SPATIOTEMPORAL VARIABILITY OF TARGET-SPECIES IN TUNA AND TUNA-LIKE FISHING IN BRAZIL*

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ABSTRACT

Knowing the history of fishing-target catches and identifying them is essential for fish species conservation, mainly for the conservation of migratory species, whose stock assessment data are often provided by commercial fleets. Data on the catch, effort, and geographic distribution of fishing operations found in Banco Nacional de Dados da Pesca de Atuns e Afins - BNDA (National Database of Tuna and Tuna-like Species Fishing) were herein analyzed. The ratios between catches of different Tuna and tuna-like species were calculated and the identified patterns were used to classify what would be the target-species of the Brazilian fleet in different periods between 1978 and 2018. Based on the current results, there are three different exploration phases marking the Brazilian longline fleet. The first phase (1978-1981) was featured by the prevalence of Japanese vessels, which recorded the highest presence of swordfish on catching quantity within that period (with mean target-species indicator of $D_{k^a} = 0.30$). The second phase took place between 1982 and 2001, and it was marked by an increased indicator for tuna species, mainly of albacore (with mean of $D_{k^a} = 0.17$). Finally, the third phase (2002-2018) stood out for the leasing of several vessels, increasing the effort and the volume of swordfish (with mean of $D_{k^a} = 0.04$), and blue shark catches (with mean of $D_{k^a} = 0.19$). Moreover, the recorded CPUE reflected variations in fleet targeting over the years, as well as the biomass of the analyzed species.

Keywords: fishery effort; catch rate; fishing target.

VARIABILIDADE ESPAÇO TEMPORAL DAS ESPÉCIES-ALVOS DA PESCA DE ATUNS E AFINS NO BRASIL

RESUMO

O conhecimento sobre o histórico de capturas e a identificação de espécies alvo da pesca é essencial para a conservação destas espécies, principalmente as migratórias, cujos dados de avaliação dos estoques são comumente obtidos da frota comercial. Foram analisados os dados disponíveis sobre captura, esforço e localização geográfica dos lances de pesca, presentes no Banco Nacional de Dados da Pesca de Atuns e Afins (BNDA). Foram calculadas as razões entre as capturas das diferentes espécies de atuns e afins e os padrões identificados foram utilizados para classificar quais seriam as espécies-alvo da frota brasileira em diferentes períodos entre 1978 e 2018. Os resultados apontaram três momentos distintos de exploração da frota de espinhel brasileira. O primeiro (1978-1981), caracterizado pela hegemonia das embarcações japonesas, tendo o espadarte com maior participação na quantidade de peixes capturados durante este período (com indicador de direcionamento médio de $D_{k^a} = 0,30$). A segunda fase teve vigência entre 1982 e 2001, marcada por um aumento do indicador para as espécies de albacoras, principalmente a branca (média de $D_{k^a} = 0,17$). E por fim, a terceira fase (2002-2018), na qual ocorreu o arrendamento de várias embarcações, aumento no esforço e na captura de espadarte (média de $D_{k^a} = 0,04$) e tubarão azul (média de $D_{k^a} = 0,19$). Além disso, a CPUE calculada reflete as variações do direcionamento da frota ao longo dos anos, bem como da biomassa das espécies analisadas.

Palavras-chave: esforço de pesca; taxa de captura; alvo de pesca.

INTRODUCTION

Marine species presenting wide oceanic distribution such as tuna, swordfish and shark species, are the catch-target in several countries (Hobday et al., 2017; Pons et al., 2018). The meat of these species is quite appreciated and has high commercial value

in the international market, mainly in the USA, Europe and Asia (Arrizabalaga et al., 2011; Guillotreau et al., 2017). Most stocks of these species are overfished or their catch stays within their maximum sustainable limit (Punt et al., 2015; FAO, 2020). The following species are among the main commercial catch targets worldwide: bigeye tuna (*Thunnus obesus*), albacore tuna (*Thunnus alalunga*), yellowfin tuna (*Thunnus albacares*), swordfish (*Xiphias gladius*) (Arrizabalaga et al., 2015; Pons et al., 2017; Erauskin–Extramiana et al., 2019) and blue shark (*Prionace glauca*) – which, by the way, is the most often caught elasmobranch through pelagic longline fishery focused on tuna and tuna-like species (Fiedler et al., 2015; Coelho et al., 2018).

Population conservation and the management of tuna and tuna-like fishery are assessed by Regional Fisheries Management Organizations known as RFMO. These organizations request information about fishery activity in member countries in order to fulfill their ordering task. Most stock assessment models are based on commercial-fishery catch and effort data (Campbell, 2015; Xu et al., 2018) or, yet, on some estimates about relative abundance (Hilborn and Walters, 1992; Campbell, 2016). These estimates are oftentimes calculated based on catch per unit effort (CPUE) reported by the commercial fleet.

The association between CPUE and population abundance is given by the equation: $CPUE = qN$; wherein, q represents the catchability coefficient, which is related to the efficiency of fishing gear, and N is population abundance. Accordingly, if variable q is constant (regardless of time, space and fishery vessels), changes in CPUE are proportional to variations in stock abundance (Campbell, 2004; Maunder and Punt, 2004; Lynch et al., 2012). However, changes in target-species in the long-term, as well as systematic variations in vessel flags, catch strategies, action zones and time spent in these zones can change the catchability coefficient. These changes make raw CPUE disproportional to the abundance of the assessed population, but, on the other hand, it turns it into a local density indicator (Maunder et al., 2006; Chang et al., 2011; Campbell, 2016; Hiraoka et al., 2016; Xu et al., 2018).

