

CPUE AND CATCH TRENDS OF SHARK SPECIES CAUGHT BY BRAZILIAN LONGLINERS IN THE SOUTHWESTERN ATLANTIC OCEAN

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SUMMARY

Although pelagic sharks are caught in a variety of fishing gears in the Atlantic Ocean, pelagic longline fisheries targeting tunas and swordfish account for the majority of their catch. With the widest geographic range among all large sharks, Prionace glauca is the most abundant elasmobranch caught by longline in oceanic areas. It is a common species throughout the Brazilian coast, being frequently caught by the Brazilian longline fishery. Although much less abundant than the blue shark, the shortfin mako, Isurus oxyrinchus, is also a common epipelagic species found in tropical and warm-temperate seas. In the present study, catch and effort data from the Brazilian tuna longline fleet (national and chartered) (53.713 sets), which operates in the western South Atlantic Ocean, from 1980 to 2004 (25 years), were analyzed. Catch per unit of effort, as the number of fish caught per hundred hooks, was used as an indicator of relative abundance. A delta-lognormal GLM analysis was done in order to standardize the CPUE of blue and mako sharks, based on the following factors: year, month, area, target species, moon phase, Sea Surface Temperature (SST), and depth of the fishing ground. A nominal CPUE series was also calculated for the sharks of the genus Carcharhinus (except C. longimanus). Catch and effort data on the bigeye tresher and oceanic whitetip shark, however, proved to be too fragmentary to generate a CPUE series, so only an estimate of total landings was attempted.

RÉSUMÉ

Bien que les requins pélagiques soient capturés par divers engins de pêche dans l'océan Atlantique, les pêcheries palangrières pélagiques ciblant les thonidés et l'espadon réalisent la majorité de leurs captures. Doté de la plus large gamme géographique de tous les grands requins, le Prionace glauca représente l'élastombranch le plus abondant qui est capturé à la palangre dans les zones océaniques. Il s'agit d'une espèce commune dans l'ensemble du littoral brésilien, fréquemment capturée par la pêcherie palangrière brésilienne. Bien que moins abondant que le requin peau bleue, le requin taupe bleu (Isurus oxyrinchus) est également une espèce épipelagique commune que l'on rencontre dans les mers tropicales et tempérées. La présente étude analyse les données de prise et d'effort de la flottille palangrière thonière du Brésil (nationale et affrétée) (53.713 opérations), qui opérait dans l'océan Atlantique Sud-Ouest, de 1980 à 2004 (25 ans). On a utilisé la capture par unité d'effort, étant le nombre de poissons capturés pour cent hameçons, afin d'indiquer l'abondance relative. Une analyse GLM delta-lognormal a été réalisée afin de standardiser la CPUE du requin peau bleue et du requin taupe bleu, basée sur les facteurs suivants : année, mois, zone, espèce-cible, phase lunaire, température de surface de la mer et profondeur de la zone de pêche. Une série de CPUE nominale a également été calculée pour les requins du genre Carcharhinus (sauf le C. longimanus). Toutefois, les données de prise et d'effort du renard à gros yeux et du requin océanique se sont avérées trop fragmentaires pour créer une série de CPUE ; c'est pourquoi on a seulement tenté de réaliser une estimation des débarquements totaux.

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RESUMEN

Aunque los tiburones pelágicos se capturan con una gran variedad de artes de pesca en el océano Atlántico, las pesquerías palangreras pelágicas que dirigen su actividad a los túnidos y pez espada responden de la mayor parte de sus capturas. La tintorera (*Prionace glauca*), que tiene la distribución geográfica más amplia de los grandes tiburones, es el elasmobranquio más capturado por el palangre en zonas oceánicas. Es una especie común por toda la extensión de la costa brasileña, y es frecuentemente capturado por la pesquería palangrera brasileña. Aunque mucho menos abundante que la tintorera, el marrajo dientuso (*Isurus oxyrinchus*) es también una especie epipelágica que se encuentra comúnmente en aguas tropicales templadas. En ese estudio, se analizaron los datos de captura y esfuerzo de la flota palangrera atunera brasileña (nacional y fletada) (53.713 calados), que opera en el océano Atlántico suroccidental desde 1980 hasta 2004 (25 años). La captura por unidad de esfuerzo, como el número de ejemplares capturados por cien anzuelos, se utilizó como un indicador de la abundancia relativa. Se llevó a cabo un análisis GLM delta lognormal para estandarizar la CPUE de tintorera y marrajo, basándose en los siguientes factores: año, mes, zona, especie objetivo, fase de la luna, temperatura de la superficie del mar (SST) y profundidad de la zona de pesca. También se calculó la CPUE nominal para los tiburones del género *Carcharhinus* (excepto *C. longimanus*). Sin embargo, se observó que los datos de captura y esfuerzo del zorro ojón y del tiburón oceánico eran muy fragmentarios para generar una serie de CPUE, por lo que sólo se intentó realizar una estimación de los desembarques totales.

