Fisheries Research 264 (2023) 106730

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

The Portuguese industrial pelagic longline fishery in the Northeast Atlantic: Catch composition, spatio-temporal dynamics of fishing effort, and target species catch rates

Hugo Parra [a,b,*], Christopher K. Pham [a,b], Miguel Machete [a,b], Marco Santos [c], Karen A. Bjorndal [d], Frederic Vandeperre [a,b]

[a] IMAR, Department of Oceanography and Fisheries, University of the Azores, 9901-862 Horta, Portugal
[b] OKEANOS – Instituto de Investigação em Ciências do Mar, University of the Azores, 9901-862 Horta, Portugal
[c] DRPM – Direção Regional de Políticas Marítimas, Colónia Alemã, apartado 9, 9900-014 Horta, Portugal
[d] ACCSTR – Archie Carr Center for Sea Turtle Research, University of Florida, Gainesville, FL 32611, USA

A R T I C L E I N F O

Handled by Jason M. Cope

Keywords:
Drifting longline
Swordfish
Blue shark
Bycatch
GAMM
Global fishing watch

A B S T R A C T

The multispecific and highly dynamic nature of pelagic longline fisheries demands a holistic view that will likely benefit the development of effective management strategies. This study aims to provide an integrated perspective of the Portuguese longline fishery targeting swordfish *Xiphias gladius* and blue shark *Prionace glauca* in the Northeast Atlantic, regarding fishing dynamics, target species catches and associated bycatch. Data from 896 observed fishing sets (887,641 hooks) collected between 2015 and 2020 were used in a cluster analysis to group sets according to the target species. These sets were investigated for spatio-temporal patterns, and the relationship between target species catches and environmental and operational characteristics were examined using generalized additive mixed models (GAMM). A total of 46,306 individuals from 54 species (30 fish, 11 sharks, 2 manta rays, 6 cetaceans, 2 sea turtles and 2 seabirds) were recorded. Swordfish and blue shark comprised over 88.3% of the total catch in numbers (33.6% and 54.7%, respectively). Overall, most of the fishing effort occurred west off mainland Portugal, congregated during autumn when vessels targeted mostly swordfish, and dispersed over the region during spring and summer, when vessels targeted mostly blue shark. The bycatch of sea turtles and a relatively higher diversity of bony fish species, yet low catch in terms of abundance, appeared more associated with sets identified as targeting swordfish. Recorded catch of tunas *Thunnus* spp. and pelagic sharks, such as the shortfin mako *Isurus oxyrinchus* and the porbeagle *Lamna nasus*, were more associated with blue shark sets. Bigeye thresher *Alopias superciliosus*, thresher *Alopias vulpinus*, pelagic stingray *Pteroplatytrygon violacea* and lancetfish *Alepisauros ferox* were found equally associated with both targeted species. Management strategies for the region are discussed in light of these new findings.

1. Introduction

Industrial pelagic fishing uses a range of methods that involve the use of nets (e.g., purse seines, drift nets), and hooks and line (e.g., drifting longline, pole and line) to catch highly migratory tunas, billfishes and sharks (Crespo and Dunn, 2017). These species are important contributors to food security and income in many countries (Pons et al., 2018), and represented 10% (9.1 million t) of the global marine capture fisheries production in 2019 (FAO, 2021). The multispecific nature of these fisheries results in the incidental take, or bycatch, of non-targeted species, as well as of undesirable sizes or age classes of targeted species, also termed as discards (Hall et al., 2000; Lewison et al., 2004; Pérez Roda, 2019). Technological advancements over the past decades in fishing gears, practices, vessels autonomy and refrigeration, resulted in increased fishing capacity (Ward and Hindmarsh, 2007), and enabled the expansion of operations beyond national jurisdictions into the high seas (Swartz et al., 2010; Tickler et al., 2018). Currently, commercial drifting longline fisheries occur in a third of the global ocean, encompassing areas with limited monitoring and regulations (Kroodsma et al., 2018; Queiroz et al., 2019). The persistence of these trends will likely

* Correspondence to: Instituto do Mar (IMAR), Department of Oceanography and Fisheries, University of the Azores, 9901-862 Horta, Portugal.
E-mail address: parra.hugo@gmail.com (H. Parra).

https://doi.org/10.1016/j.fishres.2023.106730
Received 17 June 2022; Received in revised form 10 March 2023; Accepted 21 April 2023
Available online 3 May 2023

result in the collapse of pelagic fish stocks, currently considered overexploited (Ward and Myers, 2005; Collete et al., 2011; Hillary et al., 2016), while posing a serious threat for internationally protected species, especially for those considered "endangered" or "critically endangered" under the International Union for the Conservation of Nature (IUCN) Red List criteria for populations conservation status (Mace et al., 2008).

The Portuguese pelagic longline fishery developed after 1986 (Santos et al., 2002), following an increasing trend of swordfish *Xiphias gladius* catch in the Atlantic Ocean and Mediterranean Sea that started in the 1950s (Neilson et al., 2013). The International Commission for the Conservation of Atlantic Tunas (ICCAT) studies and manages fisheries for swordfish and other large pelagic species in the ICCAT Convention Area, which includes the North Atlantic. Stock assessments, total allowable catch (TAC) and quotas are determined periodically and attributed to each contracting party (e.g., Portugal). According to ICCAT's Standing Committee on Research and Statistics (SCRS), swordfish nominal catch in the North Atlantic peaked in 1987 (20,238 t) and then declined until the late 1990s (Anonymous, 2019). This trend was attributed to a decreased abundance of swordfish in the region, fleet relocation to other areas (e.g., South Atlantic), and the introduction of quotas and size limits (Ward et al., 2000; Neilson et al., 2013). Since the early 2000s, the stock has shown signs of improvement, and catches (landings plus dead discards) remained stable over the past decade (annual average of 11,245 t; Anonymous, 2019). In 2018, the catch (8858 t) decreased by 56.2% since the 1987 peak, attributed to several reasons including ICCAT regulatory recommendations, shifts in fleets distribution, changes to target species with relatively higher catch rates and increased market conditions (e.g., sharks and/or tuna), and/or due to socio-economic factors (Neilson et al., 2013; Anonymous, 2019). Swordfish catches by the Portuguese fleet reached 2414 t in 2019 (INE, 2020), representing approximately 21% of the annual averaged North Atlantic swordfish catch over the past decade (11,245 t; Anonymous, 2019).

Pelagic sharks, namely blue shark *Prionace glauca* and shortfin mako *Isurus oxyrinchus*, are also frequently caught by the Portuguese swordfish fishery (Aires-da-Silva and Pereira, 1999; Santos et al., 2002; Aires-da-Silva et al., 2008; Santos et al., 2014; Vandeperre et al., 2014a; Coelho et al., 2016). Blue shark is the most commonly caught shark species by drifting longline in the North Atlantic (Buencuerpo et al., 1998; Aires-da-Silva and Pereira, 1999; Simpfendorfer et al., 2002; Mejuto et al., 2009; Vandeperre et al., 2014a). Over the past decade, this species has been increasingly targeted by the fleet in response to a reduced swordfish quota, low swordfish abundance during part of the year, and an increased commercial interest for shark fins and meat in international markets (Vandeperre et al., 2014a; Dent and Clarke, 2015). A similar increasing trend was reported for blue shark landings in Portuguese fishing ports (Roxo et al., 2017), and in ICCAT's North Atlantic blue shark stock assessments, showing a steady increase in catches over the past two decades, reaching a peak in 2016 (44,096 t; Anonymous, 2019). In 2018, blue shark catches in the North Atlantic showed a considerable decrease (33,853 t; Anonymous, 2019). Despite this overall stability in North Atlantic blue shark catches since early 2000s, stock assessment results have been considered uncertain, and do not exclude the possibility of the stock being overfished (Anonymous, 2019). In 2020, ICCAT adopted Recommendation 19–07 which establishes an annual TAC for blue shark in the North Atlantic of 39,102 t, and a quota allocation recommendation was also considered (Anonymous, 2022). The Portuguese pelagic longline fleet was estimated to catch 5195 t of blue shark in the North Atlantic during 2018, representing approximately 13% of the established TAC (Anonymous, 2019).

Marine megafauna bycatch by pelagic longline fisheries mainly includes pelagic fish and elasmobranchs, seabirds, sea turtles and marine mammals (Lewison et al., 2004a; Lewison et al., 2009; Lewison et al., 2014; Anderson et al., 2011; Wallace et al., 2013; Werner et al., 2015; ICES, 2022). These species are highly migratory with extremely wide-range distributions that overlap considerably with areas of intense fishing effort. Data limitations remain a key point when determining the effect of fisheries bycatch on those species and populations (Lewison et al., 2004b, Soykan et al., 2008, ICCAT Recommendation 11–10, ICES, 2022). Research on bycatch by pelagic longline for the Northeast Atlantic has mostly focused on a particular species group (e.g., pelagic sharks: Coelho et al., 2012, Santos et al., 2014; sea turtles: Ferreira et al., 2001) and, to the best of our knowledge, only few studies have reported the diversity of species affected by this fishery in the region (Buencuerpo et al., 1998; Mejuto et al., 2009; Fernandez-Carvalho et al., 2015).

The paucity of high-quality data regarding total catches, catch composition, and spatio-temporal patterns in fishing effort has been a long recognized issue for fisheries management (Lewison et al., 2004, 2009; Lewison and Crowder, 2007; Worm et al., 2013; Gilman et al., 2014; Queiroz et al., 2016). Such data are collected by trained observers onboard vessels, yet it's highly costly and practically unfeasible to achieve complete coverage of fleet operations (Lewison et al., 2004). In a comparative assessment of regional fisheries management organizations (RFMO) governance of bycatch and discards, Gilman et al. (2014) estimated a relative low score (36%) for ICCAT fisheries in terms of observer coverage and data quality. These data limitations can deter the progress in conservation efforts because the implementation of management actions to protect a species can be delayed until conclusive evidence is available (Lewison et al., 2004).

Furthermore, most studies focus on particular species or species-groups, which masks the larger picture of the impact of these fisheries on the ecosystems. Studies on Portuguese pelagic longline fisheries in the North Atlantic have addressed a multitude of aspects regarding swordfish and blue shark catches (e.g., Aires-da-Silva and Pereira, 1999, Santos et al., 2002, Aires-da-Silva et al., 2008, Vandeperre et al., 2014a), sea turtles (e.g., Parra et al. 2023; Bolten et al., 1994; Martins et al., 2001; Ferreira et al., 2001; 2011; Santos et al., 2012; Coelho et al., 2015), and pelagic sharks bycatch (e.g., Correia et al., 2003; Maia et al., 2007; Queiroz et al., 2016; Roxo et al., 2017). These studies have greatly improved the knowledge of life-history characteristics and impacts of this fishery on these species.

Nevertheless, improved knowledge of these fisheries likely requires an integrated perspective of fishing dynamics, target species catches and the amount and diversity of bycatch associated with each of the targeted species. This will likely and ultimately enable the scientific community to provide sound answers to policy makers and the public, in general, on the "when, where, how and what" pelagic longline fleets are fishing. Using observer data collected onboard Portuguese longline vessels operating in the Northeast Atlantic, we investigate spatio-temporal patterns in fishing effort and catch composition. In addition, we explore the relationship between catch of the two target species (swordfish and blue shark) with environmental and operational factors, along with their level of association with bycatch species.

2. Methods

2.1. Fisheries observer data

Data were collected under the Azores Fisheries Observer Program (POPA – Programa de Observação das Pescas dos Açores; www.popaobserver.org) and COSTA project (COnsolidating Sea Turtle Conservation in the Azores; www.costaproject.org) on-board Portuguese commercial longline fishing vessels between September 2015 and December 2020. Observers embarked on longliners departing from the ports of Ponta Delgada (Azores, Portugal), Peniche (mainland Portugal) and Vigo (Spain). Data on fish catch (in number of individuals), operational characteristics (e.g., set locations, number of hooks, start and end time of gear deployment and retrieval, leader type, hook type) and environmental conditions (recorded sea surface temperature, rSST; Beaufort sea state; location depth) were recorded by trained observers for each set. A total of 896 sets was monitored by 6 different observers during 72 fishing trips performed by 18 different longline vessels measuring between 18 and 33 m in length, resulting in 887,641 hooks deployed in the area between 10°– 42° W and 20°– 46° N (Fig. 1; Table 1). A fishing trip including travel and fishing lasted 18.4 days on average ± 10.2 standard deviation [S.D.]. The fishing gear used was the "American style" longline which consisted of a monofilament nylon mainline with approximately 100 km in length and weighted branchlines suspended by two types of buoys: large (LB) and small buoys (SB). LB are used to locate the gear at the surface and, together with SB, provide stability to the gear (Ferreira et al., 2011). The number of LB per set varied between 7 and 29, resulting in sets with 6–28 sections, respectively. Each section had 8–19 SB and between each SB, 3–5 hooks. Hooks were separated by intervals of 60–120 m. Branchlines measured from 12 to 18 m and were composed with a wire and/or monofilament nylon leader. Light-sticks were used in all sets. Hook types used were the Ancora (16/0 and 17/0) Offset J (75% of all sets), the Straight J (22%) or a combination of both (3%). Hooks were mainly baited with mackerel (*Scomber* spp.), squid (*Loligo* spp.), and occasionally with shark meat (*Prionace glauca*), and long snouted lancetfish (*Alepisaurus ferox*). The number of hooks per section varied from 36 to 80, with a total number of hooks per set ranging from 360 to 1792 (mean: 990 ± 127 S.D.). The gear was typically deployed between 5:00 and 8:00 pm and retrieved at dawn. Set duration, estimated by the difference between the beginning of gear deployment and the end of gear retrieval, ranged between 12.7 and 42.8 h (mean: 23.8 ± 2.5 S.D.). Soaking time, calculated as the difference between the starting time of gear deployment and starting time of retrieval, ranged between 9.1 and 32.6 h (mean: 13.9 ± 1.8 S.D.).