Analyses were carried out in order to minimize the effect of several factors associated with the catchability coefficient (e.g., fishing strategy and target species) over observed CPUE (Maunder and Punt, 2004; Maunder et al., 2006; Lynch et al., 2012; Campbell, 2016) in order to find indices to reflect stock abundance based on commercial fishery data. Information about the target species is not often recorded in logbooks filled by fishing masters (Okamura et al., 2018). Lack of knowledge on this topic can lead to unreliable estimates of relative abundance indices calculated based on CPUE, since information on fleet targeting is relevant for the abundance index construction process.

Indices based on clustering methods (e.g., cluster analysis) (Carvalho et al., 2014; Hazin et al., 2014; Fiedler et al., 2015), catch composition (Biseau, 1998; Chang et al., 2011; Hiraoka et al., 2016), and the number of hooks per basket (Chang et al., 2011) have been used to identify targets and fisher intentions concerning fishing trips or operation, worldwide. As well as in the principal component analysis (Winker et al., 2014), spatial imputation methods (Carruthers et al., 2011), factor analysis of spatial dynamics (Thorson et al., 2016), decision-tree approach (Campbell, 2016)

and directed the residual mixture model (Okamura et al., 2018). However, although these indices are useful to estimate possible catch targets, it is still essential for investigating practical and objective alternatives to identify the target-species of different fleets.

The RFMO responsible for evaluating tuna and tuna-like stocks in the Atlantic Ocean is known as the International Commission for the Conservation of Atlantic Tunas (ICCAT), which has been facing situations whose relative abundance index estimates present low reliability. The last bigeye tuna stock assessment has pointed towards the fact that these species are facing overfishing (ICCAT, 2017; 2019). The last assessment of blue shark stocks was not conclusive due to the high uncertainty of available data and estimates (ICCAT, 2016; 2019). However, assumingly, blue shark stocks are facing overfishing or have been overexploited (ICCAT, 2016; 2019). Swordfish overfishing stood out in the South Atlantic stocks; albacore and yellowfin tuna stocks are not likely overfished or facing overfishing (ICCAT, 2019). Simultaneously, some ecological risk analyses reinforce concerns with the conservation status of tuna, billfish (Lucena-Frédou et al., 2017) and blue shark (Cortés et al., 2010) caught through pelagic longline in the Atlantic Ocean.

In Brazil, the introduction of industrial longline fishing focused on tuna and tuna-like species happened in 1956 by Japanese fishing vessels moored in Recife harbor; these vessels used to operate devices with multifilament nylon main cable (Meneses de Lima et al., 2000). This activity outspread fast in the equatorial region and reached Southern and Southeastern Brazil (Meneses de Lima et al., 2000). After the development of this fishing process in Brazil, there was a large number of different vessels and great variation in flag leasing, catch targets and catch technologies (Mourato et al., 2011; Guimarães-Silva and Andrade, 2014; Barreto et al., 2016).

This complex scenario has impaired management at a national scope, as well as the interpretation of results for important analyses applied to stocks management and assessment. The swordfish stock assessment in South Atlantic, held in 2017 evidenced that most Brazilian time series stood out for presenting great and noisy variability, without any temporal trend (ICCAT, 2016; 2019). CPUE use can lead to wrong interpretations about the trajectory of population biomass, in case a careful analysis of studies on exploration history is not carried out to identify target species, a fact that can also impair fishery management (Maunder et al., 2006; Barreto et al., 2016; Campbell, 2016; Xu et al., 2018).

Overall, there is great concern about the real conservation status of albacore, bigeye, yellowfin, swordfish and blue shark stocks. Continuous monitoring and further studies demanding fishery management in decision-making processes are essential for the conservation of these animals. However, the present study aimed to review the historical catches, as well as the catch of different species to identify space-time patterns in the tuna and tuna-like pelagic longline fishing adopted by the Brazilian longline fleet in West Tropical and Sub-tropical Atlantic.

MATERIAL AND METHODS

Database

Data provided by *Banco Nacional de Dados da Pesca de Atuns e Afins – BNDA,* which is held by *Secretaria de Aquicultura e Pesca – SAPA*, linked to the *Ministério da Agricultura, Pecuária e Abastecimento - MAPA* of the Brazilian government, were analyzed. This database is composed of information provided by logbooks filled by fishing masters from commercial vessels. Although it is mandatory in the Brazilian legislation (Brasil, 2014), the number of logbooks recorded in BNDA does not cover all commercial fishing trips. In 2018, for example, the production reported on logbooks corresponded to 36% of the total production of the Brazilian pelagic longline fleet reported to ICCAT (2020). Therefore, it is the official sample of information on longline fishing operations carried out in the Brazilian Exclusive Economic Zone (EEZ) and in adjacent international waters.

BNDA counts on records of 97,679 fishing operations carried out between 1978 and 2018 by 614 national and leased vessels. The analyzed period showed the records of vessel operations from 19 different flags in BNDA, including the Brazilian flag (national vessels). Of this total, flags acting for at least 10 years were selected for analysis: National vessels (BRA), leased Spanish (ESP), Dutch (HND), Japanese (JPN), Panamanian (PAN) and China Taipei (TAI) vessels. In total, 81,794 fishing sets were analyzed.

Variables used in the analysis were vessels flag, fishing operation geographic location (latitude and longitude), fishing effort and species caught. The number of hooks per fishing operation was used as effort measurement. Catches were recorded in weight, but the record expressed in the number of fish was the most frequent one; therefore, it was the measurement unit adopted for analysis. Catch per unit effort (CPUE) recorded for each operation is $CPUE = (C / f) \times 1000$; wherein, f is the effort in the number of hooks and C is the number of caught specimens. Descriptive analyses were applied to variables such as fishing effort and catch, including the generation of maps based on resolution 5º x 5º (latitude x longitude). The values distributions of the CPUE were analyzed by species and illustrated with boxplots (middle line = median, box = inter-quartile range; whiskers = non-outlier range), as they provide a visual summary of the data enabling to quickly identify median values and the dispersion of the data set.