KEYWORDS

Sharks, by-catch, GLM, CPUE standardization, abundance

1. Introduction

Although pelagic sharks are caught in a variety of fishing gears in the Atlantic Ocean, pelagic longline fisheries targeting tunas and swordfish account for the majority of their catch (ICCAT, 2005). Being either caught as by-catch or directly targeted. Shark landings are increasing worldwide. Due to their peculiar biological characteristics, though, their stocks, not only of sharks but of elasmobranchs in general, are less resilient than those of teleost species. Concerns on the impact of fisheries on shark populations have motivated FAO to adopt the International Plan of Action for the Conservation and Management of Sharks. In 2004, for the first time in its history, ICCAT carried out an exercise of stock assessment of Atlantic blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*), whilst in the following year it decided to address shark issues, in the context of the fisheries managed by the Commission, under a specific group. The main problem faced by the stock assessment exercise carried out in 2004 was, by far, the lack of accurate data. Although a significant improvement on the submission of catch and effort data on shark species has been noticed in ICCAT, great deficiencies still remain.

The blue shark, *Prionace glauca*, is a pelagic oceanic species, with a worldwide distribution in temperate and tropical waters. With the widest geographic range among all large sharks, it is the most abundant elasmobranch caught by longline in oceanic areas. It is a common species throughout the Brazilian coast, being frequently caught by the longline fishery for tunas and swordfish. Due to its relatively high abundance, it has been well studied, with a considerable amount of information being available on its biology from the South Atlantic Ocean (Amorim, 1992; Lessa *et al.*, 2004; Hazin, 1991; Hazin *et al.*, 1990; Hazin *et al.*, 1994a, b, c; Hazin *et al.*, 1998; Hazin *et al.*, 2000). Although much less abundant than the blue shark, the shortfin mako, *Isurus oxyrinchus*, is also a common epipelagic species found in tropical and warm-temperate seas (Compagno 1984). In spite of its relatively low catches, because of its high commercial value, together with the blue shark, it is one of the best recorded shark species in commercial operations (Clarke *et al.*, 2004). Previous work (Hazin and Lessa, 2005) has shown that along the Brazilian coast both species have a trend of increasing abundance with latitude. The main species included in the genus *Carcharhinus*, the night shark, *C. signatus*, is also relatively well studied (Menni *et al.*, 1995; Hazin *et al.*, 1998; Hazin *et al.*, 2000b; Santana and Lessa, 2000). Both biological information as well as catch and effort data on the oceanic whitetip, *C. longimanus*, and the bigeye tresher, *Alopias superciliosus*, however, are much scantier.

Recently, clustering methods (*e.g.* cluster analysis) have been applied in the analysis of fishing data, aiming at categorizing fishing efforts based on the proportion of the several species in the catches, as a way to detect changes in fishing tactics, in various fisheries (He *et al.*, 1997; Ward *et al.*, 1996; Wu and Yeh, 2001; Alemany and Alvarez, 2003; Hazin *et al.*, 2007a; Hazin *et al.*, 2007b; Hazin, 2006). The main advantage of such methods, instead of using the percentage of a single species as an expression of the targeting strategy, rely in the fact that they consider the frequency distribution of all species in each set, thus providing a much more reliable estimation. Hazin *et al.* (2007a) were able to group 62,007 sets of Brazilian tuna longline sets, performed from 1978 to 2005, in six different clusters, according to the catch composition, corresponding to the following target species: C1: yellowfin tuna; C2: albacore; C3: blue shark; C4: swordfish; C5: bigeye tuna; and C6: *Carcharhinus* spp. Based on this exercise, in the present paper, GLM analyses were done in order to standardize the CPUE of blue and mako sharks caught by commercial longliners operating from Brazil. The temporal series considered in the present work, however, was narrower, spanning from 1980 to 2004 (25 years) (53,713 sets). A nominal CPUE series was also calculated for the sharks of the genus *Carcharhinus* (except *C. longimanus*). Catch and effort data on the bigeye treshner and oceanic whitetip shark, however, proved to be too fragmentary to generate a CPUE series, so only an estimate of total landings was attempted.

2. Material and methods

In the present study, catch and effort data from the Brazilian tuna longline fleet (national and chartered) (53,713 sets), which operates in the western South Atlantic Ocean, from 1980 to 2004 (25 years), were analyzed. Catch per unit of effort, as the number of fish caught per hundred hooks, was used as an indicator of relative abundance. The spatial distribution of the fishing effort is shown in **Figure 1**. A delta-lognormal GLM analysis (Gavaris, 1980) was done in order to standardize the CPUE of blue and mako sharks, due to the high percentage of sets with zero catches for both species (61.2% and 89.0%, respectively). The following factors were considered in the analyses: year (25), month (12), area (3), target species (6), moon phase (3), Sea Surface Temperature (SST) (3) and depth of the fishing ground (2). The depth of the fishing ground was obtained from the National Geophysical Data Center (ETOPO5- Earth Topography), from latitude and longitude at the beginning of each set. SST values for each set were obtained from the Physical Oceanography Distributed Active Archive Center, of Jet Propulsion Laboratory/ NASA, Geophysical Fluid Dynamics Lab/ Ocean data IRI/ ARCS/ Ocean assimilation, averaged by 1°x1° squares. SST values were grouped in the model as lower than 20°C, from 20° to 25°C, and greater than 25°C. The depth of the fishing ground was separated into shallower and deeper than 3,500m. The fishing ground, extending from 7°N to 50°S, was divided into 3 areas: from 7°N to 8°S, from 8°S to 23°S, and to the south of that latitude (**Figure 1**). Moon phases were classed into 3: full, new or quarters (first and last). The target species was defined by cluster analysis (Hazin *et al.*, 2007a), as follows: C1: yellowfin tuna; C2: albacore; C3: blue shark; C4: swordfish; C5: bigeye tuna; and C6: *Carcharhinus* spp.