2.2. *Fleet composition and effort*

The Portuguese pelagic longline fleet was sampled based on an opportunistic sampling design, in which observers embarked on vessels that provided suitable accommodation for the observer and with the collaboration of vessels owners and captains. According to the EU Fleet Register database (https://webgate.ec.europa.eu/fleet-europa/index_en), a total of 63 vessels were registered in 2020 with Portuguese flag and drifting longline as main fishing gear, and with sizes ranging between 5 and 46 m. Some of the vessels are polyvalent, and an unknown part of the fleet shifts to other fishing techniques (e.g., bottom longline) for unknown reasons. The Portuguese swordfish fishing quota is attributed to licensed vessels according to the region of registration (quota percentage of the total weight: 66% Portugal mainland, 31% Azores, 3% Madeira; Ordinance nº 237/2022, September 14th 2022). In 2020, 39 mainland vessels were attributed a swordfish quota for the North Atlantic (https://www.dgrm.mm.gov.pt/), while the fleet of the Azores consisted of 6 vessels. Sizes ranged between 15 and 46 m (mean 24 m), with a mean total gross capacity of 179 t per vessel, and an unknown portion of the fleet with freezing capacity. These 45 vessels were used in this study as representative of the Portuguese industrial pelagic

\

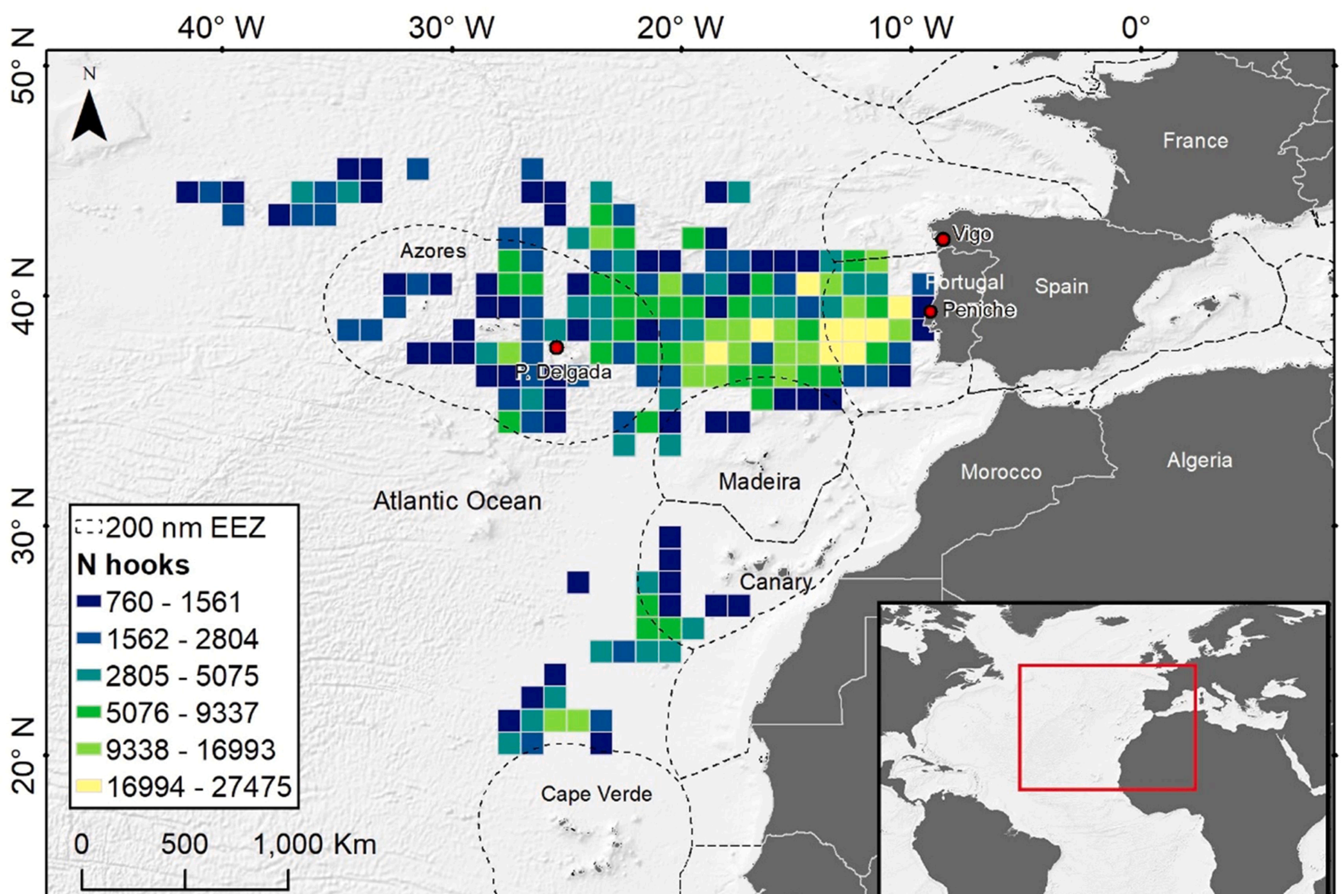

Fig. 1. Distribution of the observed fishing effort (i.e., number of hooks) by Portuguese pelagic longliners operating in the Northeast Atlantic between 2015 and 2020. Data are summarized within a 1-degree cell grid. Red dots indicate the ports where observers embarked. Dashed line represent the 200 nautical mile economic exclusive zone (EEZ).

Table 1
Observed numbers of sets and vessels (in parentheses) per month and year collected by observers of the Azores Fisheries Observer Program on Portuguese pelagic longliners operating in the Northeast Atlantic. Dash indicate that no data were collected.

Month	Year												Total
	2015		2016		2017		2018		2019		2020		
1	–	–	19	(2)	23	(2)	34	(2)	11	(1)	2	(1)	89
2	–	–	21	(2)	6	(1)	29	(4)	24	(2)	30	(2)	110
3	–	–	31	(2)	24	(2)	22	(3)	–	–	26	(1)	103
4	–	–	23	(2)	8	(1)	4	(2)	4	(1)	7	(1)	46
5	–	–	–	–	20	(2)	18	(2)	3	(1)	2	(1)	43
6	–	–	22	(2)	–	–	9	(2)	19	(1)	13	(1)	63
7	–	–	14	(1)	–	–	–	–	–	–	5	(1)	19
8	–	–	17	(2)	–	–	14	(2)	4	(1)	16	(2)	51
9	13	(2)	–	–	20	(2)	16	(1)	11	(1)	10	(2)	70
10	18	(2)	23	(3)	12	(2)	–	–	26	(2)	9	(1)	88
11	20	(2)	41	(2)	24	(2)	32	(2)	6	(1)	11	(1)	134
12	27	(2)	9	(1)	8	(2)	14	(2)	20	(2)	2	(1)	80
Total	78		220		145		192		128		133		896

longline fleet that regularly fish with drifting longline gear in the North Atlantic.

Fishing effort (hours of fishing) data for the fleet and individual vessels, was obtained from Global Fishing Watch (GFW) (available at https://globalfishingwatch.org/datasets-and-code/). GFW used raw automated identification system (AIS) vessel tracking data to estimate fishing effort and derive 0.01-degree gridded data, described in detail in Kroodsma et al. (2018). AIS was developed for vessel safety and anti-collision purposes, yet its global spatio-temporal coverage of thousands of vessels enables effort distribution to be analyzed (MacCauley et al., 2016; Kroodsma et al., 2018; Shepperson et al., 2018; Sala et al., 2018; Queiroz et al., 2019). Under the Portuguese jurisdiction, the obligation of the carriage of AIS is restricted to fishing vessels with more than 15 m in length (Decree-law 52/2012, March 7th 2012). A total of 60 vessels carrying AIS were identified for the Portuguese drifting longline fleet (https://webgate.ec.europa.eu/fleet-europa/index_en). GFW data gaps can result when a vessel turns off its AIS or travels in a region with exceptionally poor satellite coverage, such as the area off the coast of Europe (Kroodsma et al., 2018), where most of the observed fishing effort occurred in this study. The amount of effort that may be unaccounted for due to these data gaps is unknown. Therefore, and to address these issues, matching GFW data were extracted for individual vessels recorded in the observer dataset for the period between September 2015 and December 2020, and correspondence was assessed in terms of daily effort and spatial coordinates using Pearsoǹs correlation coefficient (Becker et al., 1988). In order to have a comparable unit of effort between the observer and GFW data, we converted the observer data by calculating the fishing time as the difference between the starting time of gear deployment to the end of gear retrieval (expressed in hours of fishing). ICCAT also provides fishing effort data for pelagic longline fisheries (https://www.iccat.int/en/accesingdb.HTML), however, it was under revision by the SCRS, hence unavailable. Other possible sources of fishing activity would be vessel monitoring system (VMS) and/or electronic fishing logbooks, but access is not public.

Furthermore, and in order to evaluate the spatial representativeness of the observed versus the GFW data, we extracted GFW data for the Portuguese fleet with drifting longline gear type, and cropped within the period and geographical extent of interest (10°−42° W; 20°−46° N). Subsequently, we summed the number of hours fished (expressed as days, where 24 h of fishing hours = 1 day) within each 1-degree cell for which we had observed effort. Overall and seasonal correspondence between the observer and GFW data was assessed using Pearsoǹs correlation coefficient (Becker et al., 1988). Seasonal maps of the kernel home range density estimates (Benhamou and Cornélis, 2010) of fishing sets using the observed locations and GFW effort data were produced using the kernelUD function from the "adehabitatHR" package v0.4.16 (Calenge, 2006) with the reference bandwidth selection. For season, we considered the following quarters: autumn (September−November), winter (December−February), spring (March−May), and summer (June−August).

2.3. Cluster analysis

All analyses were conducted within the R statistical environment v3.5.3 (R Core Team, 2018). In order to characterise the fishery, a non-hierarchical cluster analysis (k-means method; Legendre and Legendre, 2012) was used to group fishing sets according to the catch composition using nominal catch-per-unit-effort (CPUEn; in number of individuals per 1000 hooks). The catch composition is largely the result of the fishing tactics employed, i.e., the fishing intentions with respect to species targeted, fishing area and fishing gear (He et al., 1997; Pelletier and Ferraris, 2000; Ziegler, 2012). For the cluster analysis, the data matrix consisted of the observed CPUEn for each species and for each fishing set (896 ×39). Considering that the two target species made up almost 90% of the total catch in numbers, CPUEn was standardized using the "Hellinger" distance (Legendre and Gallagher, 2001) in which square roots of matrix values are used to reduce highest abundance values (Borcard et al., 2011). The optimal number of clusters within the data was determined using the "Calinski-Harabasz" index criterion of the cascadeKM function from the "vegan" package v2.5.5 (Oksanen et al., 2019), as the lowest number of clusters with the highest index value. After clusters were identified, they were named after the species that was most abundant within or characteristic of a particular cluster. Clusters were then considered as a categorical variable and each fishing set was assigned accordingly, and compared statistically in terms of species proportions, and environmental and operational characteristics, with a significance level of $p = 0.05$. Differences in species proportions and leader type between clusters were tested with the Pearson chi-square statistic (Agresti, 2007), while differences in environmental characteristics (i.e., location depth, sea surface temperature recorded on-board vessels) and in operational factors (i.e., soaking time, number of hooks, distance between LB) were assessed by the Mann-Whitney-Wilcoxon unpaired two-sample tests (Hollander and Wolfe, 1973). Bonferroni post-hoc test was performed when significant differences were observed between clusters for each individual species and for each type of leader (Zar, 2010).

2.4. GAMM analysis

To investigate spatio-temporal trends, and significant environmental and operational influences in swordfish and blue shark catches, we used generalized additive mixed models (GAMM). Such approach is commonly used to derive "standardized" catch rates that account for differences in fishing operations and/or variability in temporal and spatial distribution of the resources (Maunder and Punt, 2004). GAMMs were developed with a negative binomial family and a log link function using the number of individuals per set as response variable. Effort (log of number of hooks) was used as an offset variable, and "fishing trip" was added as a random effect to account for possible effects derived from captain's experience, vessel characteristics and/or target species market trends.

The operational and environmental variables considered as explanatory variables in this study that were suggested in previous studies to influence the distribution and catchability of blue shark (e.g., Bigelow et al., 1999, Vandeperre et al., 2014a), and swordfish (e.g., Damalas et al., 2007, Chang et al., 2013), included leader type, soaking time, latitude, longitude, month, sea surface temperature (SST), standard deviation of the mean SST (SSTsd), sea level anomaly (SLA), mixed layer depth (MLD), sea surface chlorophyll concentration, finite-size Lyapunov exponents (FSLE), bathymetry and lunar phase. Operational factors used to compare clusters (number of hooks and distance between LB) were not included in this analysis due to data gaps that resulted in the exclusion of 10% (~90 sets) of the dataset and decreased model performance, and therefore we opted not to include them. Daily mean SST (°C) was obtained from Copernicus Marine Environmental Monitoring Service (CMEMS; https://resources.marine.copernicus.eu/products) Global Ocean Operational Sea Surface Temperature and Ice Analysis (OSTIA; Good et al., 2020), a reprocessed product available at 0.05-degree grid resolution and based on in-situ and satellite data providing foundation SST (the temperature free of diurnal variability). SLA is the sea surface height above mean sea surface computed with respect to a twenty-year period (1993 –2012) and was included as it is indicative of mesoscale processes such as eddies. Daily SLA (m) was obtained from CMEMS and is a global delayed-time SSALTO/DUACS multi-mission (Topex/Poseidon, Jason-1, OSTM/Jason-2, Jason-3) altimeter data merged product available at a 0.25-degree grid resolution. Daily mean MLD (m) was obtained from CMEMS at a 0.25-degree grid resolution and indicates the depth of the thermocline (Lea et al., 2015). Daily mean sea surface chlorophyll-a concentration (mg/m^3) was obtained from CMEMS and is a product based on the merging of data collected from multiple satellite sensors (SeaWiFS, MODIS, MERIS, VIIRS-SNPP&JPSS1 and OLCI-S3A&S3B) available at a 4 km grid cell resolution. FSLE is associated with front intensity, with higher values indicating frontal regions with strong ocean dynamic. Daily mean FSLE were obtained from Archiving Validation and Interpretation of Satellite Oceanographic (AVISO; https://www.aviso.altimetry.fr) and available on a 0.25-degree grid resolution. Bathymetry (m) was obtained from ETOPO1 global relief model of earth's surface available at a 0.017-degree resolution and provided by NOAA's National Geophysical Data Center (NOAA National Geophysical Data Center, 2009). Lunar phases were extracted from the "lunar" package v.0.1–04 (Lazaridis, 2014) with values varying between 0 and 6, both representing new moon and with 3 representing full moon. Month was used as a categorical variable. For data extraction, deployment and retrieval locations were averaged to get one geographical position per fishing set. A radius of uncertainty of around 50 km (i.e., half of a typical length of longlines) exists for the location of catches, which, and to a certain degree, dictates the appropriate scale for integration of environmental data (Bigelow et al., 1999). Environmental gridded data was averaged over a 0.25-degree cell resolution (~25 km), which was the coarsest scale of the candidate variables, and the average value within a 0.5-degree radius (~50 km) for each variable was extracted.

Spearman's rank correlation and Variance Inflation Factor (VIF) were used to test for collinearity between variables (Zuur et al., 2010). SST was found highly and significantly correlated with month, latitude, MLD and Chlorophyll. Notwithstanding the well-established importance of SST for predicting swordfish and blue shark distribution and abundance (e.g., Bigelow et al., 1999, Walsh and Kleiber, 2001, Damalas et al., 2007, Vega and Licandeo, 2009, Dewar et al., 2011, Chang et al., 2012, 2013, Vandeperre et al., 2014a, 2016, Braun et al., 2019, Su et al., 2020, Druon et al., 2022), we opted to exclude SST from the GAMM analysis since we were more interested in investigating spatial and temporal patterns in catch rates.

Models were fitted to the data in both backward and forward stepwise selection processes to select significant variables. Variables were removed or added, respectively, according to the level of significance (i.e., highest P-value based on Chi-squared or Z-test statistic) and based on the Akaike's information criterion (AIC; Sakamoto et al., 1986). AIC was computed as a measure of the "goodness-of-fit" and models with the lowest AIC value were selected as the most parsimonious model. In each step, models were examined for over-dispersion and evaluated by visual inspection of standard QQ-plot and a histogram of the residuals to check for the normality of the residuals assumption in which a good model fit is expected to show a linear relationship between the deviance residuals and the normal theoretical quantiles, and a normal distribution of the residuals. Pearson residuals were plotted against fitted values and explanatory variables for visual inspection of homogeneity of variance (Zuur et al., 2009). Deviance explained and the adjusted R-squared (R^2adj) were calculated to evaluate the adequacy of the model fit. GAMM analysis were performed using the "mgcv" package v.1.8.24 (Wood, 2011).