Target-species identification

The classification of which would be the target species of the Brazilian fleet in different periods between 1978 and 2018 was elaborated using the catch composition methodology (Biseau, 1998; Chang et al., 2011; Hiraoka et al., 2016), associated with use quartiles (Hiraoka et al., 2016) to more accurately represent fishermen's targeting practices.

The following ratio was calculated in order to estimate targeting-indicators for target-species: $I_{k,j} = C_{k,j} / \sum_{i=1}^{n} C_{i,j}$; wherein, $I_{k,j}$ is the proportionality ratio for the jth fishing set between the catch of the kth species and the sum of catches of the n species (albacore,

bigeye, yellowfin, swordfish and blue shark), including k The set of values were classified according to the flag $b = \{1,...,B\}$, and to the year $a = \{1,...,A\}$. For each ath year and b^{th} flag, there is, at least, one value vector $I_k^{a,b}$ of length corresponding to the number of sets performed by the flag in that year. Next, the third quartile was chosen because it was the lesser sensitive to inter-annual variations in fishing effort, since the choice for other measurements (also sensitive to these variations, i.e., average) could be the cause of biases in the presented results.

Marginal means recorded for each year and fleet are calculated as $M_k^b = \sum Q_k^{a,b} / A$ and $M_k^a = \sum Q_k^{a,b} / B$, respectively. The vector of differences $D_k^b = Q_k^{\{1,...,A\};b} - M_k^b$ for each bth fleet was calculated as the index of variation in the targeting of each bth fleet throughout the years. The vector of differences between indices $D_k^a = Q_k^{\{1,...,A\};a} - M_k^a$ of each ath year and the mean were calculated as the index of general annual variation of integrated targeting by taking into account all added fleets.

Positive and negative values in vector D_k^b of length A indicated the targeting, or not, of the bth fleet for the kth species throughout the A years. Positive and negative values of vector D_k^a, of length A have indicated that, overall, there was longer or shorter focus for the bth of different moments throughout A years, by taking into account the total set of flags in operation. All analyses in these, and other, aforementioned phases, were performed in the R software, version 3.5.1 (R Core Team, 2019), using the ggplot2 package (Wickham, 2016) for the construction of the graphs and the generation of maps were performed with the package Rworldmap (South, 2011), mapplots (Gerritsen, 2018), reshape2 (Wickham, 2007) and sp (Pebesma and Bivand, 2005).

RESULTS

The number of fishing sets, the number of different vessels per flag and operation year are shown in Table 1. The total number of vessels per flag and of all aggregated flags significantly changed throughout the years. For example, there is a record of only four vessels in 1978, all of them of the Japanese flag. Subsequently, there was the participation of vessels with different flags, whereas, back in 2018, at the end of the time series, there were 61 vessels, all national. In total, the record of 345 different vessels – 200 national and 125 leased ones – was analyzed. Among the assessed fishing sets, 52.9% were carried out in national vessels, which were followed by Spanish (18.9%) and Japanese leased vessels (10.3%).

There was a fast increase in the number of hooks registered in BNDA in the late 1990s, and the peak of it was in 2001 (9.4 million hooks) (Figure 1). Subsequently, there was great variation in the number of hooks and a drastic drop was observed in it in 2003 (3.6 million hooks), as well as a new increase in its number in 2004 (6.7 million hooks), which was followed by a significant drop in it between 2006 and 2010 (by approximately 70%). From 2010 on, there was a hook-number-rise trend until 2013; however, it was more moderate than that observed in early 2000. There was one more hook-number drop register in

Table 1. Number of records of fishing sets, number of acting vessels (in brackets) - per year and flag -, and the total number of different vessels (indicated in curly brackets). Fleets: National (BRA) and Spanish (BRA-ESP), Dutch (BRA-HND), Japanese (BRA-JPN), Panamanian (BRA-PAN), China Taipei (BRA-TAI) and Saint Vincent (BRA-VCT) leased vessels.

