant and low along all quarters of the year (**Figure 11**).





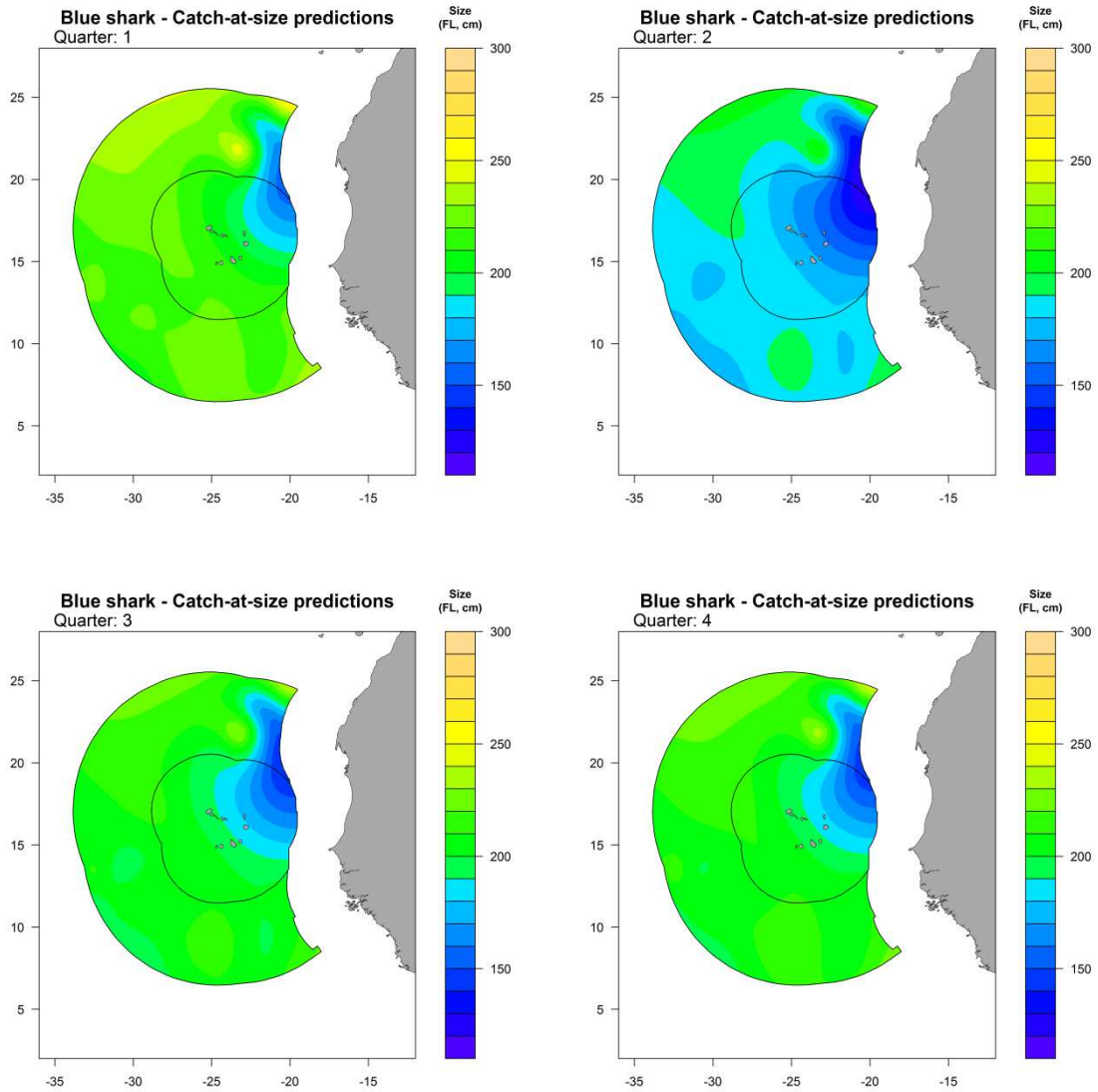
487 **Figure 11.** Seasonal prediction of the catch rates (CPUEs) of shortfin mako in the Cabo Verde  
 488 EEZ and 300nm adjacent waters. The predicted values are the result of a Generalized Additive  
 489 Model (GAM) with lognormal distribution, taking into consideration the smooth terms of catch  
 490 location estimated with thin plate regression splines and the quarter of the year used as a  
 491 parametric term.