For both species, a binomial error distribution was assumed for the proportion of positive sets, and a Gaussian error distribution for the positive catches. A stepwise approach was initially used to identify the variables with a significant influence in the CPUE. Since all variables were considered significant, only those representing more than 1% of the deviance were included in the final model. The distribution of residuals was used to verify the assumption of the lognormal distribution of the positive catches. The diagnostic plots described by Ortiz and Arocha (2004) were run to evaluate the fitness of the models. Deviance analysis tables for the proportion of positive observations and for the positive catch rates were provided for both species. For the nominal CPUE series, 2005 data were also included. Although the monthly distribution of data showed a relatively small variation, there was a clear concentration of sets in recent years, particularly after 1998 (**Figure 2**). The total landings of both species were also estimated for the most recent 6 years (2000 to 2005). Although data on shark landings separated by species are available since 1996, they became significantly more accurate in recent years, so the earlier data were not considered. Nominal CPUE series for Natal-RN and Santos-SP, based only on Brazilian vessels (chartered vessels excluded), from Hazin and Lessa (2005), were also included in the figure in order to facilitate comparisons. Besides, the Natal series was updated to 2005.

A nominal CPUE series was also generated for the sharks of the genus *Carcharhinus*, except *C. longimanus*, only for the cluster targeting the group (C- 6) (Hazin *et al.*, 2007c). This strategy was adopted due to the very limited geographic distribution of the night sharks, *C. signatus*, which are largely concentrated over shallow seamounts (Hazin *et al.*, 1998), off northeast coast. Although the group included *C. falciformis*, *C. obscurus*, and *C. plumbeus*, its vast majority (over 90%) was made up by *C. signatus* (Hazin *et al.*, 1990). Due to the more fragmentary catch and effort data on the bigeye treshner and oceanic whitetip shark, it was not possible to generate a CPUE series for them, so only an estimate of total landings was attempted, for recent years (2000 to 2005).

3. Results and discussion

For both positive catches and proportion of positives for blue shark, the main factors explaining the variance were year and cluster, together accounting for about 65% of it, followed by the interactions year: month and year: cluster (**Table 1**). Like for billfishes (Hazin *et al.*, 2007b), the environmental variables, again, seemed to show little influence on blue shark CPUE. The high proportion of the variance explained by the cluster factor indicates that blue shark is often a target species, as shown by the cluster analysis, both in cluster 3, which has the blue shark as the main target (32.0%), as well as cluster 4, which has swordfish as a target species, with a mean proportion of blue shark equal to 8.0%.

Differently from the blue shark, the cluster as an independent factor explained less than 2% of the variance of the positive catches of mako sharks (**Table 2**). This result is similar to those found for white and blue marlins (Hazin *et al.*, 2007b) and, likewise, it is likely the consequence of the fact that they are not targeted at all. The targeting strategy, however, was the main factor explaining the variance in the proportion of positive catches of mako sharks. Again, like for the white marlin, this is probably related to coincidences of habitat use and behavior with some other target species, probably the blue shark, since in the cluster having the blue shark as the main target (C-3), the proportion of mako sharks (3%) was about 3 times higher than the second one (0.8%, in cluster 4) for the species, which, in turn, was also the cluster where the blue shark had its second percentage of occurrence, as discussed in the previous paragraph.

The model showed a good distribution of residuals, both for the blue shark (**Figures 3 and 4**) and for the mako (**Figures 6 and 7**). For both species, the nominal and standardized yearly CPUE also did not differ much during the whole period, although they tended to be slightly lower than the nominal values (**Figures 5 and 8**). Except for 1993, when the blue shark CPUE was abnormally lower, the standardized CPUE for the species showed a remarkably stable trend, ranging roughly from 0.1 to 0.2 fish/ 100 hooks, up to 2000. From that year on, it began an upward move, increasing to values above 0.20. The highest nominal CPUE for the whole series was recorded in 2005 (0.43) (**Figure 5**). This rise of CPUE in recent years coincides with the trend detected for swordfish, based on the same data (Hazin *et al.*, 2006). Since both species are most caught in the same clusters (3 and 4), it is possible that their catchability is being increased by common factors, other than a higher abundance of the species. On the other hand, a possible source of bias could rely on the standardization method used, based on a cluster analyses, as extensively discussed by Hazin *et al.* (2007b). Nevertheless, the similar trends shown by the nominal CPUE series, as well as by the CPUE of other fleets operating in the South Atlantic (Mejuto *et al.*, 2006), seem to suggest that this is not the case. Besides, both standardized as well as nominal CPUE of the mako shark, which also has the highest frequency of occurrence in the clusters 3 and 4, showed an analogous upward swing from 2000 on, suggesting that changes in catchability might be affecting the three species in a similar way. A detailed description of the possible causes for the CPUE variation of Santos and Natal can be found in Hazin and Lessa (2005). The several changes of blue shark CPUE along the years, from both Natal and Santos fleet, seemed to be strongly related to the changes of target species, being relatively stable, though, during the periods of time when the targeting strategy has remained the same. These results suggest that the recent increase in CPUE shown by these 3 species is more likely due to changes in catchability than to a real increase in abundance. The total catch of blue shark has fluctuated in recent years at around 2,000t, whilst those of mako sharks have been at around 250t.