YEAR	BRA	BRA-ESP	BRA-HND	BRA-JPN	BRA-PAN	BRA-TAI	TOTAL
1978	-	-	-	499(4)	-	-	499(4)
1979	16(1)	-	-	466(5)	-	-	482(6)
1980	155(1)	-	-	427(5)	-	-	582(6)
1981	160(1)	-	-	306(5)	-	-	466(6)
1982	226(3)	-	-	666(6)	-	-	892(9)
1983	179(2)	-	-	440(4)	-	-	619(6)
1984	192(2)	-	-	404(4)	-	120(1)	716(7)
1985	173(2)	-	-	297(4)	-	-	470(6)
1986	361(4)	-	-	630(6)	-	-	991(10)
1987	506(4)	-	-	421(5)	-	-	927(9)
1988	334(3)	-	-	886(5)	-	-	1,220(8)
1989	281(4)	-	-	751(6)	-	-	1,032(10)
1990	261(3)	-	-	29(3)	-	-	290(6)
1991	135(2)	-	-	364(5)	-	494(9)	993(16)
1992	178(3)	-	-	58(1)	-	978(13)	1,214(17)
1993	162(2)	-	-	9(1)	-	92(4)	263(7)
1994	173(3)	-	-	333(2)	-	257(6)	763(11)
1995	247(3)	-	-	248(2)	-	867(4)	1,362(9)
1996	348(3)	50(2)	-	-	-	-	398(5)
1997	473(10)	481(3)	3(1)	-	-	-	957(14)
1998	1,189(23)	734(5)	310(3)	24(1)	56(1)	105(4)	2,418(37)
1999	1,620(24)	1,166(8)	301(4)	-	123(1)	713(6)	3,923(43)
2000	2,062(30)	2,606(16)	296(4)	34(2)	362(2)	999(7)	6,359(61)
2001	1,386(31)	2,929(18)	447(4)	19(2)	227(3)	954(6)	5,962(64))
2002	1,900(32)	1,506(9)	605(4)	-	235(2)	430(6)	4,676(53)
2003	1,361(33)	1,585(9)	224(4)	-	176(3)	-	3,346(49)
2004	3,218(29)	729(8)	454(4)	-	820(20)	-	5,221(61)
2005	2,474(34)	948(6)	330(2)	-	1,627(17)	-	5,379(59)
2006	1,673(20)	575(5)	369(2)	-	667(10)	-	3,284(37)
2007	2,390(45)	644(3)	158(1)	-	201(1)	-	3,393(50)
2008	1,192(25)	163(4)	142(2)	-	-	-	1,497(31)
2009	1,054(20)	369(4)	137(1)	-	-	-	1,560(25)
2010	6,770(15)	497(4)	-	-	-	-	1,174(19)
2011	7,180(11)	399(3)	-	769(11)	-	-	1,886(25)
2012	2,391(39)	169(3)	-	442(6)	-	-	3,004(48)
2013	1,082(37)	-	-	-	-	-	1,082(37)
2014	3,679(76)	-	-	-	-	-	3,679(76)
2015	1,538(63)	-	-	-	-	-	1,538(63)
2016	2,722(78)	-	-	-	-	-	2,722(78)
2017	1,682(40)	-	-	-	-	-	1,682(40)
2018	2,873(61)	-	-	-	-	-	2,873(61)
TOTAL	43,441{220}	15,550{25}	3,778{6}	8,522{41}	4,494{23}	6,009{30}	81,794{345}

the last five years of the time series, which reached 1.7 million hooks in 2015 and 2.0 million hooks in 2017.

In the early years until 1989, the Japanese flag was the most active one due to the highest number of hooks; between 1990 and 2002, China Taipei and Spain stood out among the other flags. Between 2003 and 2018, the national fleet was the one recording the greatest effort, except for 2011, when leased Japanese vessels returned to operation. Panamanian leased vessels recorded the highest frequencies between 2004 and 2006. Honduras recorded between 1998 and 2009, it presented low inter-annual variation fishing effort, but higher values in 2002 – approximately 1 million hooks.

The recorded catches were low until 1997, as shown by the low values recorded: between 14,000 and 57,000 fish (Figure 2). From 1997 on, the production recorded for almost all species assessed until 2000 increased when catches reached their peak (more than 200,000 specimens). Subsequently, there was a minimum drop in fish caught in 2003, which was followed by a new increase in its values (higher than 100,000 fish) from 2004 to 2007. After such a period, there was a new fish-catching drop until 2010. From this point on, there were great fluctuations in this variable.

Swordfish catches stood out between 1978 and 1988. However, after this period, there was a production drop until 1997, which was

followed by a production increase until 2007. From 2008 to 2018, catches of this species remained between 9,000 and 20,000 fish. Albacore tuna was the species recording the greatest added production between 1987 and 2002; however, after such period, catches of this species reduced and remained between 3,000 and 12,000 fish. When it comes to bigeye tuna and yellowfin tuna, these species recorded between 2,500 and 17,000 fish caught throughout almost the whole time series, except for the period between 1997 and 2007, when higher values were recorded. Blue shark catches recorded numbers lower than 3,000 specimens until 1997; however, there was a progressive increase in this number after this period with a production peak (49,206 fish) in 2002.

CPUE of the main tuna and tuna-like species caught with longline reported to BNDA are shown in Figure 3. There was a first period (1978-1986) when swordfish and bigeye stood out, they recorded medians close to 3 fish/1,000 hooks and 1 fish/1,000 hooks,
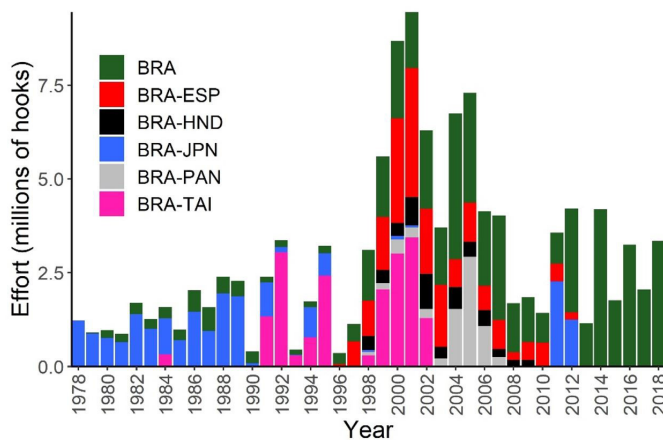
Figure 1. Effort in number of hooks for national vessels (BRA) and Spanish (ESP), Honduran (HND), Japanese (JPN), Panamanian (PAN), China Taipei (TAI) and Saint Vincent (VCT) leased vessels recorded in *Banco Nacional de Dados da Pesca de Atuns e Afins*.
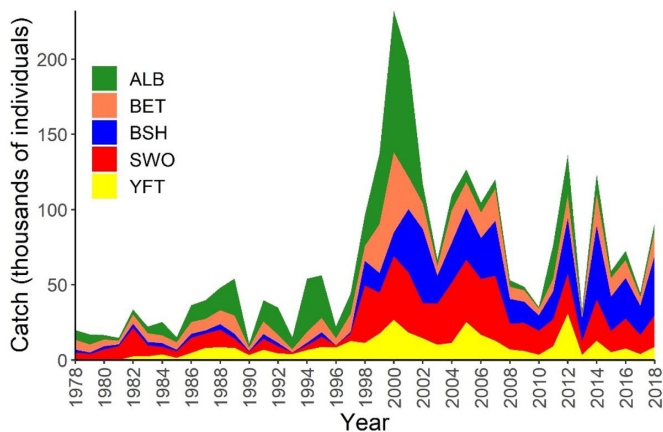
Figure 2. Catch (thousands of individuals) of albacore (ALB), yellowfin (YFT) and bigeye (BET), blue shark (BSH) and swordfish (SWO), registered in *Banco Nacional de Dados da Pesca de Atuns e Afins*.