3. Results

3.1. Fishing effort distribution patterns

The spatial distribution of the observed fishing effort by Portuguese longline vessels showed a marked seasonal pattern between 2015 and 2020 (Fig. 2). During autumn (September to November), the observed fishing effort was mainly concentrated within the 200 nm EEZ of mainland Portugal and in adjacent international waters, between 10°– 24° W and 36°– 42° N. From winter to spring (December to May), observed effort gradually moved away westwards towards the Azores, whereas during summer (June to August), was dispersed over the study area between 10°– 40° W and 35°– 50° N (Fig. 2). Visual inspection of the GFW effort seasonal kernel density maps for the fleet showed a similar distribution pattern (Fig. 2). This correspondence was further corroborated with a significant correlation between the observed and GFW data in terms of daily effort ($R = 0.23$, $p < 0.001$, $n = 1046$) and spatial coordinates ($R = 1$, $p < 0.001$, $n = 988$) for individual vessels, and also for the fleet effort ($R = 0.65$, $p < 0.001$, $n = 182$) within 1-degree cells where observed effort was recorded (Supplementary Fig. S1). Seasonal effort correlation was significant ($p < 0.001$) for all seasons except during summer ($p = 0.34$; Supplementary Fig. S2), where the lowest number of fishing sets were observed (months 6–8; Table 1). According to the GFW effort data, the Portuguese pelagic longline fleet fished a total of 15,995 days between September 2015 and December 2020, and the observed effort, estimated as the difference between the starting time of gear deployment to the end of gear retrieval, covered 5.5% (884 fishing days) of this total.

3.2. Fishery characterization

The k-means method identified two distinct clusters within the data and, according to species proportions, clusters were named as: BSH = blue shark (71.2%) and SWO = swordfish (60.7%; Table 2). Differences in species proportions were significant between the two clusters (Pearson Chi-square test followed by Bonferroni, $p < 0.001$) for all species, except for lancetfish *Alepisauros ferox*, pelagic stingray *Pteroplatytrygon violacea*, bigeye thresher *Alopias superciliosus*, oilfish *Ruvettus pretiosus*, and unidentified dolphinfish of the *Coryphaena* genera. Fishery operational and environmental characteristics between the two clusters were also significantly different (Mann-Whitney test, $p < 0.05$) in terms of mean number of hooks and distance between LB, sea surface temperature and bathymetry at set locations (Table 2). Soak time was not significantly different between clusters (Mann-Whitney test, $p = 0.48$), with a similar average soaking time of approximately 14 h. The mean number of hooks between LB was slightly greater in the

\

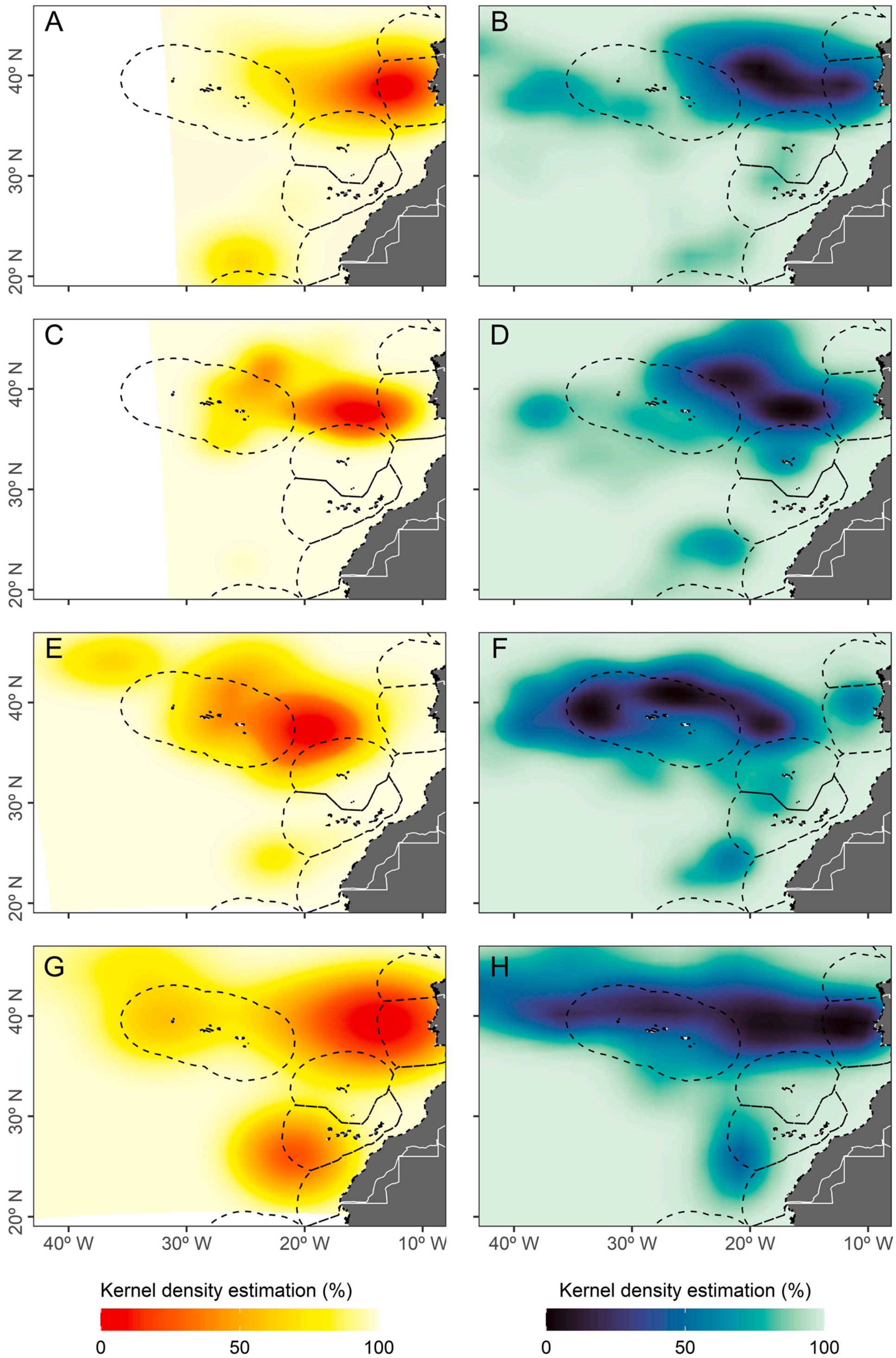

Fig. 2. Seasonal kernel density estimation maps of the observed (left column) and GFW (right column) Portuguese longline fishing effort in the Northeast Atlantic between September 2015 and December 2020. (A, B) autumn: September–November, (C, D) winter: December–February, (E, F) spring: March–May, and (G, H) summer: June–August. Dashed lines represent the 200 nautical mile economic exclusive zone (EEZ).

BSH sets compared to the SWO sets (60.9 and 60 hooks, respectively), and the distance between LB was greater in SWO compared to BSH sets (7.9 and 7.5 Km, respectively). Environmental characteristics at set locations showed that the BSH sets were in significantly deeper (3300 and 2930 m, respectively) and colder waters (18 and 19.4 °C, respectively) compared to SWO sets (Mann-Whitney test, $p < 0.001$; Table 2). Considering the proportion of leader type, monofilament nylon was preferably used (60–75%) in all seasons, while sets using wire leader showed highest frequency (40%) during summer (Fig. 3). Leader type differences between the two clusters were significant for wire and monofilament nylon (Pearson Chi-square test followed by Bonferroni, $p < 0.001$) yet non-significant for the use of both leader types in the

Table 2
Species proportions (in relation to the total number of individuals caught for each cluster), and operational and environmental characteristics for each cluster identified by the k-means partitioning analysis on the catch composition data. Mann-Whitney, and Pearson Chi-square followed by Bonferroni post-hoc tests, significance levels (*p* value) are also shown. Only species with > 0.1% of the total catch in numbers are shown (see Table 3). Standard deviation of the mean (± S.D.) in parentheses. BSH = blue shark; SWO = swordfish. LB = large buoys; df = degrees of freedom.

	BSH	SWO	Total	N sets	df	*p* value
% Species				896	13	<0.001
Prionace glauca	71.22	21.78		883		<0.001
Xiphias gladius	20.23	60.72		892		<0.001
Alepisaurus ferox	2.61	5.87		484		0.054
Lepidocybium flavobrunneum	1.54	6.14		521		<0.001
Isurus oxyrinchus	1.92	2.11		394		0.001
Pteroplatytrygon violacea	0.27	0.61		117		0.23
Thunnus thynnus	0.46	0.23		96		<0.001
Alopias superciliosus	0.24	0.61		108		0.067
Caretta caretta	0.13	0.65		80		<0.001
Ruvettus pretiosus	0.25	0.40		95		0.9
Coryphaena spp.	0.16	0.11		34		0.06
Thunnus alalunga	0.14	0.08		43		0.006
Lepidopus caudatus	0.17	0.00		17		0.002
Lamna nasus	0.15	0.03		32		0.003
Operational characteristics						
Number of sets	490	406	896			
Mean soaking time (h)	14.01 (1.96)	13.86 (1.59)	13.9 (1.8)	896		0.477
Mean number of hooks between LB	60.9 (7.4)	60.0 (7.0)	60.3 (7.2)	788		< 0.05
Mean distance between LB (Km)	7.5 (1.0)	7.9 (0.9)	7.7 (1.01)	755		< 0.001
Leader type (%)				896	2	<0.001
Nylon	65	90	69.6			<0.001
Wire	24	3	25.1			<0.001
Both	11	6	5.3			1
Environmental characteristics						
Mean temperature rSST (°C)	18.01 (2.74)	19.42 (2.31)	18.64 (2.65)	818		< 0.001
Mean location depth (m)	3300 (1271)	2970 (854)	4158 (1039)	896		< 0.001

same set (Table 2). Both clusters used a large percentage of monofilament nylon leader (SWO = 90%, BSH = 65%;), whereas wire and a combination of both monofilament and wire leaders were more frequent in blue shark sets (24% and 11%, respectively; Table 2). Furthermore, seasonal distribution of sets location according to the identified clusters further highlighted the pattern of aggregation of vessels while targeting swordfish during autumn and winter, and a more dispersed pattern all year around for blue shark sets (Fig. 4).

3.3. Catch composition

A total of 46,306 individuals from 54 species was recorded as caught during the studied period, of which 11 were sharks, 3 rays, 30 bony fishes, 2 sea turtles, 2 seabirds and 6 cetacean species (Table 3). Target species catches accounted for 88.3% of the total catch in numbers, with a total of 15,537 (33.6%) swordfish and 25,327 (54.7%) blue sharks caught. Other species with considerable representation (> 2% of the total catch in numbers) were the long snouted lancetfish *Alepisaurus ferox* (3.69%), escolar *Lepidocybium flavobrunneum* (3.06%) and shortfin mako *Isurus oxyrinchus* (2.05%). Bycatch of threatened species included the sea turtles *Caretta caretta* (0.3%) and *Dermochelys coriacea* (0.08%), shark species of the genera *Alopias* (0.5%) and the smooth hammerhead *Sphyrna zygaena* (0.02%), and the cetaceans *Balaenoptera acutorostrata*, *Grampus griseus*, *Stenella coeruleoalba*, *Tursiops truncatus*, *Globicephala* spp. and *Hyperoodon ampullatus*, with each species representing less than 0.004% of the total catch in numbers. Furthermore, results showed different levels of association of bycaught species (in terms of the proportion of the total number of individuals caught per species), with the target species identified in the cluster analysis (Table 3). Swordfish sets showed a higher proportion of bycatch of the 2 sea turtles species, and 6 species of bony fishes and unidentified *Alopias* spp., whereas blue shark sets showed higher bycatch of pelagic sharks of the Lamnidae family (mako sharks *Isurus* spp. and porbeagle *Lamna nasus*), tuna (*Thunnus* spp.), and 4 bony fish species. Lancetfish, pelagic stingray, thresher and bigeye thresher sharks, crocodile shark and smooth hammerhead were found equally associated with both targeted species.

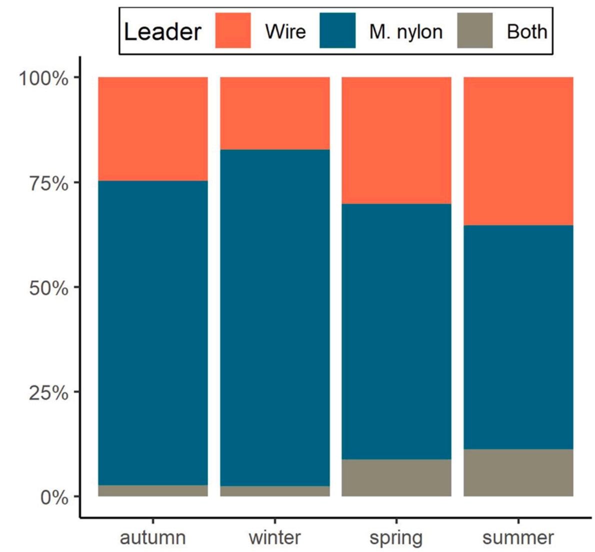

Fig. 3. Seasonal frequency of leader type observed in Portuguese longline vessels between 2015 and 2020 in the Northeast Atlantic. M. nylon = monofilament nylon.

3.4. GAMM analysis

For swordfish, significant variables retained in the final model were month, leader type, SLA, the interaction between latitude and longitude and moon phase, while the significant variables for the blue shark were month, leader type, the interaction between latitude and longitude, soak time, moon phase, chlorophyll, SLA, and bathymetry (Table 4). SST was not included in the final models since it was correlated with month and latitude. MLD, FSLE and SSTsd were found to be not significant for any of the target species. In the swordfish final model, the explained deviance was 67.3% and the dispersion parameter was 1.01, whereas in the blue shark final model, the explained deviance was 79.5% and the dispersion parameter was 1.02. Model assumptions were considered to be met in both cases. The histogram of deviance residuals was close to a normal distribution and the normal QQ-plot of deviance residuals against theoretical quantiles showed no considerable deviation from the constant variation assumption. The plot of Pearson residuals against fitted values showed that, in general, points were distributed randomly between − 2.1 and 3.8 for the swordfish model and between − 1.8 and 4.3 for the blue shark model (Supplementary Fig. S3).