The CPUE of the sharks of the genus *Carcharhinus*, in turn, except for a peak in 1990, has remained relatively stable, at around 0.07 fish/ 100 hooks, throughout the whole period. The total catch, however, has shown a wide fluctuation, ranging from less than 250t to more than 2,500t. Such a wide variation is directly related to the erratic nature of the targeting strategy of the Brazilian tuna longline fleet, aimed at sharks of the genus *Carcharhinus* only sporadically. This also explains why its cluster (C-6), showed the lowest effort among all (about 10% of the highest value, recorded for cluster 1) (Hazin *et al.*, 2007c).

Catches of the thresher shark has been always low, ranging from 46t to 111t, in recent years. The total landings of the oceanic whitetip, in turn, has shown a continuous decline, decreasing 8 times along the past 6 years, from about 640t, in 2000, to 80t, in 2005. Since no CPUE series is available for the species, it is impossible to evaluate if such a decline resulted from a lower abundance or from changes in catchability, related, for instance, to targeting strategies, as previously discussed. It is clear, however, that sharks that represent a minor component of the catches, such as the thresher and the oceanic whitetip, along with many other species, need to have their catches better monitored in order to assure their sustainability. This is particularly true for those species which lack economic importance, such as the crocodile shark, since in their case, the actual amount caught is largely ignored.

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Table 1. Deviance analysis table of explanatory variables in the delta lognormal model for blue shark CPUE for positive catches and for the proportion of positives.

<i>Model factors for positive catches</i>	<i>Df</i>	<i>Deviance</i>	<i>Resid. Df</i>	<i>Resid. Dev</i>	<i>%</i>
Year	24	4560.061	20802	23195.96	34.0
Cluster	5	4121.476	20784	18073.78	30.8
Year: Month	246	1207.917	20531	16765.05	9.0
Year: Cluster	115	971.6408	20416	15793.41	7.3
Area	2	932.9176	20800	22263.04	7.0
Year: Área	48	903.3633	20379	14890.05	6.7
Cluster: Month	55	222.0907	20296	14522.73	1.7

<i>Model factors for the proportion of positives</i>	<i>Df</i>	<i>Deviance</i>	<i>Resid. Df</i>	<i>Resid. Dev</i>	<i>%</i>
Cluster	5	11486.97	11999	26143.17	45.0
Year	24	5267.121	12007	38440.9	20.7
Year: Cluster	120	2682.112	11598	20395.39	10.5
Year: Month	264	2607.238	11718	23077.5	10.2
Year: Area	48	1239.488	11557	19155.9	4.9
Area	2	810.7576	12005	37630.14	3.2
Month	11	305.2229	11988	25837.95	1.2
Cluster: Month	57	234.724	11471	18671.59	1.0
Year: Depth	24	219.4058	11533	18936.49	1.0

Table 2. Deviance analysis table of explanatory variables in the delta lognormal model for mako shark CPUE for positive catches and for the proportion of positives.

<i>Model factors for positive catches</i>	<i>Df</i>	<i>Deviance</i>	<i>Resid. Df</i>	<i>Resid. Dev</i>	<i>%</i>
Year	24	908.1849	5879	3825.293	41.3
Year: Month	264	545.1521	5635	3135.563	24.8
Year: Cluster	120	404.6648	5533	2730.898	18.4
Year: Area	48	112.5179	5499	2618.38	5.1
Month	11	56.73021	5866	3761.092	2.6
Cluster	5	33.32683	5861	3727.765	1.5
SST	2	27.18559	5859	3700.58	1.2

<i>Model factors for the proportion of positives</i>	<i>Df</i>	<i>Deviance</i>	<i>Resid. Df</i>	<i>Resid. Dev</i>	<i>%</i>
Cluster	5	4023.166	11999	14617.62	33.5
Area	2	1946.442	12005	18640.78	16.2
Year	24	1692.993	12007	20587.22	14.1
Year: Cluster	120	1547.138	11598	11438.34	12.9
Year: Month	264	1400.627	11718	12985.48	11.7
Year: Area	48	660.0708	11557	10778.27	5.5
Cluster: Month	55	240.3854	11471	10408.48	2.0
Month	11	200.1517	11988	14417.46	1.7