respectively. The following period (1987-2001) showed reduced CPUE values recorded for swordfish, blue shark and bigeye, as well as for the rates of yellowfin and albacore catches. Finally, the third period (2002 – 2018) showed reduced CPUE values for albacore and bigeye, and an increasing trend CPUE for yellowfin, swordfish and blue shark, with emphasis on this last species.

Spatial distribution of effort, catch and CPUE

The fishing effort in the first part of the time series (1978-1986) was concentrated in oceanic areas close to the equator line and Southern Brazil (Figure 4A). Subsequently, between 1987-2001, it was possible seeing an expansion in the fishing effort distribution area covering most of the South Atlantic, but with greater concentration in Central and Western regions adjacent to the Brazilian coast. The effort ranged from 100 to 500 thousand hooks in the Western and Center regions, and from 1 to 2 thousand hooks in the Eastern region (Figure 4B). From 2002 to 2018, there was a decrease in the number of effort registrations, but the fleet coverage area was similar to that of the previous phase (Figure 4C).

The special distribution of catches is quite similar to that of the fishing effort. The greatest catches of swordfish, bigeye and albacore tuna were recorded from 1978 to 1986, mainly at areas close to latitude 25°S and longitude 035°W (Figure 4D). However, between 1987 and 2001, there was albacore in almost all action areas of the Brazilian fleet, including national and leased vessels (Figure 4E).

From 2002 until the end of the time series, catches were concentrated in two different regions: close to the equator line, until latitudes close to 10°S, where more *Thunnus* sp. and swordfish were caught, while the blue shark was mainly caught between latitudes 25° to 35°S and longitudes 055° to 035°W (Figure 4F). The highest CPUE values obtained from 1978 to 1986 were concentrated in equatorial oceanic regions and in the western South Atlantic where catch rates of albacore and swordfish were high, and between latitudes of 25° to 35 °S and longitudes of 055° to 035° W, with the highest values for bigeye and swordfish (Figure 4G).

Between 1987 and 2001, there were high albacore CPUE at the West side in the equatorial region and to the South at 25°S, as well as in a more central area in the South Atlantic, at approximately 20°S and 030°W (Figure 4H). After 2002, there was swordfish CPUE increase in oceanic areas located between coordinates 10°-25°S and 015°-045°W and blue shark CPUE increase at latitudes 25° S and 40°S (Figure 4I).
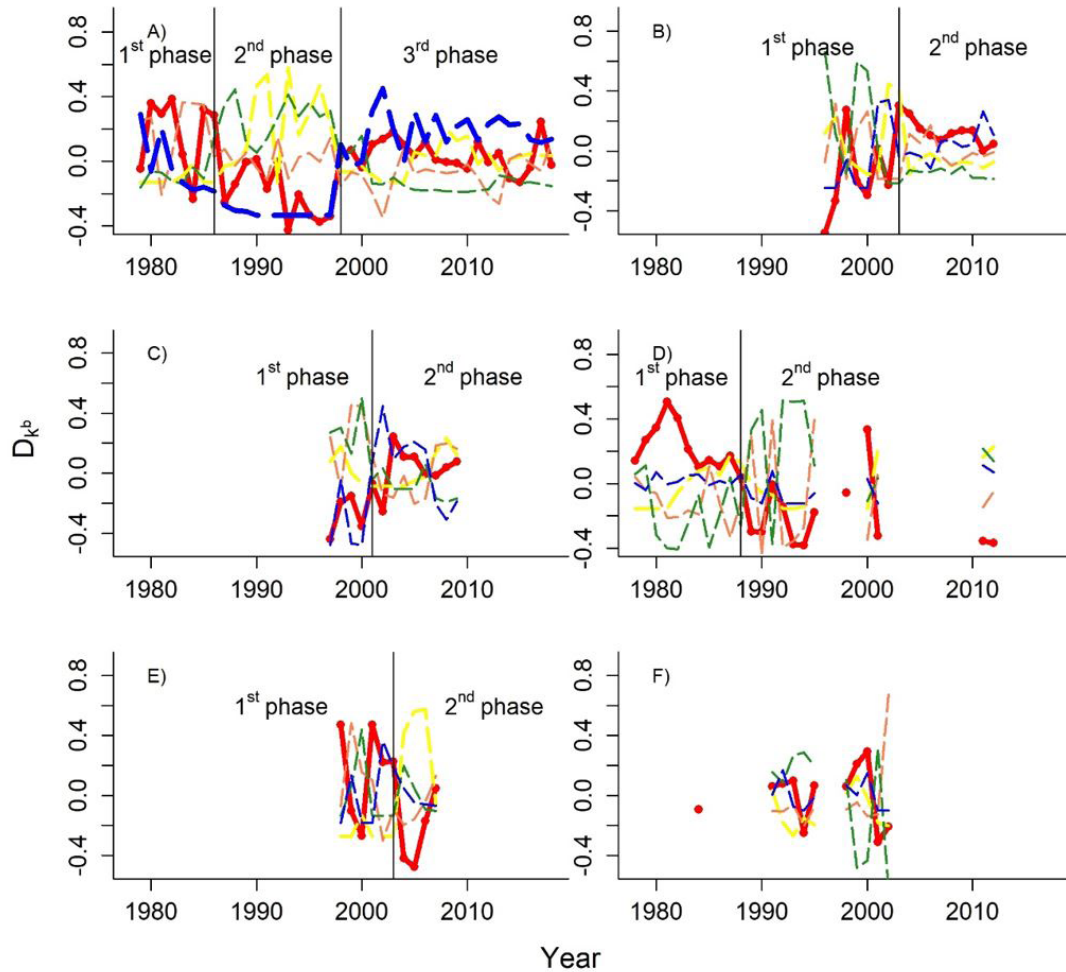
Target-species indicators