Swordfish catches were positively affected by the full moon, with leader type (monofilament nylon and both wire and monofilament nylon leaders), and SLA values above 0 m, corresponded to areas of anticyclonic eddies (Fig. 5). The number of blue shark catches were positively influenced during intermediate moon phases and during the new

\

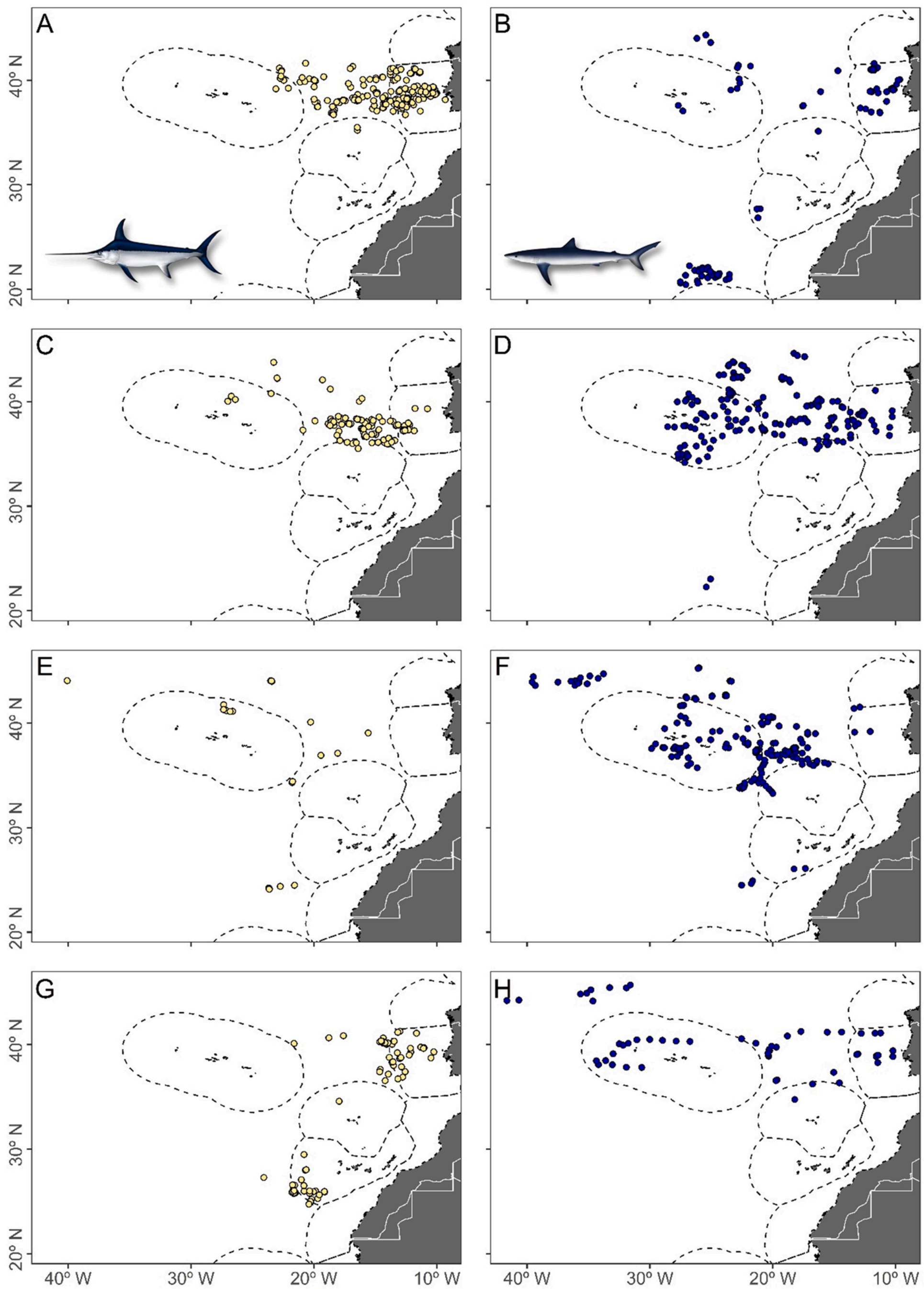

Fig. 4. Seasonal map locations of observed fishing sets (n = 896) identified as targeting swordfish (light yellow dots; left column) and blue shark (blue dots; right column), based on a cluster analysis of the catch composition data collected onboard Portuguese longline vessels between 2015 and 2020. (A, B) autumn: September–November, (C, D) winter: December–February, (E, F) spring: March–May, and (G, H) summer: June–August. Dashed lines represent the 200 nautical mile economic exclusive zone (EEZ).

Table 3
Catch composition (in number of individuals and % of the total catch in numbers), species proportions (in relation to the total number of individuals caught per species) associated with each of the targeted species (SWO=swordfish; BSH=blue shark) identified by the cluster analysis. Cells highlighted in red represent proportions with more than 60% of the total number of individuals recorded for that species, and in yellow between 40% and 60%. Species with less than 5 individuals were considered rare occurrences and were not highlighted.

Group Family	Scientific name	Common name	N	N (%)	SWO (%)	BSH (%)
SHARKS						
Alopiidae	*Alopias superciliosus*	Bigeye thresher	168	0.363	56	44
	Alopias vulpinus	Thresher	38	0.082	47	53
	Alopias spp.	Thresher shark	24	0.052	81	19
Carcharhinidae	*Prionace glauca*	Blue shark	25327	54.695	13	87
	Carcharhinus longimanus	Oceanic whitetip shark	1	0.002	100	0
	Carcharhinus falciformis	Silky shark	1	0.002	100	0
Lamnidae	*Isurus oxyrinchus*	Shortfin mako	948	2.047	31	69
	Lamna nasus	Porbeagle	50	0.108	8	92
	Isurus paucus	Longfin mako	13	0.028	23	77
Pseudocarchariidae	*Pseudocarcharias kamoharai*	Crocodile shark	10	0.022	60	40
Sphyrnidae	*Sphyrna zygaena*	Smooth hammerhead	7	0.015	43	57
RAYS						
Dasyatidae	*Pteroplatytrygon violacea*	Pelagic stingray	177	0.382	53	47
Mobulidae	*Mobula tarapacana*	Chilean devil ray	3	0.006	33	67
	Mobula birostris	Giant manta	2	0.004	50	50
BONY FISH						
Alepisauridae	*Alepisaurus ferox*	Long snouted lancetfish	1707	3.686	53	47
Bramidae	*Taractichthys longipinnis*	Big-scale pomfret	16	0.035	69	31
	Taractes rubescens cf.	Pomfret	10	0.022	70	30
	Brama brama	Atlantic pomfret	4	0.009	50	50
	Taractichthys steindachneri	Sickle pomfret	4	0.009	100	0
	Eumegistus illustris	Brilliant pomfret	2	0.004	100	0
Coryphaenidae	*Coryphaena spp.*	Dolphinfish	68	0.147	25	75
	Coryphaena hippurus	Common dolphinfish	5	0.011	80	20
Gempylidae	*Lepidocybium flavobrunneum*	Escolar	1418	3.062	67	33
	Ruvettus pretiosus	Oilfish	138	0.298	45	55
Istiophoridae	*Makaira nigricans*	Blue marlin	10	0.022	90	10
	Tetrapturus albidus	Atlantic white marlin	4	0.009	33	67
	Tetrapturus pfluegeri	Longbill spearfish	4	0.009	50	50
Lampridae	*Lampris guttatus*	Opah	1	0.002	100	0
Luvaridae	*Luvarus imperialis*	Luvar	1	0.002	0	100
Molidae	*Mola mola*	Ocean sunfish	29	0.063	45	55
	Masturus lanceolatus	Sharptail mola	5	0.011	20	80
Nomeidae	*Cubiceps gracilis*	Driftfish	1	0.002	100	0
Polyprionidae	*Polyprion americanus*	Wreckfish	25	0.054	36	64
Scombridae	*Thunnus thynnus*	Atlantic bluefin tuna	176	0.38	20	80
	Thunnus alalunga	Albacore	54	0.117	22	78
	Thunnus obesus	Bigeye tuna	41	0.089	39	61
	Thunnus albacares	Yellowfin tuna	9	0.019	33	67
	Katsuwonus pelamis	Skipjack tuna	6	0.013	17	83
	Thunnus spp.	Tuna	5	0.011	40	60
Tetraodontidae	*Lagocephalus lagocephalus*	Oceanic puffer	5	0.011	20	80
Trachipteridae	*Trachipterus arcticus*	Dealfish	1	0.002	100	0
Trichiuridae	*Lepidopus caudatus*	Silver scabbardfish	52	0.112	0	100
	Aphanopus carbo	Black scabbardfish	12	0.026	97	8
Xiphiidae	*Xiphias gladius*	Swordfish	15537	33.553	60	40
SEA TURTLES						
Cheloniidae	*Caretta caretta*	Loggerhead turtle	139	0.3	72	28
Dermochelyidae	*Dermochelys coriacea*	Leatherback turtle	38	0.082	68	32
SEABIRDS						
Sulidae	*Morus bassanus*	Northern gannet	1	0.002	0	100
Procellariidae	*Puffinus gravis*	Greater shearwater	1	0.002	0	100
CETACEANS						
Balaenopteridae	*Balaenoptera acutorostrata*	Common minke whale	1	0.002	100	0
Delphinidae	*Grampus griseus*	Risso's dolphin	2	0.004	100	
	Stenella coeruleoalba	Striped dolphin	2	0.004		
	Tursiops truncates	Bottlenose dolphin	1	0.002	0	100
	Globicephala spp.	Pilot whale	1	0.002	0	100
Ziphiidae	*Hyperoodon ampullatus*	Northern bottlenose whale	1	0.002	100	0

Table 4
Results from the final GAMMs of swordfish and blue shark catches in numbers by Portuguese longline vessels between 2015 and 2020 in the Northeast Atlantic. "re" = random effect.

Swordfish (Deviance explained = 67.3%; R^2_{adj} = 0.59)				
	Estimate	Std. Error	*z* value	*p*-value
(Intercept)	-4.47	0.12	-35.3	< 2.00E-16
	df / edf	Ref.df	Chi.sq	*p*-value
Month	11		45.24	4.41E-06
Leader	2		31.1	1.77E-07
SLA	1		8.87	2.90E-03
s(lon,lat)	21.39	25.32	84.4	1.52E-08
s(Moon)	5.44	8	769.78	< 2.00E-16
s(Trip, bs="re")	55.33	70	349.84	< 2.00E-16
Blue shark (Deviance explained = 79.5%; R^2_{adj} = 0.62)				
	Estimate	**Std. Error**	***z* value**	***p*-value**
(Intercept)	**-3.45**	**0.22**	**-16.01**	**< 2.00E-16**
	df / edf	Ref.df	Chi.sq	*p*-value
Month	11		99.2	2.57E-16
Leader	2		31.2	1.68E-07
SLA	1		19.01	1.30E-05
s(lon,lat)	21.5	25.35	123.92	7.27E-15
s(Soak time)	4.41	5.38	57.59	1.45E-10
s(Moon)	4.65	8	87.05	3.74E-06
s(Chlorophyll-a)	6.46	7.58	32.91	6.35E-05
s(Bathymetry)	2.92	3.67	30.33	3.39E-06
s(Trip,bs="re")	56.82	70	438.11	< 2.00E-16

moon, by soak times ranging between 15 and 22 h, and by wire and both wire and monofilament nylon leader types (Fig. 6). Blue shark catches were positively influenced by SLA values above 0.1 m indicating higher catch rates in areas of anti-cyclonic eddies, and by chlorophyll-a values between 0.15 mg/m^3 with a marked peak at 0.25 mg/m^3. Blue shark catches were positively influenced above 4000 m depth and with an increasing trend towards the minimum recorded depth of approximately 450 m (Fig. 6).

CPUEn values per set ranged from 0.0 to 57.5 ind./1000 hooks for swordfish, and 0.0 and 275 ind./1000 hooks for blue shark. The seasonal dynamics of the fishing effort is further reflected in the catch rates of the target species (Fig. 7). Nominal and standardized swordfish CPUEs followed similar patterns, with highest monthly mean catch rates recorded in autumn, with a peak in September (22.5 ± 2.4 S.D.) followed by a gradual decrease during winter and spring, reaching minimal values during summer (July, 9.1 ± 5.9). Blue shark monthly mean CPUEn showed maximum values during spring (April, 58.7 ± 54.2), decreased during summer, reaching a minimum value during October (6.0 ± 7.2), after which it gradually increased again during winter. Standardized CPUE of blue shark followed a similar evolution of the CPUEn, yet monthly mean values differed considerably during April and May, when the CPUEn standard deviation was higher, likely reflecting the lower observed fishing effort. Monthly mean observed sea surface temperature (rSST) recorded onboard vessels at set locations ranged from 21.7 °C in August and 15.8 °C in February (Fig. 7).

4. Discussion

The present study used detailed observer data and currently available tools to provide a contemporary assessment of the Portuguese pelagic longline fishery in the Northeast Atlantic in terms of fishing operations, catch composition and spatio-temporal dynamics. Although observer data only covered 5.5% of the total effort estimated by GFW between 2015 and 2020, overall results showed a fairly good correspondence between both datasets, determined visually by season and spatially (Fig. 2) and by significant correlations in terms of daily effort and sets locations of individual vessels (Fig. S1). According to Gilman et al. (2014), at a 5% observer coverage, bycatch estimates will likely have large uncertainties for species with low catch rates, but likely would be sufficient to enable determining the spatio-temporal distribution of bycatch. Nevertheless, error can be expected from the GFW effort data and results should be interpreted cautiously. Moreover, the opportunistic sampling of the fleet is subject to some caveats, namely the observer data is biased towards vessels larger than 18 m of length. Hence, our results do not capture the operational characteristics and dynamics of smaller vessels (15 –18 m), which compose approximately 13% (n = 6) of the industrial Portuguese pelagic longline fleet here considered. Other source of uncertainty is the actual number of vessels that regularly fish with drifting longline in the North Atlantic, which is highly dynamic due to the polyvalence of an unknown part of the fleet, likely influenced by the vessel's quotum availability, target species market trends, and operational costs related to fuel prices, bait and gear.

The pronounced and asynchronous seasonal pattern between swordfish and blue shark catches is consistent with the pattern derived from vessel logbook data previously reported in the North Atlantic (Santos et al., 2002), specifically in the Azores (Aires-da-Silva and Pereira, 1999; Aires-da-Silva et al., 2008) and also from commercial landings at Portuguese ports (Roxo et al., 2017). This is substantiated by the cluster analysis on the catch composition data that showed two fishing tactics according to the target species (swordfish and blue shark). The distribution of fishing effort by the Portuguese fleet further showed a well-defined seasonal pattern during the studied period, clearly clustered in space inside the EEZ of mainland Portugal and adjacent international waters during autumn, when vessels target swordfish. Environmental differences in SST and bottom depth between swordfish and blue shark sets further reflect this spatio-temporal dynamics of fishing effort. Fisheries that target swordfish adapt their fishing strategies and tactics according to the species migration patterns, applying effort in regions with high concentrations of fish (Nielsen et al., 2013). Swordfish display a consistent latitudinal pattern of movement in the North Atlantic, with residence in foraging grounds in temperate waters from June to October (north of 40° N), followed by a southwards migration in winter and spring (Abascal et al., 2015).

Results suggest that swordfish explore Portuguese coastal waters during autumn likely to forage on small schooling fish associated with the northerly wind-induced upwelling regime off west Portugal (Lemos and Pires, 2004). Upwelling conditions are more strong from April to September, with consequent higher levels of phytoplankton and zooplankton, inducing favourable feeding conditions to sardine *Sardina pilchardus* and horse mackerel *Trachurus trachurus* (Santos et al., 2001). Fish is an important part of swordfish diet in the Northeast Atlantic (40 –50% by mass; Clarke et al., 1995, Chancollon et al., 2006), and sardine was found as having the highest percentage by weight in the diet of juvenile swordfishes in the Aegean Sea (Ceyhan and Akyol, 2017). The displacement of the fleet westwards in an aggregated pattern during winter, likely following swordfish movements searching for other feeding opportunities further west, coincides with the period that the upwelling regime off west Portugal weakens (Lemos and Pires, 2004), and the period when the southward wind-driven Ekman transport near the Azores Archipelago is stronger (Caldeira and Reis, 2017). From an economic perspective, the presence of swordfish relatively close to mainland Portugal during autumn enable vessels to land a more valuable fresh product with shorter trips and reduced fuel costs. For example, the average price for fresh swordfish in a Spanish market nearly tripled ($31/kg) that compared to frozen swordfish ($11/kg) from March 2017–2018 (Schiller et al., 2018).