492

### 493 3.3.2. Modeling and predicting catch sizes

494 For blue shark, smaller specimens were predicted both inside the Cabo Verde EEZ and the 300  
 495 nm adjacent waters, especially in the northeastern areas, as well as outside the study area  
 496 towards the southwest. Seasonality was important in the blue shark predicted sizes, with  
 497 overall smaller specimens expected during the spring months, in quarter 2 (**Figure 12**).

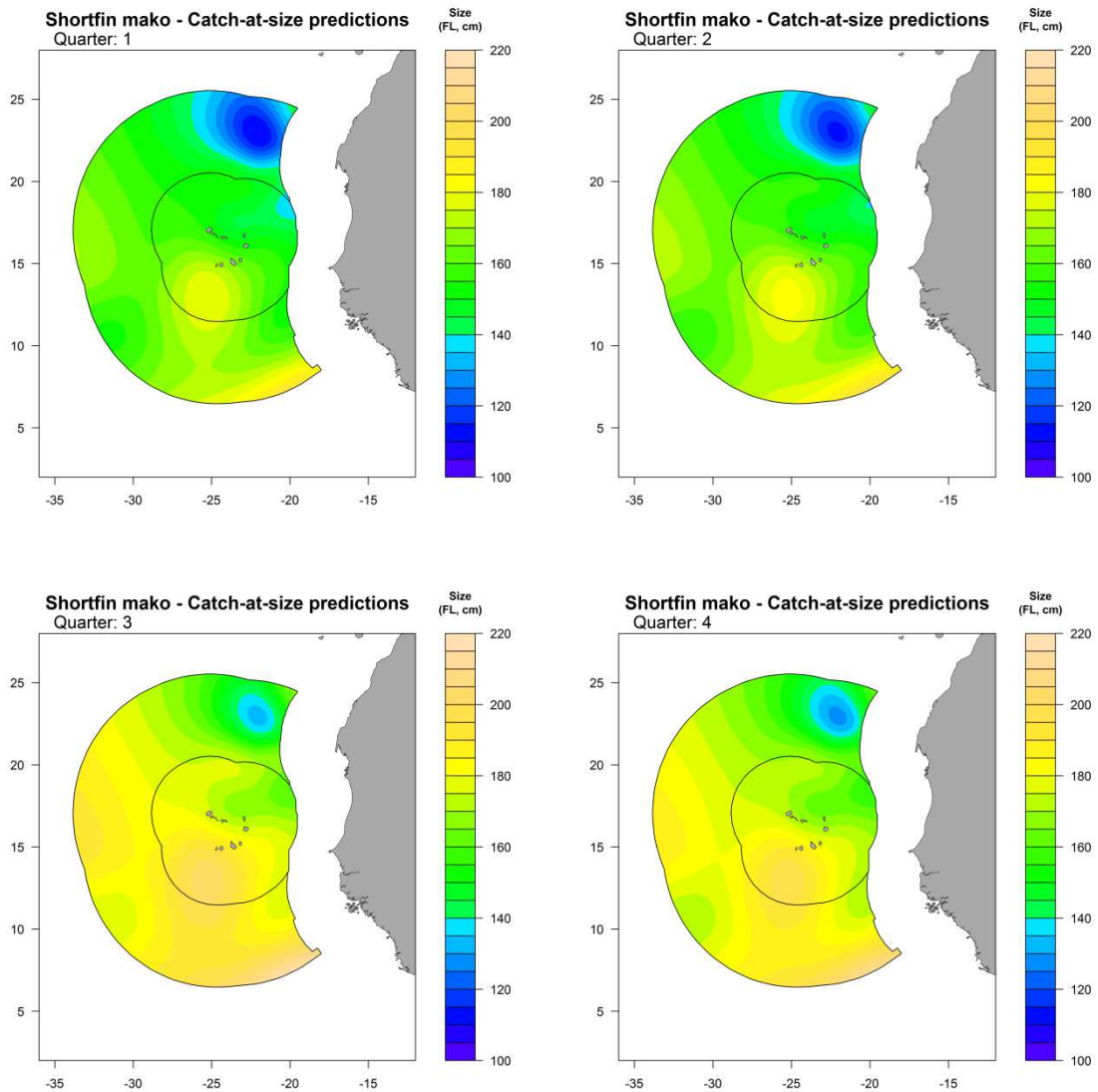
498 Nonetheless, it is important to note that the overall predicted blue shark sizes are relatively  
499 large for the species, given that blue sharks mature at 185.1 cm FL (females) and 200.1 cm FL  
500 (males). As such, most of the blue shark sizes predicted to occur in the study area along the  
501 entire year corresponds to large juveniles or sub-adults, and adults.