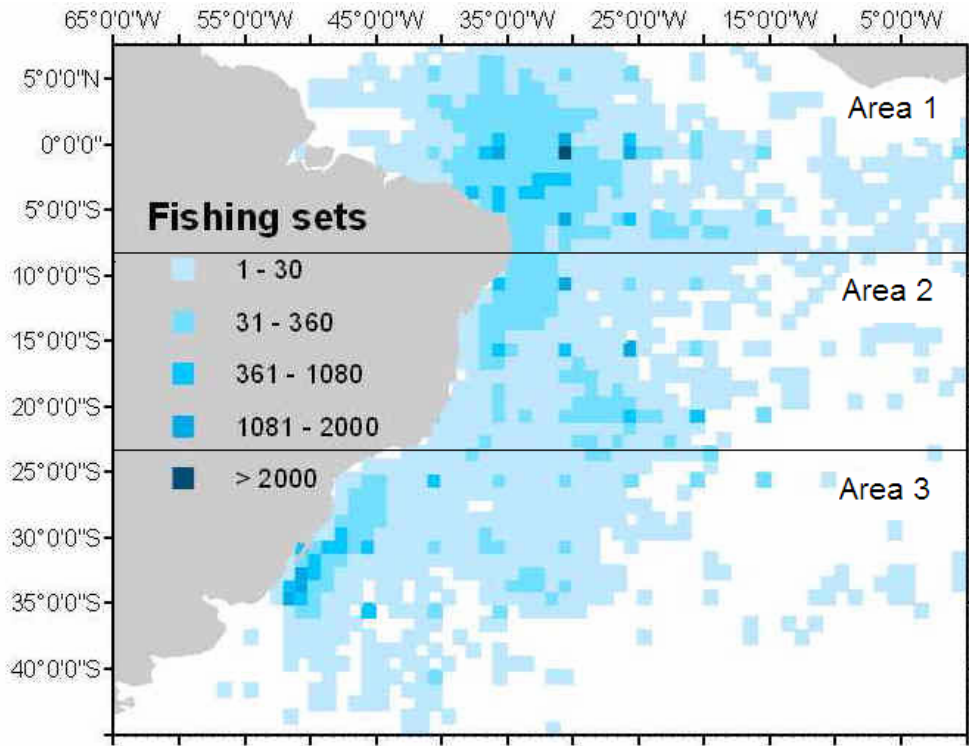


Figure 1. Distribution of the longline sets done by the Brazilian tuna longline fishery in the Atlantic Ocean, from 1980 to 2005.

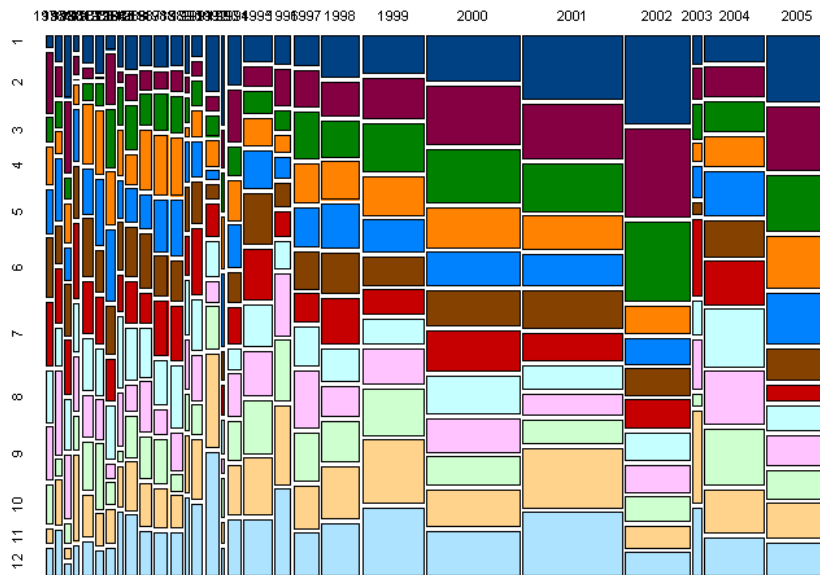


Figure 2. Mosaic-plot distribution of 62,007 longline sets done by Brazilian longliners, by month and year, from 1980 to 2005.

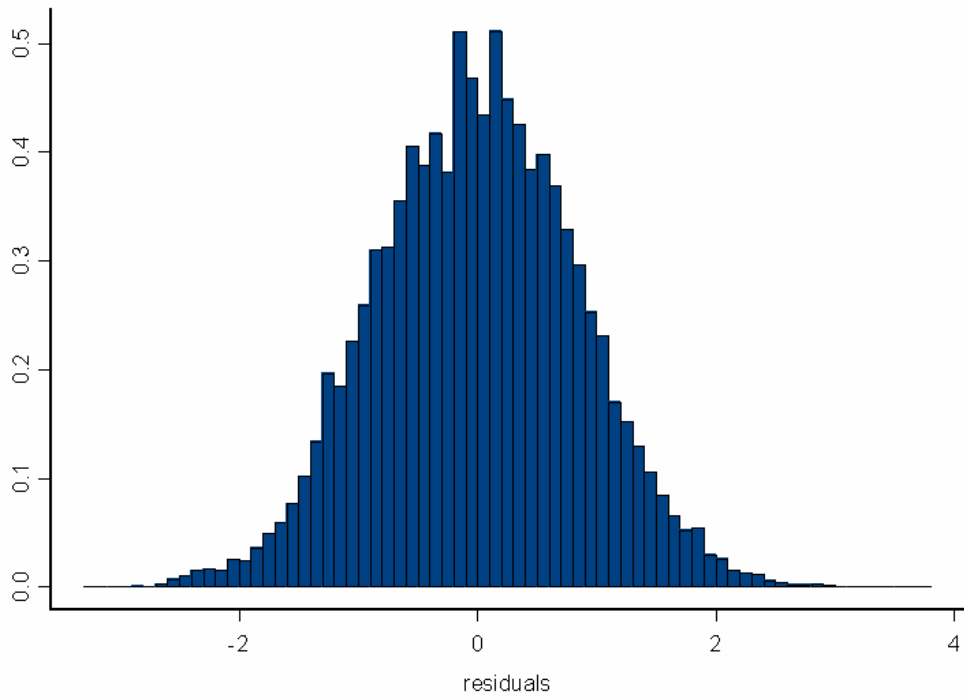


Figure 3. Histogram of residuals for the sets with positive blue shark catches.