Figure 5 presents the annual variation in the target-species indicators of the main tuna and tuna-like species adopted by national and leased flag vessels. Overall, national flag vessels showed three different phases, the first one between 1979 and 1986, when swordfish was the main caught species with the mean target-species indicator of $D_{k^b} = 0.18$ (Figure 5A). From 1987 to 1998 on, there was a change in the target-species, yellowfin and albacore became
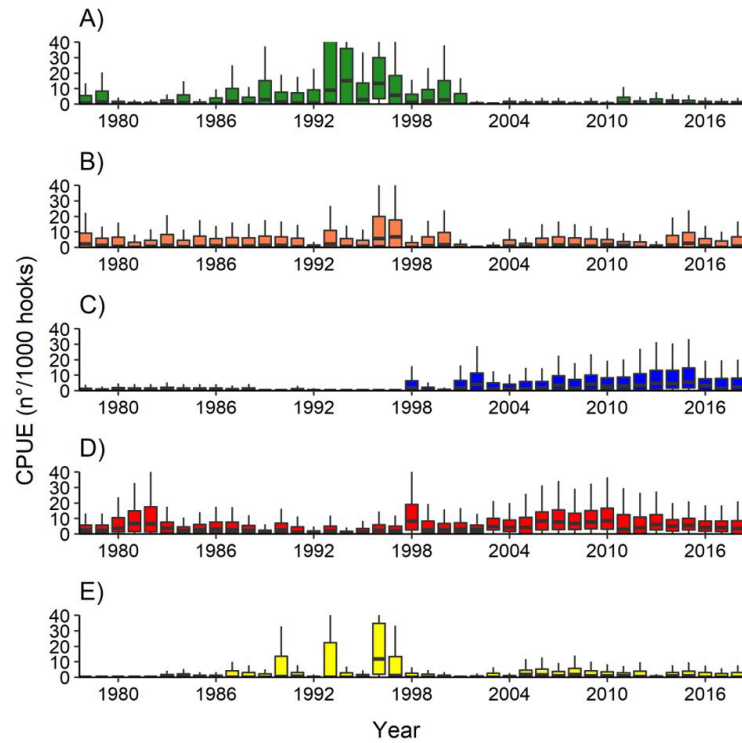
Figure 3. Catches per Unit Effort (CPUE) (number of specimens/1,000 hooks) of albacore (A), bigeye (B), blue shark (C), swordfish (D) and yellowfin (E) registered in BNDA, between 1978 and 2018. In the boxplots the middle lines represent the median, the box the quartiles, the whiskers the non-outlier range.
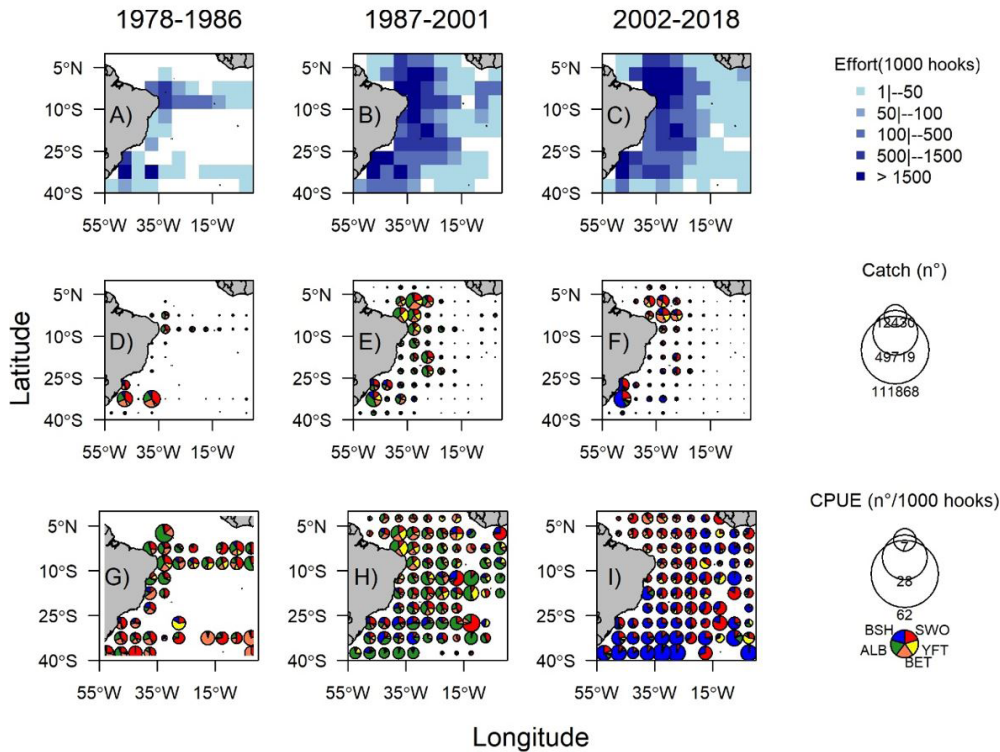
Figure 4. Space-time distribution of the sum of fishing efforts (n. of hooks) (panels A, B and C), catches (n. of specimens) (panels D, E and F) and mean Catch per Unit Effort (number of specimens/1000 hooks) (panels G, H and I) of albacore (ALB), yellowfin (YFT), bigeye (BET), blue shark (BSH) and swordfish (SWO), per period.