502 **Figure 12.** Seasonal prediction of the size distribution of blue shark in the Cabo Verde EEZ and  
503 adjacent waters (300 nm). The predicted values are the result of a Generalized Additive Model  
504 (GAM) with Gaussian distribution and identity link function, taking into consideration the  
505 smooth terms of catch location estimated with thin plate regression splines and the quarter of  
506 the year as a parametric term.

507

508 For shortfin mako, there were also marked spatial effects in the predicted size of the  
509 specimens, in this case with smaller specimens expected inside the study area, especially in the  
510 northeastern waters. Smaller specimens were expected to occur in quarters 1 and 2 and larger  
511 specimens were expected to occur mainly in the 2nd semester (**Figure 13**). Contrary to blue  
512 shark, for shortfin mako the overall expected specimen sizes corresponded mostly to small size  
513 specimens. As such, most of the shortfin mako specimens expected to occur in the study area  
514 along the entire year, particularly the females, correspond to juveniles.



515 **Figure 13.** Seasonal prediction of the size distribution of shortfin mako shark in the Cabo Verde  
516 EEZ and 300 nm adjacent waters. The predicted values are the result of a Generalized Additive  
517 Model (GAM) with Gaussian distribution and identity link function, taking into consideration  
518 the smooth terms of catch location estimated with thin plate regression splines and the  
519 quarter of the year used as a parametric term.

520

## 521 **4. Discussion**

### 522 **4.1. Shark indicators in the regional (NE Atlantic) context**

523 In the region of the Cabo Verde EEZ and adjacent waters, the elasmobranch catch composition  
524 from pelagic fisheries is largely composed by blue shark, followed by shortfin mako. This is  
525 common in pelagic longline fisheries operating in other regions of the Atlantic Ocean (e.g.,  
526 Mejuto et al., 2009; Coelho et al., 2012; Frédou et al., 2015). However, other less frequently  
527 captured elasmobranch species, which include threshers, silky shark, longfin mako, oceanic  
528 whitetip, hammerheads and the crocodile shark, were also recorded in similar proportions in  
529 pelagic longlines operating in other Atlantic regions (e.g., Coelho et al., 2012).

530 A CPUE standardization procedure was carried out for the two main shark species using  
531 statistical models, specifically Generalized Linear Models (GLMs) and Generalized Linear Mixed  
532 Models (GLMMs). Such standardization procedure was carried out to remove the fishery-  
533 dependent effects of the nominal CPUE data (i.e., spatial, seasonal and targeting effects), which  
534 allows the estimation of relative indexes of abundance that can then be used as population  
535 status indicators (Hilborn and Walters, 1992). The value of such standardization lies in the  
536 improvement in the proportionality between the derived index and true abundance (Ye and  
537 Dennis, 2009). Standardized CPUE series are also often used in stock assessment models by  
538 most RFMOs (Regional Fisheries Management Organizations). In this case the results from the  
539 CPUE standardization process showed an increase for the blue shark index of abundance over  
540 the entire time series, between 2006 and 2015. For the shortfin mako the abundance index  
541 was more variable, showing an increase in the earlier years of 2006-2009, followed by a  
542 decrease in 2010, and then an overall slight increase in the more recent period until 2015.