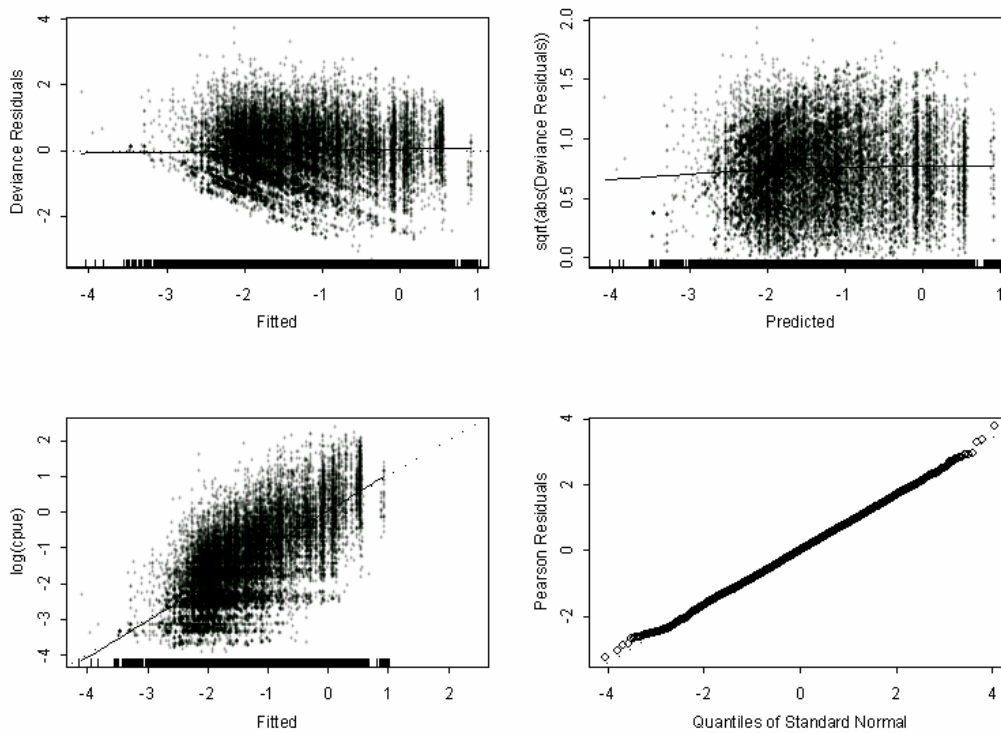


Figure 4. Residual analysis for the sets with positive blue shark catches.

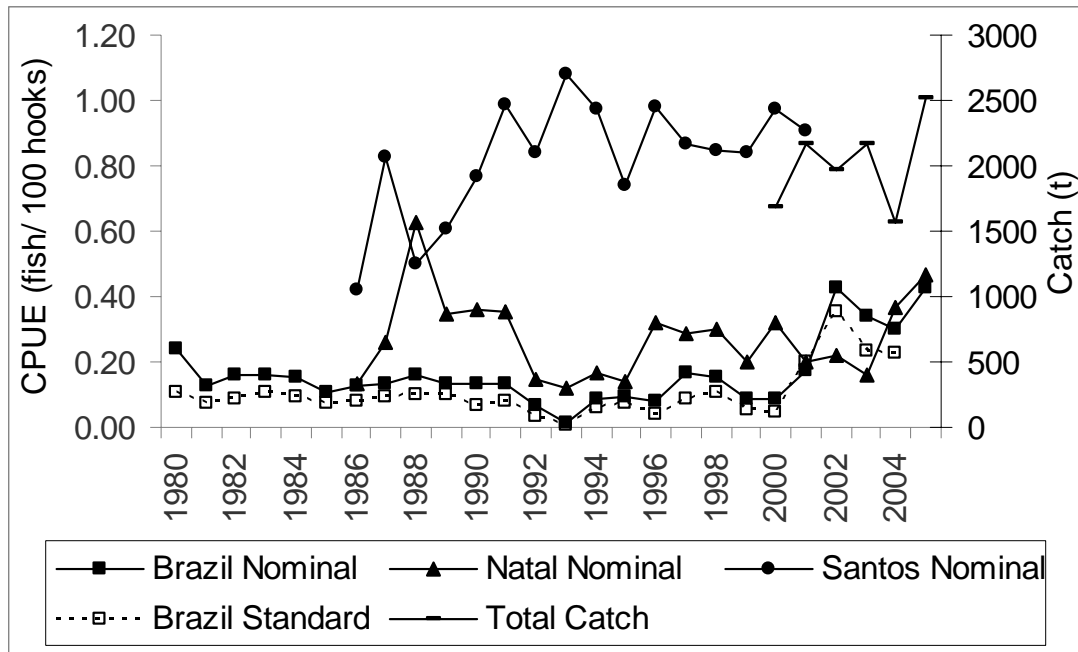


Figure 5. Nominal and standardized CPUE of blue shark for Brazilian tuna longliners, from 1980 to 2005.