The seasonal distribution pattern of fishing sets identified as targeting blue shark appeared dispersed in the region throughout the year, reflecting a wider habitat range given the spatial structuring and segregation by sex and size of this population, shaped by different ranges of SST preferences for small juveniles (15 –25 °C), large juvenile females (10 –20 °C) and large juvenile males (15 –28 °C; Vandeperre et al., 2016). In addition, this study found higher catch rates during spring, namely in April-May, which is in agreement with previous studies on blue shark longline fishery assessments for the Northeast Atlantic that also reported April-May monthly averages up to 300

\

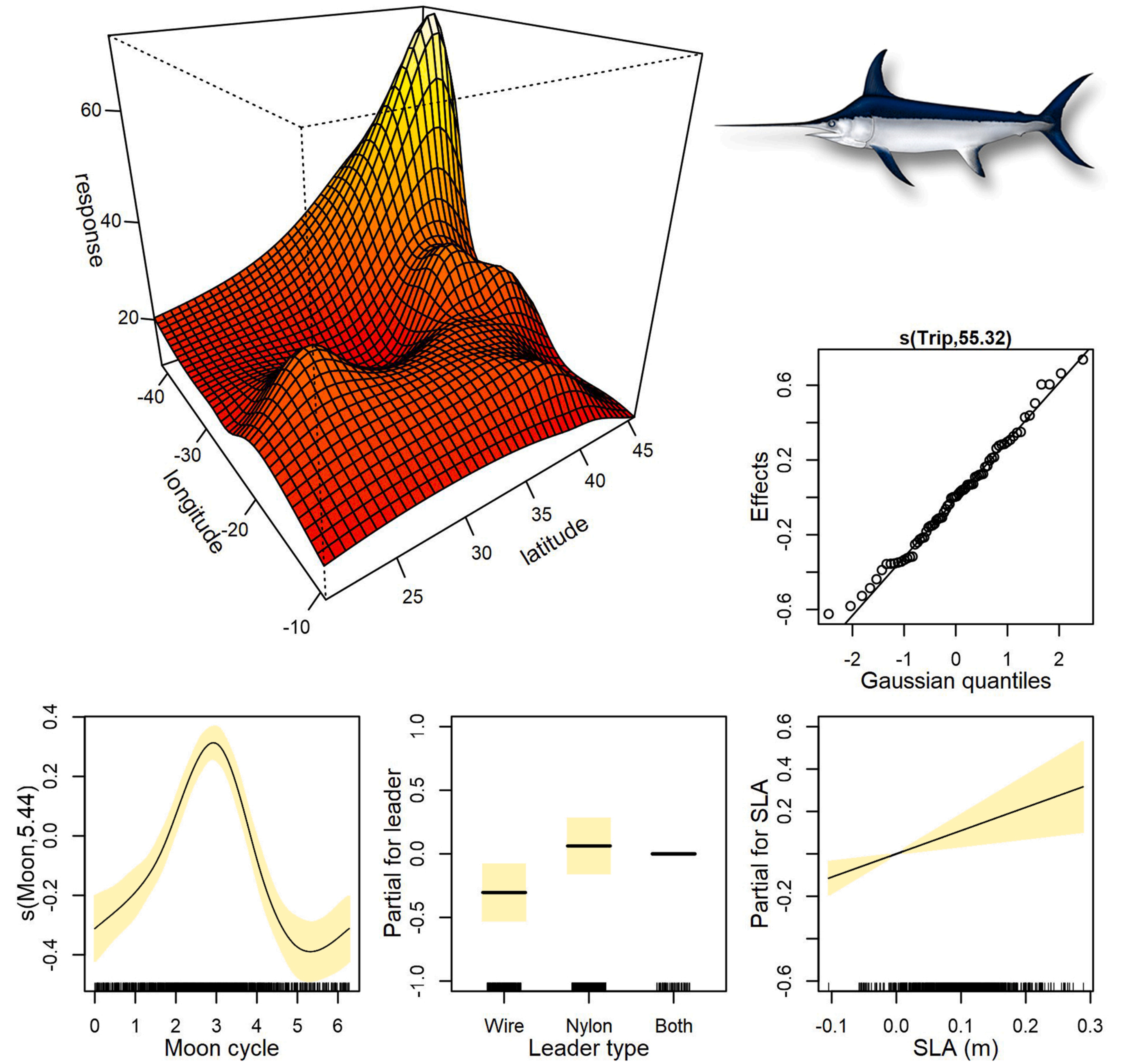

Fig. 5. Smooth term plots of significant variables included in the final GAMM for the swordfish catches in numbers. Top left panel: smoothed surfaces of the smooth term plotted at the scale of the response. Top right panel: Gaussian quantiles for the residuals of the random effect fishing trip. Shaded areas indicate 95% confidence intervals. Thick marks on the x-axis represents the distribution of the observations. Value in parentheses in the y-axis label represents the estimated degrees of freedom.

individuals per 1000 hooks (Buencuerpo et al., 1998; Aires-da-Silva and Pereira, 1999; Santos et al., 2002; Aires-da-Silva et al., 2008; Vandeperre et al., 2014a). Our results demonstrated that blue shark catch rates were higher with wire leaders, which is in agreement with previous studies that also found shark catchability and catch rates lower on nylon compared to wire leaders because sharks can sever the nylon and escape (Ward et al., 2008; Vega and Licandeo, 2009; Santos et al., 2017). Since 2021, the Azorean fisheries authorities implemented a prohibition on the use of wire leaders in pelagic longline fishing within 100 nm off the islands, together with the mandatory use of circle hooks since 2020. The Azores is considered a nursery area for blue shark in the central North Atlantic, with high abundance and residency of immature individuals (Aires-da-Silva et al., 2008; Vandeperre et al., 2014a; b). Yet, in spring, when fishing effort in the Azores is highest, catches also consisted of mature females in advanced stages of pregnancy, besides larger juvenile and small adult males (3–5 years; Vandeperre et al., 2014a). Ultimately, there is concern that the area around the Azores is not sufficient to protect such a highly migratory species (Vandeperre et al., 2014b, 2016; Coelho et al., 2018; Druon et al., 2022).

Operational characteristics between fishing tactics were found to be similar for both target species, except for the distance between large buoys, that was on average 400 m longer in swordfish compared to blue

\

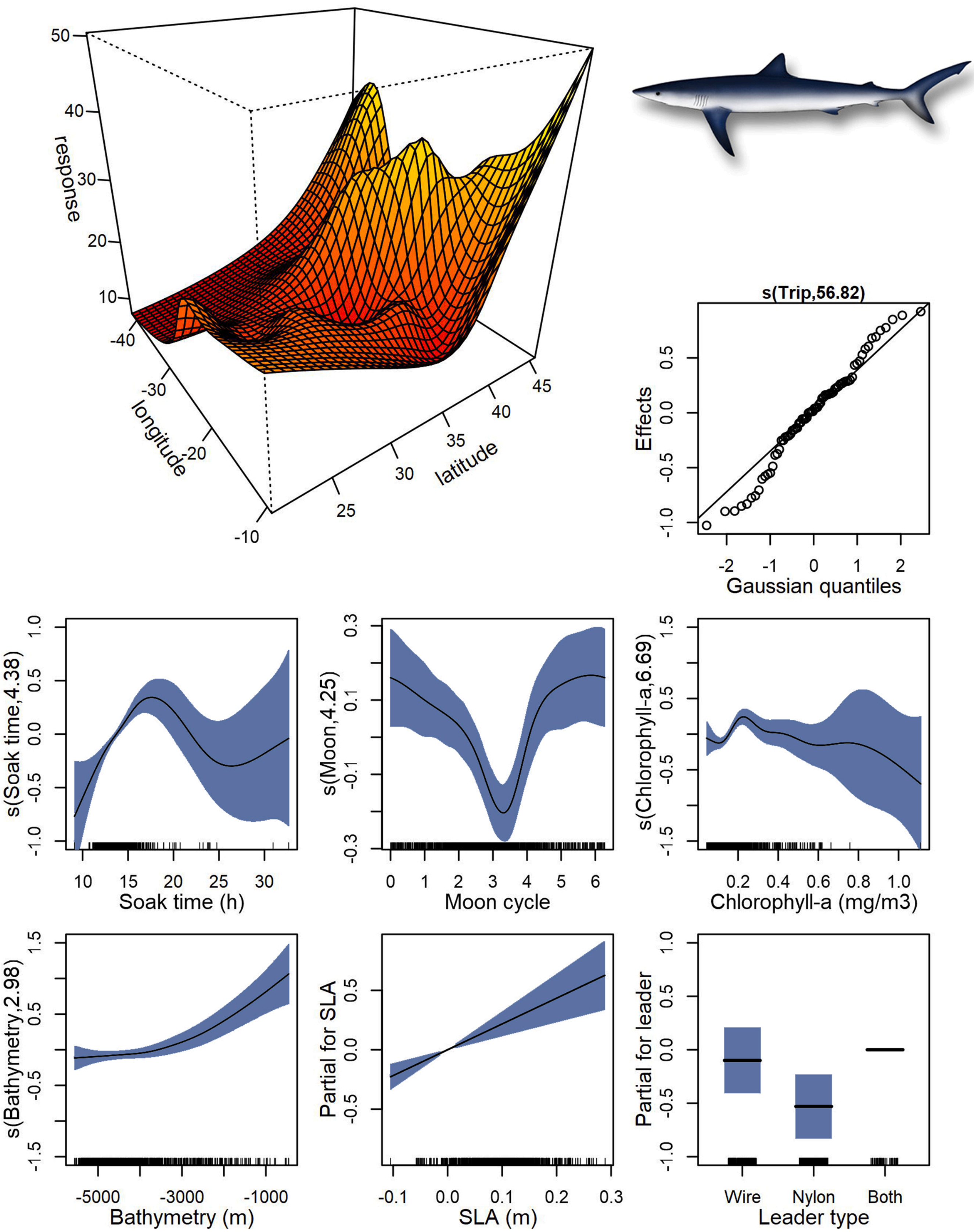

Fig. 6. Smooth term plots generated from the final GAMM for the blue shark catches in numbers. Top left panel: smoothed surfaces of the smooth term plotted at the scale of the response. Top right panel: Gaussian quantiles for the residuals of the random effect fishing trip. Shaded areas indicate 95% confidence intervals. Tick marks on the x-axis represents the distribution of the observations. Values in parentheses in the y-axis labels represent the estimated degrees of freedom.

\

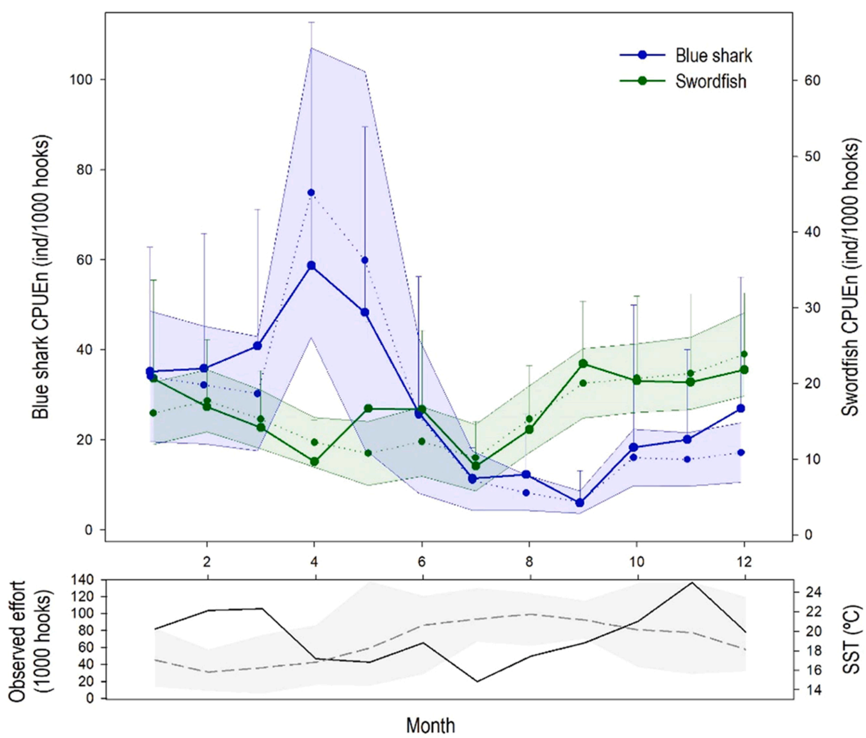

Fig. 7. Monthly mean nominal (CPUEn; solid line) and standardized (dashed line) catch rates (ind./1000 hooks) for swordfish (green) and blue shark (blue), observed effort (number of hooks; solid line, lower panel) and sea surface temperature (SST; dashed line; lower panel) recorded on board Portuguese longliners operating in the Northeast Atlantic from 2015 to 2020. Bars (upper panel) are standard deviation of the mean [S.D.] of CPUEn, and shaded areas represent the 95% confidence intervals of standardized CPUE. Shaded grey area (lower panel) represents SST maximum and minimum values.

shark sets. This suggests that the gear is set relatively deeper when targeting swordfish. Tagging studies in the Atlantic and Pacific Oceans showed swordfish nighttime depth increased around full moon (Dewar et al., 2011; Abascal et al., 2015). In this study, the highest swordfish catch rates occurred during full moon, which is consistent with what was previously reported for longline fisheries in the North Atlantic (Santos and Garcia, 2005; Kot et al., 2010), and elsewhere (Bigelow et al., 1999; Damalas et al., 2007; Su et al., 2020). Mesopelagic and diurnally migrating fauna constitute an important part of swordfish diet (Clarke et al., 1995; Chancollon et al., 2006), and its vertical distribution is influenced by lunar phase, shown to stay in deeper waters during full moon nights to avoid predation from epipelagic predators (Hernández-León et al., 2010; Prihartato et al., 2016). Swordfish is likely to concentrate at greater depths to forage during the full moon. Despite the fact that lunar phase most likely plays a major role in the captains' decisions for fishing depth, other operational and environmental factors, such as vessel bearing and speed during gear deployment and surrounding oceanographic conditions (e.g., current direction and strength), are also likely to have influenced fishing depth, since they can deform the shape of longlines and/or longline shoaling (Bigelow et al., 2006). On the other hand, blue shark sets were deployed shallower and catch rates were higher during intermediate and new moon phases. This is likely attributed to the vertical distribution of diel migrating fauna, which also constitutes an important fraction of the diet of blue shark (Clarke et al., 1996; Biton-Porsmoguer et al., 2017) in the Northeast Atlantic. These results are in agreement with Vandeperre et al. (2014a), a study that found blue shark catch rates higher during intermediate moons in the North Atlantic.

The strong association between blue shark catches and other pelagic shark species that was revealed by our analysis, namely for the "endangered" shortfin mako *Isurus oxyrinchus* (IUCN; Rigby et al., 2019a), the "vulnerable" porbeagle *Lamna nasus* (IUCN; Rigby et al., 2019b), the "endangered" longfin mako *Isurus paucus* (IUCN; Rigby et al., 2019c), and also tunas *Thunnus* spp. bycatch, suggests that stricter measures to manage the blue shark fishery likely have a positive effect on mitigating bycatch for these species. Notwithstanding, these associations should be further investigated in detail for potential spatial and temporal patterns that would provide more insights as to where and when bycatch is more likely to take place. While the blue shark has a relatively fast growth and produce a high number of offspring, making this a resilient species (Aires-da-Silva and Gallucci, 2007), most pelagic sharks are highly vulnerable to overexploitation due to their slow growth, late maturation, and production of few offspring (Dulvy et al., 2008). The limited spatial refuge resulting from the high degree of spatial overlap between these protected pelagic shark species and longline fisheries at a regional (Queiroz et al., 2016) and global scale (Queiroz et al., 2019) is a serious conservation concern. This further exacerbates the need for better management strategies focused on these species. The "vulnerable" bigeye thresher *Alopias superciliosus* (IUCN; Rigby et al., 2019d) was the most captured pelagic shark of the *Alopias* genera recorded in the observation data, and showed no significant association between swordfish and blue shark sets. This suggests that management strategies such as time/area closures designed for blue sharks, may not have an effect on *A. superciliosus* populations and that specific measures are needed for the protection of this species.