543 In terms of targeting effects, the differences in fishing strategy used in the models reflect the  
544 increased economic importance of sharks among the EU pelagic longline fleets, which  
545 traditionally targeted swordfish almost exclusively. These changes in target species were  
546 incorporated into the model by a proxy based on the ratio of the swordfish catch and the  
547 combined swordfish and blue shark catches by set. This ratio is in general considered a good  
548 proxy indicator of target criteria more clearly directed at swordfish *versus* a more diffuse  
549 fishing strategy aimed at the two main species (i.e., swordfish and sharks). Moreover, this  
550 methodology has been consistently applied to both EU fleets (Portuguese and Spanish) that  
551 have a similar method of operation, including applications to the Atlantic and Indian Oceans

552 (e.g., Mejuto et al., 2013; Coelho et al., 2014). Other approaches for including targeting effects  
553 into the CPUE standardization process have been tested in the past. Specifically, for the  
554 Portuguese pelagic longline fishery, Coelho et al. (2015a) tested a cluster analysis based on the  
555 catch composition of the 10 major species or species-groups, in an analysis, as suggested by He  
556 et al. (1997), that has been successfully applied for CPUE standardization of other fleets (e.g.  
557 Wang and Nishida, 2014; Hoyle et al., 2018). However, Coelho et al. (2015a) demonstrated that  
558 for the Portuguese pelagic longline fleet (and EU fleets in general), given that the catches are  
559 largely dominated by the two major species (i.e., swordfish and blue shark) the use of ratios or  
560 clusters resulted in very similar results.

561 Size distribution trends can also be used as stock status indicators (Tu et al., 2018) and it was  
562 observed that the catch of blue shark in the Cabo Verde region is mainly composed of relatively  
563 large adult specimens. There were no major variations in the time series trends, with the mean  
564 sizes relatively stable along the time period, both in the Cabo Verde EEZ and adjacent waters.  
565 This further suggests that there are no signs of population declines. Both the CPUE and size  
566 indicators for blue shark seem to indicate an apparently stable population in the region.

567 The catches of shortfin mako were mainly composed of small juvenile specimens, and there  
568 was a general decreasing trend in the mean catch size during the time period. This catch  
569 composed mainly of juvenile specimens and the general decreasing trend in mean sizes might  
570 be an indicator of overfishing for this species in the region. The relatively large catch rates of  
571 juvenile shortfin mako may also indicate that the Cabo Verde region and West African  
572 continental shelf is functioning as an aggregation area for juvenile specimens, that become  
573 vulnerable to the fisheries taking place in the region. Thus, fisheries indicators for shortfin  
574 mako should be closely monitored, preferably based on fishery observer programs.

575 One important aspect of this study is that it used detailed data exclusively from the EU fleets  
576 that operate in the Cabo Verde region (Portugal and Spain) but it should be noted that other  
577 fleets from other countries also operate in the region (e.g. Asian fleets). As such, the results  
578 presented here should be interpreted as representative only of the EU fleet component, while  
579 the effects of other fleets operating in the region were not considered. Although it should be  
580 noted that the Asian fleets traditionally target albacore and tropical tunas, setting their gear in  
581 deeper water and thus having lower catch rates of pelagic sharks.

582 It is important to put these results and conclusions within a wider Atlantic perspective. For the  
583 blue shark, the Ecological Risk Assessments carried out both in the Atlantic (Cortés et al., 2010;  
584 Cortés et al., 2015) and Indian Oceans (Murua et al., 2013, 2018) showed that this species is

585 one of the most productive of all pelagic shark species and therefore capable of sustaining  
586 relatively high levels of fishing mortality. Still, the overall vulnerability status was determined to  
587 be intermediate, mainly due to the also relatively large susceptibility of blue shark to pelagic  
588 fisheries, predominately pelagic longlines. The latest Atlantic blue shark stock assessments  
589 carried out by ICCAT in 2015 showed that for the north Atlantic the stock was unlikely to be  
590 overfished or subject to overfishing, even though there were high levels of uncertainty (Anon.,  
591 2015). This contrasts with the South Atlantic stock where it was not possible to discount that in  
592 recent years the stock may have been at levels near  $B_{MSY}$  and that fishing mortality has been  
593 approaching  $F_{MSY}$ , implying that future increases in fishing mortality in the southern stock could  
594 push the stock to an overfished state (Anon., 2015). The standardized CPUE increasing trends  
595 observed in this study for the blue shark in the Cabo Verde region are in line with the trends  
596 from the other fleets used in the last stock assessment by ICCAT. Specifically, for a number of  
597 fleets that operate in the North Atlantic, including both eastern and western regions (Portugal,  
598 Spain, Japan, US, Chinese-Taipei, Venezuela and Ireland). This general increasing trend has also  
599 been registered since the mid-2000s.