Figure 5. Annual variation in target-species indicators per flag recorded for the main tuna and tuna-like species in the Equatorial Atlantic and at West of South Atlantic, between 1978 and 2016. National flag vessels are presented by (A) and Spanish (b), Honduran (C), Japanese (D), Panamanian (E) and China Taipei (F) leased vessels. The analyzed species were swordfish (red), yellowfin (yellow), bigeye (coral), albacore (green) and blue shark (blue).

the main caught species with the mean target-species indicator of $D_{k^b} = 0.33$ and $D_{k^b} = 0.23$, respectively. Between 1999 and 2018 the swordfish and blue shark were the main caught species, with mean indicators of $D_{k^b} = 0.05$ and $D_{k^b} = 0.21$, respectively.

Spanish leased vessels presented two phases (Figure 5B). Between 1996 and 2002, there was targeting to catch species belonging to genus *Thunnus*, with mean $D_{k^b} = 0.27$. The second phase, between 2003 and 2012, was the time when swordfish became the species recording the highest mean value for the target-species indicator ($D_{k^b} = 0.13$), and it was followed by blue shark ($D_{k^b} = 0.08$). The relative importance of swordfish in this second phase lost relevance throughout the years, whereas the importance of blue shark increased and the target-species indicators for this species exceeded that recorded for swordfish in 2011 and 2012.

Honduran leased vessels also showed two different phases (Figure 5C). Initially (1996 to 2001), there was targeting to *Thunnus* sp. and, next, in the second phase (2002 to 2009), to

swordfish (mean $D_{k^b} = 0.12$) and to blue shark (mean $D_{k^b} = 0.11$). The Japanese flag recorded two different phases (Figure 5D). The first phase, from 1978 to 1987, with high target-species indicator for swordfish ($D_{k^b} = 0.15$); the second phase (from 1988 to 1994) recorded the main targeting for species belonging to genus *Thunnus*, mainly for albacore (mean $D_{k^b} = 0.18$). From 1994 on, there were wide gaps due to changes in the renting policies applied to the Japanese flags. However, in 2011 and 2012, it was possible observing the last opportunity to register operations by Japanese leased vessels; once more, it was possible observing the pattern found between 1988 and 1994, by targeting *Thunnus* sp.

There were two different phases recorded for Panamanian leased vessels (Figure 5E). The first phase took place between 1998 and 2002 when swordfish presented the highest targeting values $(D_{k^b} \sim 0.30)$. From 2003 to 2007, swordfish stopped being the main registered species and was replaced by yellowfin ($D_{k^b} \sim 0.23$). Finally, China Taipei leased vessels recorded high
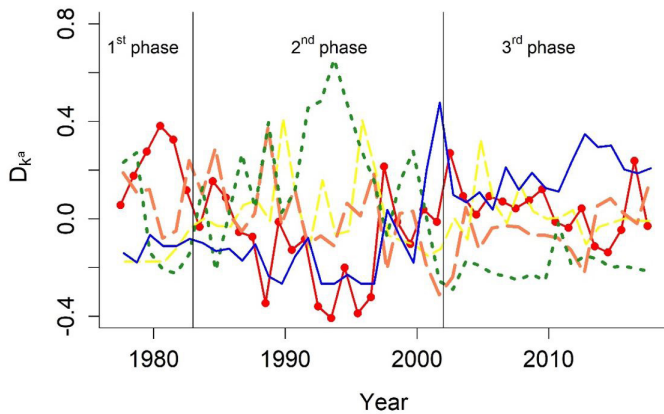
Figure 6. Annual variation in target-species indicators for the main tuna and tuna-like species caught in Equatorial Atlantic and at the West of South Atlantic, between 1978 and 2018. Acronyms: Swordfish (red), yellowfin (yellow), bigeye (coral), albacore (green) and blue shark (blue).

targeting values for albacore ($D_{k^b} \sim 0.24$) between 1990 and 1995; there was no clear pattern after this period (Figure 5F).

The overall action of the Brazilian pelagic longline fleet, added with leased and national vessels, could be divided into three different phases, based on the calculated target-species indicators (Figure 6). The first phase took place between 1978 and 1981 when swordfish was the main target-species (with the mean target-species indicator of $D_{k^a} = 0.30$). From this period on, one finds the second phase (1982 to 2001), when yellowfin gained importance, mainly of albacore with mean of $D_{k^a} = 0.17$, and the interest in swordfish decreased. The last phase, from 2002 to 2018, showed a great interest in blue shark (with mean of $D_{k^a} = 0.19$),swordfish regained its high indicators (with mean of $D_{k^a} = 0.04$) and the interest in albacore decreased (with mean of $D_{k^a} = -0.20$).

DISCUSSION

The present analysis revealed the complex background of the pelagic longline fishery carried out by the Brazilian tuna-fishery fleet, which encompasses a mosaic of vessels from different origins. Besides of its heterogeneous fleet, there are switches in the periods of actions adopted by vessels from different flags and in the target-species of each one of these flags. The action of different flag vessels and reports on variations in target-species and catch technologies have been recorded over time (Meneses de Lima et al., 2000; Guimarães-Silva and Andrade, 2014; Barreto et al., 2016). Results found in these studies point out (in numbers) all phases and targeting intensities recorded for each species.

According to data analyzed in BNDA, it is clear that flag origin influences the vessel's target-species and action area. This profile can change throughout the years due to economic, technological and biological factors. Between 1978 and the mid-1990s, most catches reported to BNDA were limited to national flags and to Japanese leased flags, which have concentrated their catches in oceanic areas close to Northeastern and Southern Brazil.