Of all the megafauna recorded in this study to interact with the longline gear, bony fishes with low commercial value are the least known and reported. Long snouted lancetfish *Alepisaurus ferox* was the most caught of these species (3.7% of the total catch in numbers), followed by escolar *Lepidocybium flavobrunneum* (3.1%; Table 3). Lancetfishes are circumglobal species that mainly inhabit tropical and subtropical waters, and are preyed upon by tunas and sharks (Post, 1984). They feed primarily on small pelagic fish such as chub mackerel *Scomber japonicas*, but also on small tunas and swordfishes (Romanov and Zamorov, 2002). Long snouted lancetfish catch in longline fisheries in the Northeast Atlantic was not previously reported (Buencuerpo et al., 1998), but catch rates of this species reached up to 1 individual per 1000 hooks in 202 monitored experimental pelagic longline sets to test for hook and bait effects in the tropical Northeast Atlantic (Fernandez-Carvalho et al., 2015). Escolar was previously reported as being occasionally caught in the Northeast Atlantic (Buencuerpo et al., 1998), and a total of approximately 742.5 t of escolar landed by the Northeast Atlantic Spanish surface longline fishery was estimated between 1997 and 2006 (Mejuto et al., 2009). More data are required for improved knowledge on these species and the impact of longline fishing on these populations.

Loggerhead and leatherback are the most frequently sea turtle species bycaught in longline gear in the North Atlantic (Gardner et al., 2008). The Northeast Atlantic hosts key foraging and developmental grounds for juvenile loggerhead turtles originated mainly from the Southeastern USA and Cape Verde Islands (Bolten et al., 1993; Bjorndal et al., 2000; Bolten, 2003). In the Portuguese pelagic longline fishery, a total of 1439 loggerhead and 604 leatherback interactions were estimated between 2016 and 2020, with an average of 75 and 4 deaths per year, respectively (Parra et al., 2023). This impact contributes to the cumulative effects of all large and small-scale fleets operating in North Atlantic (Brazner and Mcmillan, 2008; Finkbeiner et al., 2011; Kroodsma et al., 2018) and, together with other anthropogenic sources of mortality in the open ocean such as litter ingestion and entanglement (Schuyler et al., 2014; Pham et al., 2017), hampers the recovery and conservation of these populations. Effective sea turtle bycatch mitigation measures for longline fishing include the use of large circle hooks, finfish bait, deep gear setting and reduced soaking time (see Swimmer et al., 2020 for a review). Since 2021, the mandatory use of circle hooks was implemented in the Azores, while the adoption of additional sea turtle bycatch mitigation measures appears slow (ICCAT Rec. 10–09 and 13–11, EC Regulation 2017/2017).

Seabird bycatch in the Northeast Atlantic is of particular concern in the Spanish demersal longline fishery operating on Gran Sol (west off United Kingdom), with over ca. 56,000 bird interactions per year during 2006–2007, mostly greater shearwaters *Puffinus gravis* (Anderson et al., 2011). Seabird bycatch by pelagic fleets is particularly significant due to the proportion of threatened albatrosses and *Procellaria* petrels being caught, though data gaps remain for a number of fleets operating in the North Atlantic (Anderson et al., 2011). In Portugal, seabird entanglement/bycatch represented 42.5% of all seabirds admitted to a rehabilitation centre (n = 2042) from 2010 to 2016, including large gulls, auks, gannets, shearwaters and petrels (Costa et al., 2021). Seabird species use the Portuguese mainland coast during their migratory routes as feeding grounds, resting and wintering areas (Ramírez et al., 2008). From the two seabird species here reported as interacting with the longline gear, the northern gannet *Morus bassanus* is one of the most common of all seabird species known to occur in the continental Portugal, while the greater shearwater *Puffinus gravis* occurs regularly in low numbers (Ramírez et al., 2008). In a study quantifying seabird bycatch by small- and medium-sized fishing fleets operating in the Portuguese mainland coast during 2010 – 2012, Oliveira et al. (2015) reported that higher bycatch rates occurred mainly in demersal longlines (0.86 seabirds per fishing event), followed by purse seines, and bottom gillnets, and that the northern gannet was the most common bycaught species. Our results show that seabird bycatch by the Portuguese pelagic longline fishery was very low, and may not pose a serious threat to these populations. Although the Portuguese pelagic fleet operates mostly offshore in the region, the greater shearwater is quite abundant at autumn season during the pre-breeding migration, coinciding with the period when the fleet fishes closer to Portuguese coastal waters while targeting swordfish. This highlights the importance of continuing to monitor this fishery to ascertain the level of impact on seabird species.

Although cetacean bycatch is higher for some purse-seine and gillnet fisheries, bycatch by longline is a threat to several populations including Risso's dolphins *Grampus griseus* and pilot whales *Globicephala* spp. in the northwest Atlantic (Werner et al., 2015). These interactions often result in serious injury and mortality of the individuals involved (Garrison, 2007). Dolphins *Delphinus* spp. were the most reported species to interact with hook and line gear from commercial and recreational fisheries in Portugal (Werner et al., 2015). The common dolphin *Delphinus delphis* was the most bycaught species in the Portuguese sardine purse-seine fishery off the continental coast, with more than 100 deaths estimated per year (Marçalo et al., 2015). In the Azores region, cetacean bycatch in longline fisheries was not recorded, and < 1% of the 384 sets monitored showed evidence of cetacean depredation, namely by killer whales (Silva et al., 2011). Moreover, data collected onboard Spanish longliners fishing in the Azores reported two false killer whales *Pseudorca crassidens* interactions in 56 observed sets, and also found low cetacean depredation, with < 1% of fish loss per trip (Hernandez-Milian et al., 2008). Depredation observations in the observation data were anecdotal and further conclusions could not be drawn. Overall, cetacean bycatch in this study was very small, suggesting that levels of interaction between cetaceans and the Portuguese pelagic longline fishery in the Northeast Atlantic may be generally low. However, the low level of observer coverage for the fleet in this study (5.5% of the total GFW estimated effort from Sep. 2015 to Dec. 2020), combined with high levels of fishing effort in the region by the Portuguese and Spanish fleets (Queiroz et al., 2016), may underestimate the levels of cetacean interactions with these fisheries (Silva et al., 2011).

Portugal's location at the westernmost part of the European continent, along with its peripheral insular regions, has granted the Portuguese nation a privileged access to the Northeast Atlantic Ocean. With this privilege comes a greater sense of responsibility for preserving its marine resources. This study represents a contribution for a better understanding and transparency of the activity of the Portuguese pelagic longline fleet in the region, and provides insights for the development of effective management strategies. The highly migratory behaviour of these species, with movements across multiple national borders and into the high seas, makes them vulnerable to numerous fleets operating in the North Atlantic (Fossette et al., 2014; Queiroz et al., 2019; Afonso et al., 2020; Davies et al., 2021). More importantly, it makes management a very challenging task. National efforts to preserve these species will likely be unsuccessful without a broader management perspective. After years of debate, United Nations member states recently agreed on the Biodiversity Beyond National Jurisdiction (https://www.un.org/bbnj/) treaty, which will provide the legal framework to limit environmental impacts and establish marine protected areas (MPA) on the high seas. This is encouraging yet raises the question of how these high seas MPAs will be monitored. While the development of the tools to improve the monitoring of fishing activities is ongoing (e.g., Kroodsma et al., 2018, 2022, Welsh et al., 2022), there is a dire need for an investment in human and technological resources for improved surveillance and enforcement activities, to ensure a long-term sustainable use of these marine resources and ecosystems conservation.

CRediT authorship contribution statement

Hugo Parra: Formal analysis, Writing – original draft. **Christopher K. Pham**: Writing – review & editing. **Miguel Machete**: Methodology, Writing – review & editing. **Marco Santos**: Conceptualization, Methodology. **Karen A. Bjorndal**: Conceptualization, Writing – review & editing, Funding acquisition. **Frederic Vandeperre**: Conceptualization, Methodology, Validation, Writing – review & editing, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Acknowledgments

We would like to acknowledge fisheries observers Luís Martins, Márcio Duarte, Rodolfo Curralo, Filipe Tártaro, Paulo Ávila and Miguel Capela from the POPA fisheries observer program, and vessel owners, captains and crewmembers for their collaboration. This work was conducted within the framework of the project COSTA, COnsolidating Sea Turtle conservation in the Azores, financed by the U.S. Fish and Wildlife Service (Marine Turtle Conservation Fund n° F15AP00577, F16AP00626, F17AP00403 and F18AP00321), Archie Carr Center for Sea Turtle Research through funds from Disney Conservation Fund (grant nº UFF_ F019479), and the Regional Directorate for Fisheries (DRP) of the Azores Government. FV was supported by the Investigator Programme of the Fundação para a Cîencia e Tecnologia (FCT, CEECIND/03469/2017, CEECIND/03426/2020). CKP was supported by the OP AZORES2020, through the Fund 01-0145-FEDER-1279 000140 "MarAZ Researchers: Consolidate a body of researchers in Marine Sciences in the Azores" of the European Union. Okeanos is funded by FCT under the project UIDB/05634/2020 and UIDP/05634/2020, and by the Regional Government of the Azores through the initiative to support the Research Centers of the University of the Azores and through project M1.1. A/REEQ.CIENTÍFICO UI&D/2021/010. We would like to thank the two anonymous reviewers for their valuable comments and suggestions. We would like to dedicate this work to the memory of Dr. Alan B. Bolten for his inspiration and contribution to sea turtle research in the Azores.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2023.106730.

References

Abascal, F.J., Mejuto, J., Quintans, M., Garcia-Cortes, B., Ramos-Cartelle, A., 2015. Tracking of the broadbill swordfish, *Xiphias gladius*, in the central and eastern North Atlantic. Fish. Res. 162, 20–28. https://doi.org/10.1016/j.fishres.2014.09.011.

Afonso, P., Fontes, J., Giacomello, E., Magalhães, M., Martins, H.R., Morato, T., et al., 2020. The azores: a mid-atlantic hotspot for marine megafauna research and conservation. Front. Mar. Sci. 6, 826. https://doi.org/10.3389/fmars.2019.00826.

Agresti, A., 2007. An Introduction to Categorical Data Analysis, 2nd ed. New York: John Wiley & Sons. Pp 38.

Aires-da-Silva, A., Pereira, J.G., 1999. Catch rates for pelagic sharks taken by the portuguese swordfish fishery in the waters around the Azores, 1993–1997. Col. Vol. Sci. Pap. ICCAT 49, 300−305. https://www.iccat.int/Documents/CVSP/CV049_1999/n_4/CV049040300.pdf.

Aires-da-Silva, A., Ferreira, R.L., Pereira, J.G., 2008. Case study: blue shark catch-rate patterns from the portuguese swordfish longline fishery in the azores. In: Camhi, M. D., Pikitch, E.K., Babcock, E.A. (Eds.), Sharks of the Open Ocean: Biology, Fisheries & Conservation. Fish and Aquatic Resources Series 13. Blackwell Publishing, Oxford, U.K, pp. 230–235.

Aires-da-Silva, A.M., Gallucci, V.F., 2007. Demographic and risk analyses applied to management and conservation of the blue shark (*Prionace glauca*) in the North Atlantic Ocean. Mar. Freshw. Res. 58, 570–580. https://doi.org/10.1071/MF06156.

Anderson, O., Small, C., Croxall, J., Dunn, E., Sullivan, B., Yates, O., Black, A., 2011. Global seabird bycatch in longline fisheries. Endang. Species Res 14, 91–106. https://doi.org/10.3354/esr00347.

Anonymous, 2019. International Comission for the Conservation of Atlantic Tunas (ICCAT) - Report of the Standing Committee on Research and Statistic (SCRS). Madrid, Spain, 30 September to 4 October 2019, Corazón de María, 8–28002 Madrid, Spain. 454 p. https://www.iccat.int/Documents/Meetings/Docs/2019/REPORTS/2019_SCRS_ENG.pdf.

Anonymous, 2022. Compendium Management Recommendations and Resolutions adopted by ICCAT for the Conservation of Atlantic Tunas and Tuna-like Species. Madrid. Spain 218–220. ⟨https://www.iccat.int/com2022/ENG/PLE_102_ENG.pdf⟩.

Becker, R.A., Chambers, J.M., Wilks, A.R., 1988. The New S Language. Wadsworth & Brooks/Cole.

Benhamou, S., Cornélis, D., 2010. Incorporating movement behaviour and barriers to improve kernel home range space use estimates. J. Wildl. Manag 74, 1353–1360. https://doi.org/10.2193/2009-441.

Bigelow, K.A., Boggs, C.H., He, X., 1999. Environmental effects on swordfish and blue shark catch rates in the US North Pacific longline fishery. Fish. Oceano 8, 178–198. https://doi.org/10.1046/j.1365-2419.1999.00105.x.

Bigelow, K.A., Musyl, M.K., Poisson, F., Kleiber, P., 2006. Pelagic longline gear depth and shoaling. Fish. Res. 77, 173–183. https://doi.org/10.1016/j.fishres.2005.10.010.

Biton-Porsmoguer, S., Banaru, D., Boudouresque, C.F., Dekeyser, I., Béarez, P., Miguez-Lozano, R., 2017. Compared diet of two pelagic shark species in the northeastern Atlantic Ocean. Vie Milieu 67, 21–25.

Bjorndal, K.A., Bolten, A.B., Martins, H.R., 2000. Somatic growth model of juvenile loggerhead sea turtles *Caretta caretta*: duration of pelagic stage. Mar. Ecol. Prog. Ser. 202, 265–272. https://doi.org/10.3354/meps202265.

Bolten, A.B., 2003. Active swimmers – passive drifters: the oceanic juvenile stage of loggerheads in the Atlantic system. Loggerhead Sea Turtles. Smithsonian Books, Washington DC, pp. 63–78.

Bolten, A.B., Martins, H.R., Bjorndal, K.A., Gordon, J., 1993. Size distribution of pelagic-stage loggerhead sea turtles (*Caretta caretta*) in the waters around the Azores and Madeira. Arquipél. Life Mar. Sci. 11, 49–54.

Bolten, A.B.,Bjorndal, K.A.,Martins, H.R., 1994. Life history model for the loggerhead sea turtle (Caretta caretta) population in the Atlantic: potential impacts of a longline fishery. In: Balazs, G.H., Pooley, S.G. (Eds.), Research plan to assess marine turtle hooking mortality: results of an expert workshop held in Honolulu, Hawaii, 16–18 November 1993. NOAA Technical Memorandum NMFS-SWFSC 201, pp. 48–55.

Borcard, D., Gillet, F., Legendre, P., 2011. Numerical Ecology with R. Springer Science & Business Media, New York, NY.

Braun, C.D., Gaube, P., Afonso, P., Fontes, J., Skomal, G.B., Thorrold, S.R., 2019. Assimilating electronic tagging, oceanographic modelling, and fisheries data to estimate movements and connectivity of swordfish in the North Atlantic. ICES J. Mar. Sci. 76, 2305–2317. https://doi.org/10.1093/icesjms/fsz106.

Brazner, J.C., Mcmillan, J., 2008. Loggerhead turtle (*Caretta caretta*) bycatch in Canadian pelagic longline fisheries: Relative importance in the western North Atlantic and opportunities for mitigation. Fish. Res. 91, 310–324. https://doi.org/10.1016/j.fishres.2007.12.023.

Buencuerpo, V., Rios, S., Morón, J., 1998. Pelagic sharks associated with the swordfish, Xiphias gladius, fishery in the eastern North Atlantic Ocean and the Strait of Gibraltar. Fish. Bull. 96, 667–685.