600 For shortfin mako the Ecological Risk Assessments carried out in the Atlantic (Cortés et al.,  
601 2010; Cortés et al., 2015) and Indian Ocean (Murua et al., 2013, 2018) ranked the species as  
602 one of the most vulnerable of all pelagic sharks, mainly due to its very low productivity and  
603 high susceptibility to fisheries, especially pelagic longlines. In the latest shortfin mako stock  
604 assessment carried out by ICCAT in 2017 (Anon., 2017), the results indicated that there were  
605 high probabilities that the North Atlantic stock was overfished and experiencing overfishing  
606 (Anon, 2017). In terms of the CPUE indexes used on that assessment, most fleets showed  
607 increases in stock abundance between 2000 and 2009, followed by reductions since then.  
608 These results have been recently updated by ICCAT (Anon., 2019), which again highlighted the  
609 poor stock condition of the North Atlantic stock. This is contrary to the results obtained in our  
610 study, where the series between 2006 and 2015 was mostly stable or showing an increasing  
611 trend. The reasons for the differences obtained might be related with the location of the  
612 fisheries, as the series used for the stock assessment were coming from other fleets operating  
613 mostly in different regions of the North Atlantic. As such, it is possible to hypothesize that even  
614 though the shortfin mako biomass in the North Atlantic has experienced overall reductions due  
615 to overfishing, the fraction of the population in the tropical NE Atlantic still seems to be  
616 relatively stable in terms of biomass. This could be either because it is still in better condition  
617 and/or because the region is a core area for the species in the Atlantic, where specimens tend

618 to aggregate and therefore signals in population declines might take longer time to be  
619 detected.

620

#### 621 **4.2. Satellite tagging**

622 During this study, tagged blue shark and shortfin mako showed considerable movement in the  
623 region. Specifically the tagged blue sharks (tagged inside the Cabo Verde EEZ) showed very  
624 variable movements in all directions, with sharks moving both inside and outside the EEZ. It  
625 was noteworthy that for blue sharks, the females and adults tended to move further away from  
626 the islands, while on the contrary the males and juvenile blue sharks tended to aggregate more  
627 around the Cabo Verde islands.

628 As regards shortfin mako, a clearer pattern of movements was observed, with the sharks  
629 tagged in the Cabo Verde EEZ tending to move mostly towards the West African continental  
630 shelf. This corroborated the observations from the catches and the prediction models using  
631 data from the commercial fisheries, where higher catch rates were also predicted for the  
632 eastern parts of the study area. For shortfin mako, therefore, it seems that areas closer to the  
633 African continental shelf, outside the Cabo Verde EEZ but in the EEZ of other African  
634 continental countries, are of particular importance.

635 Other pelagic shark species are also present in the region. While those other species, such as  
636 oceanic whitetip, silky shark, bigeye thresher, hammerheads and crocodile shark are not as  
637 common in the region, they are also accidentally by-caught in pelagic longline fisheries, though  
638 most of these species are now discarded due to ICCAT prohibition of retention and CITES  
639 regulations. Some previous studies have focused on satellite tagging and habitat use for the  
640 less common species, such as Coelho et al. (2015b) for the bigeye thresher and Santos and  
641 Coelho (2018) for the smooth hammerhead. Still, the knowledge on those more rare species is  
642 substantially lower than for the main shark species and therefore more effort should be put  
643 into continued tagging for those species in the future.

644

#### 645 **4.3. Spatial models and predictions**

646 Higher catch rates (in weight) were predicted outside the Cabo Verde EEZ for both blue and  
647 shortfin mako. For shortfin mako, in particular, considerably higher CPUEs are predicted along  
648 the African continental shelf, in areas outside the Cabo Verde EEZ but inside the EEZ of other

649 West African countries. As noted in section 4.2 above, this was corroborated with the satellite  
650 tagging data that also showed that those areas along the West African shelf are of particular  
651 importance for this species. These results show that even though the shortfin mako is an  
652 oceanic and pelagic species, it seems to have a strong relation with continental shelf areas,  
653 especially the juveniles. A recent study using satellite telemetry to map the movements of  
654 shortfin mako shark in the West Atlantic (US and Mexico) concluded that shortfin mako  
655 displayed very region-specific movements, with little distributional overlap between the Gulf of  
656 Mexico/Caribbean Sea and the western North Atlantic (Vaudo et al., 2017). In the eastern  
657 Atlantic, our study now seems to have reached similar conclusions and a comparable situation  
658 might be occurring off West Africa, with shortfin makos showing the same type of region-  
659 specific movements mainly along the West African continental shelf area.