After the creation of the Fishery Department by the Ministry of Agriculture, Livestock and Supply in 1998 and of the Special Secretariat for Aquaculture and Fishery in 2003, a new national scenario emerged. It was marked by fiscal incentives and enhancement programs, such as licenses, permissions and authorizations focused on the fishery sector (Dias-Neto, 2010, Ruffino, 2016). This new scenario contributed to raising the number of leasing and vessels in the early 2000s, which led to production peaks of all assessed species and the expansion of fishery areas since incentives such as investment in equipment and new catch technologies were granted to fishery vessels in order to explore marine resources. This policy made it possible to explore new fishery areas and increase fish production.

The replacement of the traditional longline by the monofilament longline technique, from 1994 on, was another important factor to increase swordfish catches, as well as the use of lightsticks in national vessels. These changes have contributed to the position acquired by swordfish as one of the main fishery target-species in South Atlantic. This technique is advocated by many researchers, among them by García-Cortés et al. (2010), who stated that swordfish's catchability is much more efficient under monofilament longline than under multifilament. Published experimental data reinforce the importance of monofilament longline to broaden the catch of swordfish. According to Ortiz et al. (2010), this fishing gear improves efficiency by approximately 1.4% and 2.4% in comparison to traditional trawlers, although Mejuto et al. (2011) have reported values close to 1.7%.

Besides changes in the fishing gear, the fishing strategy was changed by alterations in operation times and by the use of squid as bait (Arfelli, 1996). In the past, setting and retrieving the longline were carried out at day light; after the introduction of the American longline, with a hydraulic pump, the setting started being done at noon and retrieving at night (Barreto et al., 2017). This strategy allowed improving the efficiency of swordfish catch since this species stays in deeper waters during the day and swims to upper layers at night (Mejuto et al., 2011). This vertical pattern was observed by fishing masters and fishers, it influenced the herein observed catch level, CPUE and the targeting for the species.

From 2012 on, due to the exit of Spanish leased vessels, blue shark became the species recording the highest catch rates in the Brazilian EEZ and adjacent waters. Such an increase in CPUE values can be related to the market expansion observed since the 1990s, mainly in Brazil, which is one of the biggest shark meat consumers in the world (FAO, 2015; Barreto et al., 2017). In addition, changes reported in fishing gear and strategy focused on catching swordfish may have contributed to increasing blue shark catch, since there is great species distribution overlap (Guimaraes-Silva and Andrade, 2014). Besides, the mandatory implementation of blue shark catch reports and the prohibition of finning may have contributed to improve this species catch records and to reduce its underreporting (Barreto et al., 2017). Actually, blue shark catch levels recorded in BNDA until the late 1990s were close to zero (0), and it reinforces the hypothesis of catch underreporting throughout this period.

The increased number of leased longlines reported in the literature and observed in the present study was essential to the formation of a national catch history and EEZ occupation (Hazin and Travassos, 2007; Dias-Neto, 2010; Fiedler et al., 2015). However, once the national fleet is not just Brazilian, the Brazilian fleet gets vulnerable to retaliation imposed by the greatest fishing countries, mainly Japan and Spain, due to its high dependence on foreign vessels (Hazin and Travassos, 2007; Dias-Neto, 2010; Ruffino, 2016). In 2002, for example, there was a significant drop, either in effort or in swordfish catch indices in Brazil (Hazin and Travassos, 2007; Hazin and Erzini, 2008), due to the dissatisfaction of the Spanish government with changes in the criterion to define the catch quotas of swordfish imposed by ICCAT and with the increased quotas of it set for the Brazilian catch in Southern (4,086 t) and Northern (200t) Brazil, in 2002 (Hazin and Travassos, 2007). Drops in albacore catch rates were also reported, and they were attributed to the canceling of activities by Asian vessels, mainly of fishing vessels, in the mid-2000s (Hazin and Travassos, 2007).

The constant entering and exit of vessels throughout the time series have influenced the catch and targeting values recorded for the assessed species, mainly because vessels were composed of different gear and focused on different target-species (Barreto et al., 2017; Lira et al., 2017). There were great variations in catch values due to effort, used fishing gear, changes in fishing strategies, variation in action area through time and fishing power and vessel origin.

With respect to CPUE growth pattern throughout time, it does not reflect the increased species biomass but represents the significant enhancement in techniques and the increased catchability coefficient, such as operational variations in fishing strategy and the likely increase in targeting for swordfish and blue shark throughout the years. Accordingly, incorporating these variations to calculations aimed at estimating relative abundance indices is essential to avoid wrong interpretations at the time of stock assessment and, consequently, fishery management.

CONCLUSIONS

Fishing effort and catch were clearly affected by the seasonality of assessed flags during tuna fishing development throughout the time series. They concentrated their operations in the period between 1997 and 2007 and contributed to a significant either the fishing effort or the catch of the herein assessed species. Overall, three different phases were observed in the development of this activity. The first phase (1978-1981) was featured by the prevalence of Japanese vessels, which concentrated 70% of the total fishing effort; swordfish played an important role in a catch during this period. The second phase (1982-2001) was marked by reduced targeting for swordfish and increased target-species indicator for *Thunnus* sp., mainly for albacore. Finally, the third phase (2002-2018) presented the leasing of several vessels, effort increase, and targeting for and catch of swordfish and blue shark. The recorded CPUE result was also observed, and it reflected a mix of factors that have influenced the catchability coefficient and catch of the studied species. Although the assessed database does not compose a census, a sample of longline operations in international waters and under the Brazilian jurisdiction, the recorded results are significant and have great value for the generation of information that can help the management of these organisms.

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