Caldeira, R., Reis, J., 2017. The Azores confluence zone. Front. Mar. Sci. 4, 37. https://doi.org/10.3389/fmars.2017.00037.

Calenge, C., 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecol. Model. 197, 516–519. https://doi.org/10.1016/j.ecolmodel.2006.03.017.

Ceyhan, T., Akyol, O., 2017. Preliminary study on the diet of juvenile swordfish (Xiphias gladius) in the Aegean Sea. Col. Vol. Sci. Pap. ICCAT 73, 1103−1107. https://www.iccat.int/Documents/CVSP/CV073_2017/n_3/CV073031103.pdf.

Chancollon, O., Pusineri, C., Ridoux, V., 2006. Food and feeding ecology of Northeast Atlantic swordfish (*Xiphias gladius*). ICES J. Mar. Sci. 63, 1075–1085. https://doi.org/10.1016/j.icesjms.2006.03.013.

Chang, Y.-J., Sun, C.-L., Chen, Y., Yeh, S.-Z., Dinardo, G., 2012. Habitat suitability analysis and identification of potential fishing grounds for swordfish, *Xiphias gladius*, in the South Atlantic Ocean. Int. J. Remote Sens 33, 7523–7541. https://doi.org/10.1080/01431161.2012.685980.

Chang, Y.-J., Sun, C.-L., Chen, Y., Yeh, S.-Z., DiNardo, G., Su, N.-J., 2013. Modelling the impacts of environmental variation on the habitat suitability of swordfish, *Xiphias gladius*, in the equatorial Atlantic Ocean. ICES J. Mar. Sci. 70, 1000–1012. https://doi.org/10.1093/icesjms/fss190.

Clarke, M.R., Clarke, D.C., Martins, H.R., da Silva, H.M., 1995. The diet of swordfish (*Xiphias gladius*) in azorean waters. Arquipélago. Life Mar. Sci. 13A, 53–69.

Clarke, M.R., Clarke, D.C., Martins, H.R., da Silva, H.M., 1996. The diet of the blue shark (Prionace glauca L.) in Azorean waters. Arquipélago. Life Mar. Sci. 14A, 41–56.

Coelho, R., Fernandez-Carvalho, J., Lino, P.G., Santos, M.N., 2012. An overview of the hooking mortality of elasmobranchs caught in a swordfish pelagic longline fishery in the Atlantic Ocean. Aquat. Living Resour. 25, 311–319. https://doi.org/10.1051/alr/2012030.

Coelho, R., Santos, M.N., Fernandez-Carvalho, J., Amorim, S., 2015. Effects of hook and bait in a tropical northeast Atlantic pelagic longline fishery: Part I-Incidental sea turtle bycatch. Fish. Res. 164, 302–311. https://doi.org/10.1016/j.fishres.2014.11.008.

Coelho, R., Santos, M.N., Lino, P.G., 2016. Standardized CPUE of blue shark in the Portuguese pelagic longline fleet operating in the North Atlantic. Col. Vol. Sci. Pap. ICCAT 72, 1044–1066. https://www.iccat.int/Documents/CVSP/CV072_2016/n_4/CV072041044.pdf.

Coelho, R., Mejuto, J., Domingo, A., Yokawa, K., Liu, K., Cortés, E., et al., 2018. Distribution patterns and population structure of the blue shark (*Prionace glauca*) in the Atlantic and Indian Oceans. Fish Fish. 19, 90–106. https://doi.org/10.1111/faf.12238.

Collete, B., Carpenter, K., Polidoro, B., Juan-Jordá, J., Boustany, A., Die, D., et al., 2011. High value and long-life–double jeopardy for tunas and billfishes. Science 333, 291–292. https://doi.org/10.1126/science.1208730.

R. Core Team, 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/.

Correia, J., Morgado, F., Erzini, K., Soares, A., 2003. Elasmobranch landings in the Portuguese commercial fishery from 1986 to 2009. Arquipelago Life Mar. Sci. 33, 81–109.

Costa, R., Sá, S., Pereira, A., Ferreira, M., Vingada, J., Eira, C., 2021. Threats to seabirds in Portugal: integrating data from a rehabilitation centre and stranding network. Eur. J. Wildl. Res 67. https://doi.org/10.1007/s10344-021-01483-5.

Crespo, G., Dunn, D., 2017. A review of the impacts of fisheries on open-ocean ecosystems. ICES J. Mar. Sci. 74, 2283–2297. https://doi.org/10.1093/icesjms/fsx084.

Damalas, D., Megalofonou, P., Apostolopoulou, M., 2007. Environmental, spatial, temporal and operational effects on swordfish (*Xiphias gladius*) catch rates of eastern

Mediterranean Sea longline fisheries. Fish. Res. 84, 233–246. https://doi.org/10.1016/j.fishres.2006.11.00.
Davies, T.E., Carneiro, A., Tarzia, M., Wakefield, E., Hennicke, J., Frederiksen, M., et al., 2021. Multispecies tracking reveals a major seabird hotspot in the North Atlantic. Conserv. Lett. 14, e12824 https://doi.org/10.1111/conl.12824.
Dent, F., Clarke, S., 2015. State of the global market for shark products. FAO Fisheries and Aquaculture Technical Paper No. 590. Rome, FAO. 187 pp.
Dewar, H., Prince, E.D., Musyl, M.K., Brill, R.W., Sepulveda, C., Luo, J., et al., 2011. Movements and behaviours of swordfish in the Atlantic and Pacific Oceans examined using pop-up satellite archival tags. Fish. Oceano 20, 219–241. https://doi.org/10.1111/j.1365-2419.2011.00581.x.
Druon, J.-N., Campana, S., Vandeperre, F., Hazin, F.H.V., Bowlby, H., Coelho, R., et al., 2022. Global-scale environmental niche and habitat of Blue Shark (*Prionace glauca*) by size and sex: a pivotal step to improving stock management. Front. Mar. Sci. 9, 828412 https://doi.org/10.3389/fmars.2022.828412.
Dulvy, N., Baum, J., Clarke, S., Compagno, L., Cortés, E., Domingo, A., et al., 2008. You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. Aquat. Conserv.: Mar. Freshw. Ecosyst. 18, 459–482. https://doi.org/10.1002/aqc.975.
FAO 2021. FAO Yearbook. Fishery and Aquaculture Statistics 2019. Rome. https://doi.org/10.4060/cb7874t.
Fernandez-Carvalho, J., Coelho, R., Santos, M.N., Amorim, S., 2015. Effects of hook and bait in a tropical northeast Atlantic pelagic longline fishery: part II-Target, bycatch and discard fishes. Fish. Res. 164, 312–321. https://doi.org/10.1016/j.fishres.2014.11.009.
Ferreira, R.L., Martins, H.R., da Silva, A.A., Bolten, A.B., 2001. Impact of swordfish fisheries on sea turtles in the Azores. Arquipelago 18A, 75–79.
Ferreira, R.L., Martins, H.R., Bolten, A.B., Santos, M.A., Erzini, K., 2011. Influence of environmental and fishery parameters on loggerhead sea turtle by-catch in the longline fishery in the Azores archipelago and implications for conservation. J. Mar. Biol. Assoc. UK 91, 1697–1705. https://doi.org/10.1017/S0025315410000846.
Finkbeiner, E.M., Wallace, B.P., Moore, J.E., Lewison, R.L., Crowder, L.B., Read, A.J., 2011. Cumulative estimates of sea turtle bycatch and mortality in USA fisheries between 1990 and 2007. Biol. Conserv. 144, 2719–2727. https://doi.org/10.1016/j.biocon.2011.07.033.
Fossette, S., Witt, M.J., Miller, P., Nalovic, M.A., Albareda, D., Almeida, A.P., et al., 2014. Pan-Atlantic analysis of the overlap of a highly migratory species, the leatherback turtle, with pelagic longline fisheries. Proc. Roy. Soc. Lond. B 281, 20133065. https://doi.org/10.1098/rspb.2013.3065.
Gardner, B., Sullivan, P.J., Morreale, S.J., Epperly, S.P., 2008. Spatial and temporal statistical analysis of bycatch data: patterns of sea turtle bycatch in the North Atlantic. Can. J. Fish. Aquat. Sci. 65, 2461–2470. https://doi.org/10.1139/F08-152.
Garrison, L.P., 2007. Interactions between marine mammals and pelagic longline fishing gear in the U.S. Atlantic Ocean between 1992 and 2004. Fish. Bull. 105, 408–417.
Gilman, E., Passfield, K., Nakamura, K., 2014. Performance of regional fisheries management organizations: ecosystem-based governance of bycatch and discards. Fish Fish. 15, 327–351. https://doi.org/10.1111/faf.12021.
Good, S., Fiedler, E., Mao, C., Martin, M.J., Maycock, A., Reid, R., et al., 2020. The current configuration of the OSTIA system for operational production of foundation sea surface temperature and ice concentration analyses. Remote Sens 12, 720. https://doi.org/10.3390/rs12040720.
Hall, M., Alverson, D., Metuzals, K., 2000. By-catch: problems and solutions. Mar. Pol. Bull. 41, 204–219. https://doi.org/10.1016/S0025-326X(00)00111-9.
He, X., Bigelow, K.A., Boggs, C.H., 1997. Cluster analysis of longline sets and fishing strategies within the Hawaii-based fishery. Fish. Res. 31, 147–158. https://doi.org/10.1016/S0165-7836(96)00564-4.
Hernández-León, S., Franchy, G., Moyano, M., Menéndez, I., Schmoker, C., Putzeys, S., 2010. Carbon sequestration and zooplankton lunar cycles: could we be missing a major component of the biological pump. Limnol. Oceanogr. 55, 2503–2512. https://doi.org/10.4319/lo.2010.55.6.2503.
Hernandez-Milian, G., Goetz, S., Varela-Dopico, C., Rodriguez- Gutierrez, J., Romón-Olea, J., Fuertes-Gamundi, J.R., et al., 2008. Results of a short study of interactions of cetaceans and longline fisheries in Atlantic waters: environmental correlates of catches and depredation events. Hydrobiologia 612, 251–268. https://doi.org/10.1007/s10750-008-9501-2.
Hillary, R., Preece, A., Davies, C., Kurota, H., Sakai, O., Itoh, T., Parma, A., Butterworth, D., Ianelli, J., Branch, T., 2016. A scientific alternative to moratoria for rebuilding depleted international tuna stocks. Fish Fish. 17, 469–482. https://doi.org/10.1111/faf.12121.
Hollander, M., Wolfe, D., 1973. Nonparametric Statistical Methods. New York: John Wiley & Sons. Pages 27–33 (one-sample), 68–75 (two-sample). Or second edition (1999).
ICES, 2022. Working group on bycatch of protected species (WGBYC). ICES Sci. Rep. 3 (107), 168. https://doi.org/10.17895/ices.pub.9256.
INE, 2020. Instituto Nacional de Estatística - Estatísticas da Pesca: 2019. Lisboa. Available at https://www.ine.pt/xurl/pub/435690295.
Kot, C.Y., Boustany, A.M., Halpin, P.N., 2010. Temporal pattern of target catch and sea turtle bycatch in the US Atlantic pelagic longline fishing fleet. Can. J. Fish. Aquat. Sci. 67, 42–57. https://doi.org/10.1139/F09-160.
Kroodsma, D.A., Mayorga, J., Hochberg, T., Miller, N.A., Boerder, K., Ferretti, F., et al., 2018. Tracking the global footprint of fisheries. Science 361, 6378. https://doi.org/10.1126/science.aao5646.
Kroodsma, D.A., Hochberg, T., Davis, P., Paolo, F., Joo, R., Wong, B., 2022. Revealing the global longline fleet with satellite radar. Sci. Rep. 12, 21004. https://doi.org/10.1038/s41598-022-23688-7.
Lazaridis, E., 2014. lunar: Lunar Phase & Distance, Seasons and Other Environmental Factors (Version 0.1–04). http://statistics.lazaridis.eu.
Lea, D.J., Mirouze, I., Martin, M.J., King, R.R., Hines, A., Walters, D., Thurlow, M., 2015. Assessing a new coupled data assimilation system based on the Met Office coupled atmosphere-land-ocean-sea ice model. Mon. Weather Rev. 143, 4678–4694. https://doi.org/10.1175/MWR-D-15-0174.1.
Legendre, P., Gallagher, E.D., 2001. Ecological meaningful transformations for ordination of species data. Oecologia 129, 271–280. https://doi.org/10.1007/s004420100716.
Legendre, P., Legendre, L., 2012. Numerical ecology, 3rd English edition. Elsevier Science BV, Amsterdam.
Lemos, R.T., Pires, H.O., 2004. The upwelling regime off the west Portuguese Coast, 1941-2000. Int. J. Clim. 24, 511–524. https://doi.org/10.1002/joc.1009.
Lewison, R., Crowder, L., Read, A., Freeman, S., 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends Ecol. Evol. 19, 598–604. https://doi.org/10.1016/j.tree.2004.09.004.
Lewison, R., Soykan, C., Franklin, J., 2009. Mapping the bycatch seascape: multispecies and multi-scale spatial patterns of fisheries bycatch. Ecol. Appl. 19, 920–930. https://doi.org/10.1890/08-0623.1.
Lewison, R., Crowder, L., Wallace, B., Moore, J., Cox, T., Zydelis, R., et al., 2014. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. Proc. Natl. Acad. Sci. U. S. A 111, 5271–5276. https://doi.org/10.1073/pnas.1318960111.
Lewison, R.L., Crowder, L.B., 2007. Putting longline bycatch of sea turtles into perspective. Conserv. Biol. 21, 79–86. https://doi.org/10.1111/j.1523-1739.2006.00592.x.
MacCauley, D., Woods, P., Sullivan, B., Bergman, B., Jablonicky, C., Roan, A., et al., 2016. Ending hide and seek at sea. Science 351, 1148–1150. https://doi.org/10.1126/science.aad5686.
Mace, G., Collar, N., Gaston, K., Hilton-Taylor, C., Akçakaya, H., Leader-Williams, et al., 2008. Quantification of extinction risk: IUCN's system for classifying threatened species. Conserv. Biol. 22, 1424–1442. https://doi.org/10.1111/j.1523-1739.2008.01044.x.
Maia, A., Queiroz, N., Cabral, H., Santos, A., Correia, J., 2007. Reproductive biology and population Dynamics of the shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, off the southwest Portuguese coast, eastern North Atlantic. J. Appl. Ichthyol. 23, 246–251. https://doi.org/10.1111/j.1439-0426.2007.00849.x.
Marçalo, A., Katara, I., Feijó, D., Araújo, H., Oliveira, I., Santos, J., et al., 2015. Quantification of interactions between the Portuguese sardine purse-seine fishery and cetaceans. ICES J. Mar. Sci. 72, 2438–2449. https://doi.org/10.1093/icesjms/fsv076.
Martins, H.R., Bolten, A.B., Ferreira, R.L., 2001. Impact of longline fisheries on sea turtles in the archipelago of the Azores. pp.76–77 In: Ciccione, S., Ross, D., Jean-Yves Le Gall (Eds). Advance in knowledge and conservation of sea turtles in south- west Indian Ocean. La Reunion 28 Nov.- 2 dec. 1999. Etudes et Colloques du Editions du Centre d'Etude et de Découverte des Tortues Marine de La Réunion (CEDTM) 1, 135 pp.
Maunder, M.N., Punt, A.E., 2004. Standardizing catch and effort data: a review of recent approaches. Fish. Res. 70, 141–159. https://doi.org/10.1016/j.fishres.2004.08.00.
Mejuto, J., García-Cortés, B., Ramos-Cartelle, A., de la Serna, L.M., 2009. Scientific estimations of by-catch landed by the spanish surface longine fleet targeting swordfish (Xiphias gladius) in the Atlantic Ocean with special reference to the years 2005 and 2006. Col. Vol. Sci. Pap. ICCAT 64, 2455–2468. https://www.iccat.int/Documents/CVSP/CV064_2009/n_7/CV0640702455.pdf.
Neilson, J., Arocha, F., Cass-Calay, S., Mejuto, J., Ortiz, M., Scott, G., et al., 2013. The recovery of Atlantic swordfish: the comparative roles of the Regional Fisheries Management Organization and species biology. Rev. Fish. Sci. 21, 59–97. https://doi.org/10.1080/10641262.2012.754842.
NOAA National Geophysical Data Center, 2009. ETOPO1 1 Arc-Minute Global Relief Model. NOAA National Centers for Environmental Information. Accessed on November 2016.
Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M., Szoecs, E., Wagner, H., 2019. vegan: Community Ecology Package. R package version 2.5–5. https://CRAN.R-project.org/package=vegan.
Oliveira, N., Henriques, A., Miodonski, J., Pereira, J., Marujo, D., Almeida, A., et al., 2015. Seabird bycatch in Portuguese mainland coastal fisheries: an assessment through on-board observations and fishermen interviews. Glob. Ecol. Conserv. 3, 51–61. https://doi.org/10.1016/j.gecco.2014.11.006.
Parra, H., Machete, M., Santos, M., Bjorndal, K.A., Vandeperre, F., 2023. Incidental capture of sea turtles in the Northeast Atlantic Portuguese pelagic longline fishery. Fish. Res. 263, 106673 https://doi.org/10.1016/j.fishres.2023.106673.
Pelletier, D., Ferraris, J., 2000. A multivariate approach for defining fishing tactics from comercial catch and effort data. Can. J. Fish. Aquat. Sci. 57, 51–65. https://doi.org/10.1139/f99-176.
Pérez Roda, M.A. (ed.), Gilman, E., Huntington, T., Kennelly, S.J., Suuronen, P., Chaloupka, M., Medley, P., 2019. A third assessment of global marine fisheries discards. FAO Fisheries and Aquaculture Technical Paper No. 633. Rome, FAO. 78 pp.
Pham, C.K., Rodríguez, Y., Dauphin, A., Carriço, R., Frias, J., Vandeperre, F., et al., 2017. Plastic ingestion in oceanic-stage loggerhead sea turtles (*Caretta caretta*) off the North Atlantic subtropical gyre. Mar. Poll. Bull. 121, 222–229. https://doi.org/10.1016/j.marpolbul.2017.06.008.
Pons, M., Melnychuk, M., Hilborn, R., 2018. Management effectiveness of large pelagic fisheries in the high seas. Fish Fish 19, 260–270. https://doi.org/10.1111/faf.12253.