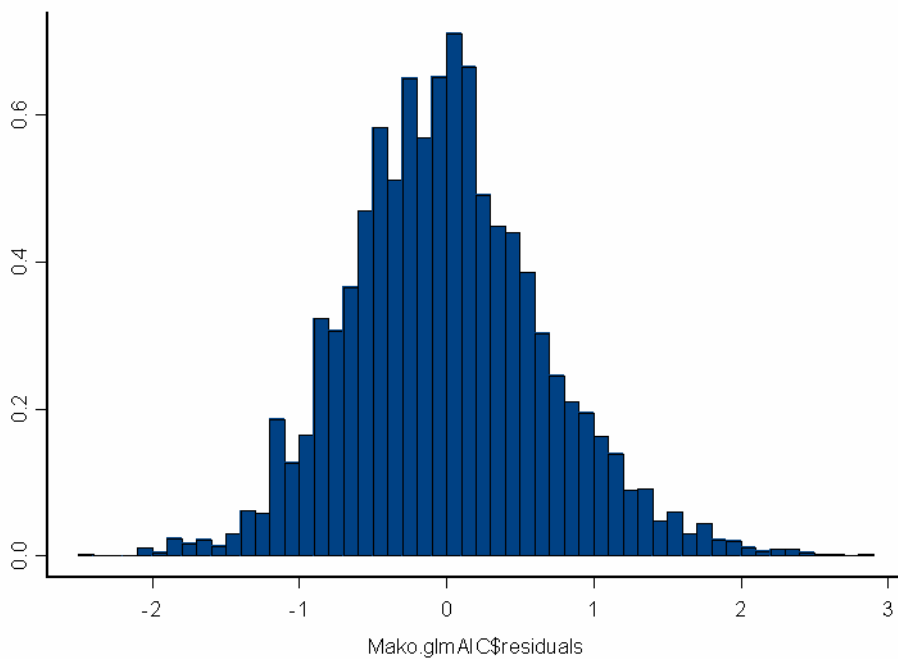


Figure 6. Histogram of residuals for the sets with positive mako shark catches.

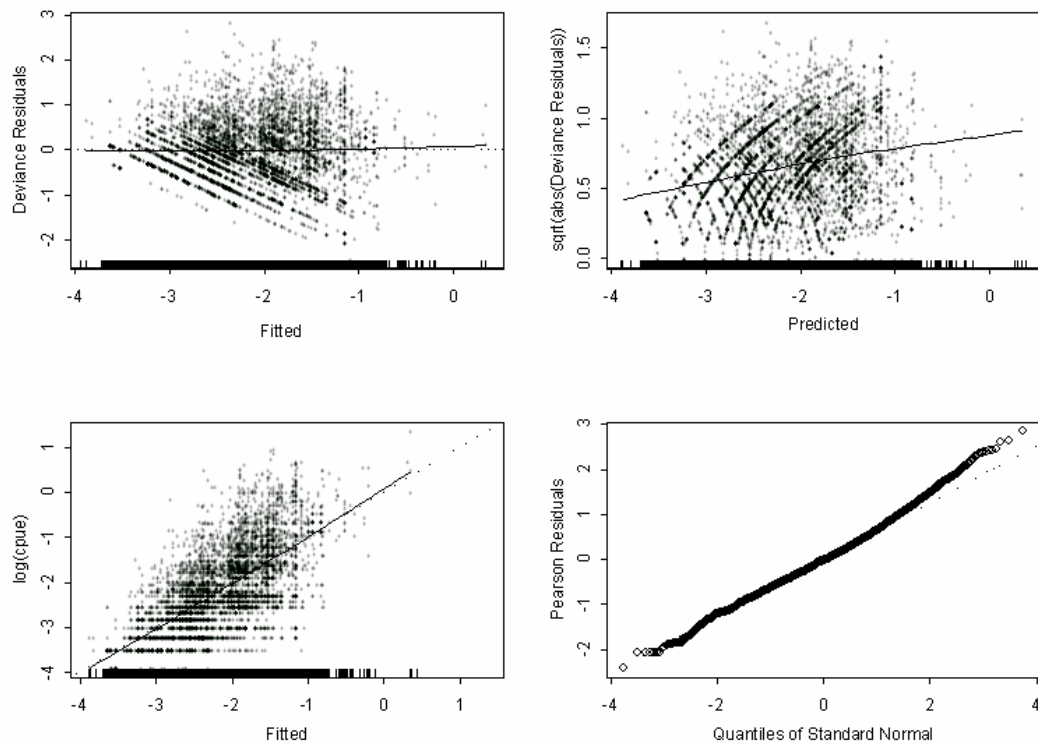


Figure 7. Residual analysis for the sets with positive mako shark catches.