660 There was considerable variability in the expected mean size for both species taking into  
661 account spatial and seasonal effects. One important note, however, is that even though those  
662 spatial and seasonal effects are important, in general the overall size of blue sharks was  
663 expected to be composed mainly of relatively large adult individuals; whereas the overall size  
664 of shortfin makos was expected to be mainly composed of relatively small juveniles. This was  
665 consistent over the entire region and throughout the year. Both the spatial and seasonal effects  
666 were influential in the expected mean size, in the case of the blue shark with the smaller  
667 specimens occurring in the area mainly during spring months (quarter 2), while) and in the  
668 case of shortfin makos the smaller specimens are expected to occur mainly in the 1st semester  
669 during the winter and spring months.

670 When comparing those results within an Atlantic wide perspective, it is important to note that,  
671 although there is some information available for blue shark, there is little information available  
672 on the shortfin mako and for other pelagic shark species. Blue shark shows a strong size  
673 latitudinal stratification pattern in all oceans, with a tendency for the larger adult specimens to  
674 occur in warmer equatorial and tropical regions and the smaller juveniles occurring in colder  
675 temperate waters (Coelho et al., 2018). However, for some other species the opposite pattern  
676 has been found, as for example for the bigeye thresher in the Atlantic, where smaller and  
677 younger sharks tend to concentrate predominantly in the tropical regions, while the larger  
678 specimens seem to prefer temperate areas of the northern and southern Atlantic (Fernandez-  
679 Carvalho et al., 2015b).

680

## 681 **5. Conclusions and recommendations**



682 As a final conclusion, the Cabo Verde region appears to be part of the Atlantic wide  
683 distributional cycle where those shark species move through their life cycles. The blue shark  
684 shows widespread and large scale movements in and out of the Cabo Verde EEZ as well as into  
685 wider regions. The presence of the large adults in the Cabo Verde region corroborates the  
686 previously hypothesized distributional patterns in the North Atlantic, with the large adult  
687 specimens occurring mainly in warmer tropical waters (Coelho et al., 2018). In the case of the  
688 shortfin mako, although the entire region appears to be an aggregation area for juveniles, the  
689 region closer to the African continental shelf seems to be of particular importance to this  
690 species, with large aggregations of small juvenile specimens.

691 The following are the main conclusions and recommendations from this study:

- 692 • Blue shark and shortfin mako are the main shark species captured in the pelagic  
693 longlines, both in Cabo Verde archipelago EEZ as well as in other regions; this is the  
694 same case of most oceanic-wide waters fished by pelagic longline gears;
- 695 • For both species the estimated indices of abundance for the Cabo Verde region showed  
696 overall increases over the time series period (2006-2015);
- 697 • Blue sharks captured in the region are mainly large adults and there were no major  
698 trends in mean sizes over time. By contrast, the shortfin makos caught in the region are  
699 relatively small juveniles, and there were some indications of possible declines in the  
700 mean sizes over time;
- 701 • Considering the abundance indexes, local depletion effects do not seem to be  
702 occurring for those two shark species in the region as there are no signs of decreasing  
703 local abundance (biomass). However, for the shortfin mako there are signs of a  
704 decreasing trend in the mean sizes that can indicate overfishing on this species;
- 705 • The satellite tagged sharks showed high mobility of the specimens with movements  
706 both inside and outside the Cabo Verde EEZ. In some cases, the sharks moved  
707 considerable distances over the tagged periods, especially in the case of blue shark;
- 708 • The shortfin mako sharks seem to have marked region-specific movements and habitat  
709 use, mainly along the West African continental shelf. This type of region-specific  
710 movements has also been recently hypothesized for this species in the West Atlantic;
- 711 • The presence of the large adult blue shark in the Cabo Verde region corroborates the  
712 hypothesis of the distributional patterns of this species in the North Atlantic, with large  
713 adult specimens occurring mainly in warmer tropical waters and juveniles in colder  
714 temperate and more coastal waters;

715 • For the shortfin mako the areas closer to the African continental shelf seem to be of  
716 particularly importance, with large aggregations of small juvenile specimens. Such  
717 areas should be of priority focus for the species conservation.

718

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736

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