Post, A., 1984. Alepisauridae. In: Whitehead, P.J.P., Bauchot, M.-L., Hureau, J.-C., Nielsen, J., Tortonese, E. (Eds.), Fishes of the north-eastern Atlantic and the Mediterranean, Vol. 1. UNESCO, Paris, pp. 494–495.
Prihartato, P.K., Irigoien, X., Genton, M.G., Kaartvedt, S., 2016. Global effects of moon phase on nocturnal acoustic scattering layers. Mar. Ecol. Prog. Ser. 544, 65–75. https://doi.org/10.3354/meps11612.
Queiroz, N., Humphries, N., Mucientes, G., Hammerschlag, N., Lima, F., Scales, K., et al., 2016. Ocean-wide tracking of pelagic sharks reveals extent of overlap with longline fishing hotspots. Proc. Natl. Acad. Sci. U. S. A 113, 1582–1587. https://doi.org/10.1073/pnas.1510090113.
Queiroz, N., Humphries, N., Couto, A., Vedor, M., da Costa, I., Sequeira, A., et al., 2019. Global spatial risk assessment of sharks under the footprint of fisheries. Nature 572, 461–466. https://doi.org/10.1038/s41586-019-1444-4.
Ramírez, I., Geraldes, P., Meirinho, A., Amorim, P., Paiva, V., 2008. Áreas Importantes paras as Aves Marinhas em Portugal. Projecto LIFE04NAT/PT/000213— Sociedade Portuguesa para o Estudo da Aves. Lisboa.
Rigby, C.L., Barreto, R., Carlson, J., Fernando, D., Fordham, S., Francis, M.P., et al., 2019a. Isurus oxyrinchus. The IUCN Red List of Threatened Species 2019, e. T39341A2903170. https://dx.doi.org/10.2305/IUCN.UK.2019–1.RLTS. T39341A2903170.en.
Rigby, C.L., Barreto, R., Carlson, J., Fernando, D., Fordham, S., Francis, M.P., et al., 2019b. Lamna nasus. The IUCN Red List of Threatened Species 2019, e. T11200A500969. https://dx.doi.org/10.2305/IUCN.UK.2019–3.RLTS. T11200A500969.en.
Rigby, C.L., Barreto, R., Carlson, J., Fernando, D., Fordham, S., Francis, M.P., et al., 2019c. Isurus paucus The IUCN Red List of Threatened Species 2019, e. T60225A3095898. https://doi.org/10.2305/IUCN.UK.2019–1.RLTS. T60225A3095898.en.
Rigby, C.L., Barreto, R., Carlson, J., Fernando, D., Fordham, S., Francis, M.P., et al., 2019d. Alopias superciliosus. The IUCN Red List of Threatened Species 2019, e. T161696A894216. https://dx.doi.org/10.2305/IUCN.UK.2019–3.RLTS. T161696A894216.en.
Romanov, E., Zamorov, V., 2002. First record of a yellowfin tuna (*Thunnus albacares*) from the stomach of a longnose lancetfish (*Alepisaurus ferox*). Fish. Bull. 100, 386–389.
Roxo, A., Mendes, S., Correia, J., 2017. Portuguese commercial fisheries of swordfish, Xiphias gladius. Rev. Fish. Sci. Aquac. 25, 150–157. https://doi.org/10.1080/23308249.2016.1251879.
Sakamoto, Y., Ishiguro, M., Kitagawa, G., 1986. Akaike Information Criterion Statistics. D. Reidel Publishing Company.
Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M., Pauly, D., Sumaila, R., Zeller, D., 2018. The economics of fishing the high seas. eaat250 Sci. Adv. Environ. Stud. 4. https://doi.org/10.1126/sciadv.aat2504.
Santos, A., Borges, M., Groom, S., 2001. Sardine and horse mackarel recruitment and upwelling off Portugal. ICES J. Mar. Sci. 58, 589–596. https://doi.org/10.1006/jmsc.2001.1060.
Santos, M.N., Garcia, A., 2005. The influence of the moon phase on the CPUEs for the Portuguese swordfish (Xiphias gladius L., 1758) fishery. Col. Vol. Sci. Pap. ICCAT 58, 1466−1469. https://www.iccat.int/Documents/CVSP/CV058_2005/n_4/CV058041466.pdf.
Santos, M.N., Garcia, A., Pereira, J.G., 2002. A historical review of the by-catch from the Portuguese surface long-line swordfish fishery: observations on blue shark (Prionace glauca) and short-fin mako (Isurus oxyrinchus). Col. Vol. Sci. Pap. ICCAT 54, 1333−1340. https://www.iccat.int/Documents/CVSP/CV054_2002/n_4/CV054041333.pdf.
Santos, M.N., Coelho, R., Fernandez-Carvalho, J., Amorim, S., 2012. Effects of hook and bait on sea turtles bycatch in an equatorial Atlantic pelagic longline fishery. B. Mar. Sci. 88, 683–701. https://doi.org/10.5343/bms.2011.1065.
Santos, M.N., Coelho, R., Lino, P.G., Fernandez-Carvalho, J., 2014. Preliminary observations on elasmobranchs by-catch-at-size and sex-ratios on the Portuguese pelagic longline fishery in the Atlantic Ocean. Col. Vol. Sci. Pap. ICCAT 70, 2416–2432. 〈https://www.iccat.int/Documents/CVSP/CV070_2014/n_5/CV070052416.pdf〉.
Santos, M.N., Lino, P.G., Coelho, R., 2017. Effects of leader material on catches of shallow pelagic longline fisheries in the southwest Indian Ocean. Fish. Bull. 115, 219–232. https://doi.org/10.7755/FB115.2.9.
Schiller, L., Bailey, M., Jacquet, J., Sala, E., 2018. High seas fisheries play a negligible role in addressing global food security. eaat8351 Sci. Adv. 4. https://doi.org/10.1126/sciadv.aat8351.
Schuyler, Q., Hardesty, B.D., Wilcox, C., Townsend, K., 2014. Global analysis of anthropogenic debris ingestion by sea turtles. Conserv. Biol. 28, 129–139. https://doi.org/10.1111/cobi.12126.
Shepperson, J.L., Hintzen, N.T., Szostek, C.L., Bell, E., Murray, L.G., Kaiser, M., 2018. A comparison of VMS and AIS data: the effect of data coverage and vessel position recording frequency on estimates of fishing footprints. ICES J. Mar. Sci. 75, 988998 https://doi.org/10.1093/icesjms/fsx230.
Silva, M., Machete, M., Reis, D., Santos, M., Prieto, R., Dâmaso, C., et al., 2011. A review of interactions between cetaceans and fisheries in the Azores. Aquat. Conserv.: Mar. Freshw. Ecosyst. 21, 17–27. https://doi.org/10.1002/aqc.1158.
Simpfendorfer, C.A., Hueter, R.E., Bergman, U., Connett, S.M.H., 2002. Results of a fishery-independent survey for pelagic sharks in the western North Atlantic, 1977−1994. Fish. Res. 55, 175–192. https://doi.org/10.1016/S0165-7836(01)00288-0.
Soykan, C.U., Moore, J.E., Zydelis, R., Crowder, L.B., Safina, C., Lewison, R.L., 2008. Why study bycatch? An introduction to the Theme Section on fisheries bycatch. Endang. Species Res. 5, 19–102. https://doi.org/10.3354/esr00175.
Su, N.-J., Chang, C.-H., Hu, Y.-T., Chiang, W.-C., Tseng, C.-T., 2020. Modeling the spatial distribution of swordfish (Xiphias gladius) using fishery and remote sensing data: approach and resolution. Remote Sens 12, 947. https://doi.org/10.3390/rs12060947.
Swartz, W., Sala, E., tracey, S., Watson, R., Pauly, D., 2010. The spatial expansion and ecological footprint of fisheries (1950 to present). Plos One 5, e15143. https://doi.org/10.1371/journal.pone.0015143.
Swimmer, Y., Zollett, E.A., Gutierrez, A., 2020. Bycatch mitigation of protected and threatened species in tuna purse seine and longline fisheries. Endang. Species Res. 43, 517–542. https://doi.org/10.3354/esr01069.
Tickler, D., Meeuwig, J., Palomares, M.-L., Pauly, D., Zeller, D., 2018. Far from home: Distance patterns of global fishing fleets. eaar3279 Sci. Adv. 4. https://doi.org/10.1126/sciadv.aar3279.
Vandeperre, F., Aires-da-Silva, A., Santos, M., Ferreria, R., Bolten, A.B., Santos, R.S., Afonso, P., 2014a. Demography and ecology of blue shark (*Prionace glauca*) in the central North Atlantic. Fish. Res. 153, 89–102. https://doi.org/10.1016/j.fishres.2014.01.006.
Vandeperre, F., Aires-da-Silva, A., Fontes, J., Santos, M., Santos, R.S., Afonso, P., 2014b. Movements of Blue Sharks (*Prionace glauca*) across Their Life History. PLoS ONE 9, e103538. https://doi.org/10.1371/journal.pone.0103538.
Vandeperre, F., Aires-da-Silva, A., Lennert-Cody, C., Santos, R.S., Afonso, P., 2016. Essential pelagic habitat of juvenile blue shark (*Prionace glauca*) inferred from telemetry data. Limnol. Oceanogr. 61, 1605–1625. https://doi.org/10.1002/lno.10321.
Vega, R., Licandeo, R., 2009. The effect of American and Spanish longline systems on target and non-target species in the eastern South Pacific swordfish fishery. Fish. Res. 98, 22–32. https://doi.org/10.1016/j.fishres.2009.03.010.
Wallace, B.P., Kot, C.Y., DiMatteo, A.D., Lee, T., Crowder, L.B., Lewison, R.L., 2013. Impacts of fisheries bycatch on marine turtle populations worldwide: toward conservation and research priorities. Ecosphere 4, 1–49. https://doi.org/10.1890/ES12-00388.1.
Walsh, W.A., Kleiber, P., 2001. Generalized additive model and regression trees analysis of blue shark (*Prionace glauca*) catch rates by the Hawaii-based commercial longline fishery. Fish. Res. 53, 115–131. https://doi.org/10.1016/S0165-7836(00)00306-4.
Ward, P., Hindmarsh, S., 2007. An overview of historical changes in the fishing gear and practices of pelagic longliners, with particular reference to Japan's Pacific fleet. Rev. Fish. Biol. Fish. 17, 501–516. https://doi.org/10.1007/s11160-007-9051-0.
Ward, P., Myers, R., 2005. Shifts in open-ocean fish communities coinciding with the commencement of commercial fishing. Ecology 86, 835–847. https://doi.org/10.1890/03-0746.
Ward, P., Porter, J.M., Elscot, S., 2000. Broadbill swordfish: status of established fisheries and lessons for developing fisheries. Fish Fish. 1, 317–336. https://doi.org/10.1046/j.1467-2979.2000.00026.x.
Ward, P., Lawrence, E., Darbyshire, R., Hindmarsh, S., 2008. Large-scale experiment shows that nylon leaders reduce shark bycatch and benefit pelagic longline fishers. Fish. Res. 90, 100–108. https://doi.org/10.1016/j.fishres.2007.09.034.
Welsh, H., Clavelle, T., White, T., Cimino, M., Osdel, J., Hochberg, T., et al., 2022. Hot spots of unsees fishing vessels. eabq2109 Sci. Adv. 8. https://doi.org/10.1126/sciadv.abq2109.
Werner, T.B., Northridge, S., Press, K.M., Young, N., 2015. Mitigating bycatch and depredation of marine mammals in longline fisheries. ICES J. Mar. Sci. 72, 1576–1586. https://doi.org/10.1093/icesjms/fsv092.
Wood, S.N., 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. J. R. Stat. Soc. B 73, 3–36. https://doi.org/10.1111/j.1467-9868.2010.00749.x.
Worm, B., Davis, B., Kettemer, L., Ward-Paige, C., Chapman, D., Heithaus, M., et al., 2013. Global catches, exploitation rates, and rebuilding options for sharks. Mar. Pol. 40, 194–204. https://doi.org/10.1016/j.marpol.2012.12.034.
Zar, J.H., 2010. Biostatistical Analysis, 5 ed. Upper Saddle River, NJ: Pearson Prentice-Hall. p. 944.
Ziegler, P.E., 2012. Fishing tactics and fleet structure of the small-scale coastal scalefish fishery in Tasmania, Australia. Fish. Res. 134, 52–63. https://doi.org/10.1016/j.fishres.2012.08.011.
Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, G.M., 2009. Mixed Effects Models and Extensions in Ecology with R. Springer Science & Business Media, New York, NY.
Zuur, A.F., Ieno, E.N., Elphick, C.S., 2010. A protocol for data exploration to avoid common statistical problems. Methods Ecol. Evol. 1, 3–14. https://doi.org/10.1111/j.2041-210X.2009.00001.x.