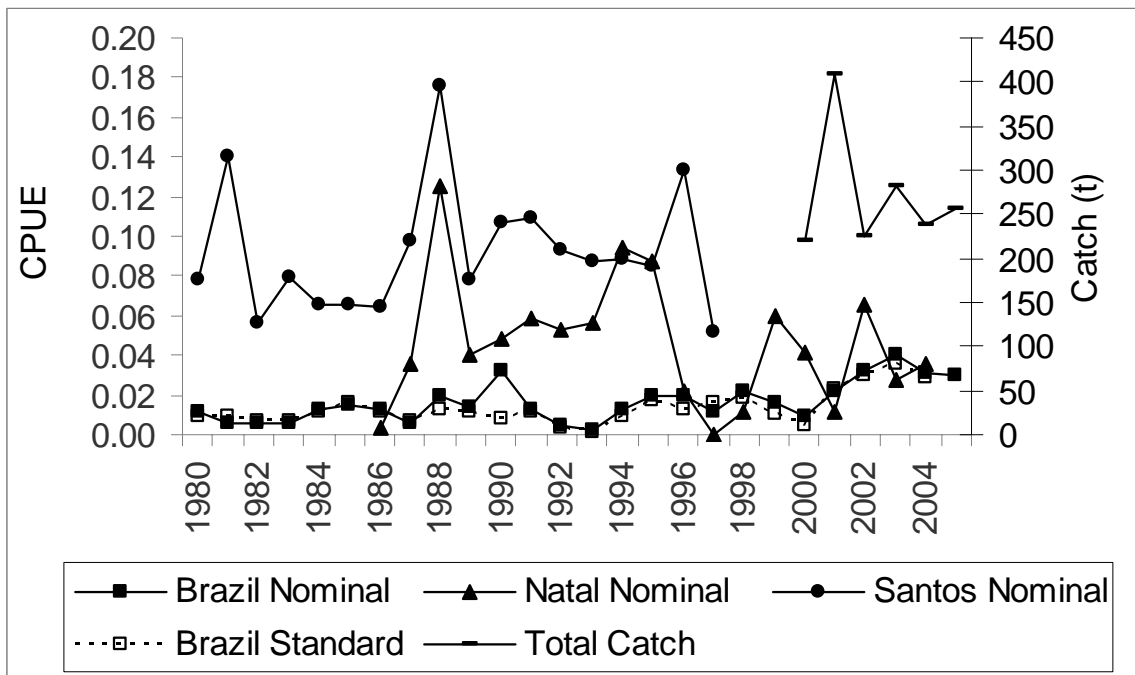


Figure 8. Nominal and standardized CPUE of mako shark for Brazilian tuna longliners, from 1980 to 2005.

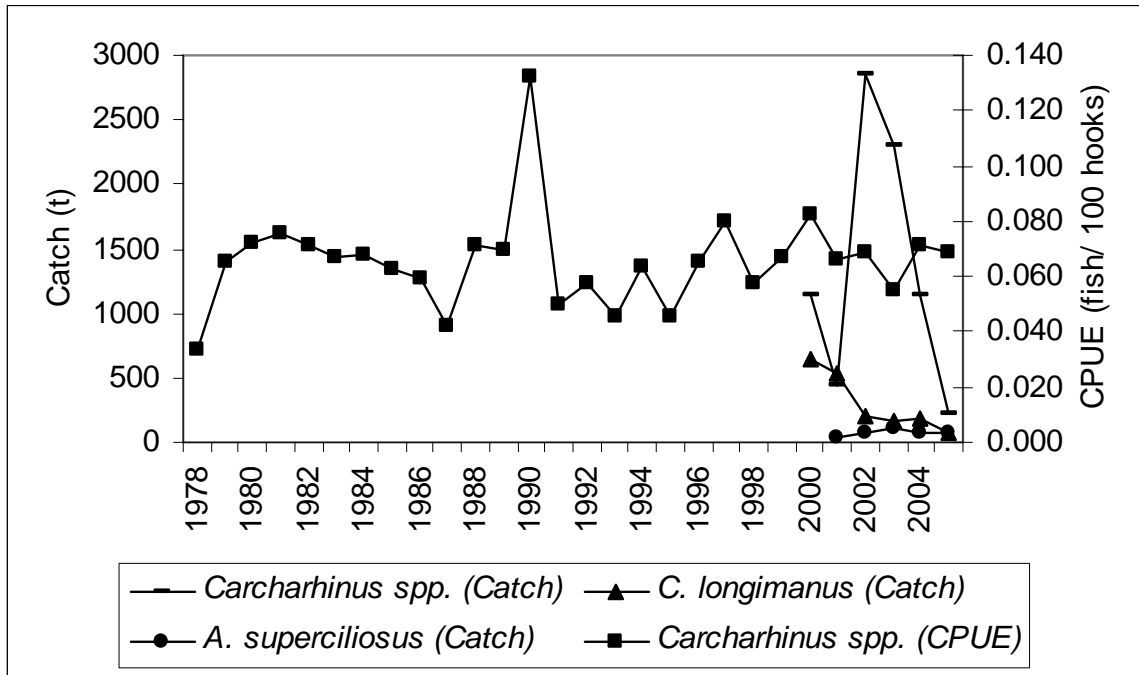


Figure 9. Total catch and nominal CPUE of *Carcharhinus* sharks, except for *C. longimanus*, and total landings of tresher shark and oceanic whitetip shark caught by Brazilian tuna longliners, from 1980 to 2005.