

INFLUENCE OF ENVIRONMENTAL, SPATIAL AND TEMPORAL FACTORS ON BLUE SHARK, *Prionace glauca*, CATCH RATE IN THE SOUTHWESTERN ATLANTIC OCEAN*

Influência dos fatores ambientais, espaciais e temporais sobre a abundância relativa do tubarão-azul, *Prionace glauca*, no Oceano Atlântico Sul-Occidental

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ABSTRACT

A Generalized Additive Model (GAM) was fitted to blue shark, *Prionace glauca* (Linnaeus, 1758), CPUE data (shark numbers per 100 hooks) from tuna longliners based in São Paulo State, Brazil, between 1998 and 2006, with the aim to observe their relationship with environmental, spatial and temporal information. GAM model accounted for 42% of the variance in nominal CPUE. Stepwise GAM revealed the relative importance of eight variables by decreasing magnitude, namely latitude, year, month, longitude, chlorophyll-*a* concentration, sea surface temperature, wind speed and ocean depth. Spatial and temporal factors accounted for 91.5% of the cumulative deviation explained by the model, while environmental factors responded for only 8.5%. The highest blue shark relative abundance was observed between January and June, with a peak in April. It increased southeastward, below 20°C, between 1,500 and 4,000 meters depth. Chlorophyll-*a* showed highest CPUE values between 0.35 and 0.90 mg.m⁻³. Wind speed presented a positive effect on catch rate up to 2 m.s⁻¹, followed by a steep decline. Standardized yearly CPUE trend was stable, with two peaks, one in 2001 and another in 2006. Both were followed by a high variance.

Key words: blue shark, *Prionace glauca*, CPUE, spatio-temporal variation, environmental effects, Generalized Additive Model.

RESUMO

Um modelo aditivo generalizado foi ajustado aos dados de CPUE (número/100 anzóis) do tubarão-azul, *Prionace glauca* (Linnaeus, 1758), capturado pela frota espinheleira de superfície sediada no Estado de São Paulo, entre 1998 e 2006. O objetivo foi analisar a influência relativa dos fatores ambientais e espaço-temporais sobre os rendimentos. O modelo explicou 42% da variância na CPUE nominal. O método passo a passo foi utilizado para a construção do modelo, revelando oito variáveis em ordem decrescente de magnitude, ou seja, latitude, ano, mês, longitude, concentração de clorofila-*a*, temperatura da superfície do mar, velocidade do vento e profundidade do local. Os fatores espaço-temporais foram responsáveis por 91,5% da variância explicada pelo modelo, enquanto que os fatores ambientais responderam por apenas 8,5%. O modelo mostrou que a espécie é mais abundante entre janeiro e junho, com pico em abril e aumentando no sentido sudeste. Os maiores rendimentos foram observados em águas com temperatura de superfície < 20°C e profundidades variando entre 1.500 e 4.000 m. O efeito da clorofila-*a* gerou maiores valores de CPUE entre 0,35 e 0,90 mg/m³, enquanto a velocidade do vento produziu efeito positivo na CPUE até 2 m/s, seguido por um declínio acentuado. A CPUE padronizada exibiu estabilidade, com dois picos, em 2001 e 2006, os quais também exibiram uma maior variância associada.

Palavras-chaves: tubarão-azul, *Prionace glauca*, CPUE, variação espaço-temporal, influência ambiental, Modelo Aditivo Generalizado.

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INTRODUCTION

Blue sharks are often caught by longliners targeting tunas and swordfish along the Brazilian coast. An average annual yield of 5,000 t of different species of sharks is caught by Brazilian longliners, with the blue shark representing approximately 60% (Anonymous, 2005). Due to its high abundance and worldwide distribution, the blue shark has been well studied and a considerable amount of information is already available on its biology for the South Atlantic Ocean (Arfelli *et al.*, 1985; Amorim *et al.*, 1989; Hazin *et al.*, 1990; Amorim, 1992; Hazin *et al.*, 1994a and b; Amorim *et al.*, 1998; Legat, 2001; Azevedo, 2003; Lessa *et al.*, 2004; Montealegre-Quijano, 2007). However, few studies have been conducted, linking commercial catch and effort data with environmental information (*e.g.* Mourato, 2007).

The relationship between the distribution of fishing resources and environmental factors has been addressed by numerous studies, particularly for highly migratory species such as the blue shark, *Prionace glauca* (Sharp, 1978; Bakun, 1983; Laurs *et al.*, 1984; Hazin *et al.*, 1994b; Hinton & Deriso, 1998; Bigelow *et al.*, 1999; Brill & Lutcavage, 2001; Walsh & Kleiber, 2001). This species has a life cycle strongly affected by environmental conditions that influence its availability and vulnerability to fishing gear. Information of the environmental effects on catch rates would greatly facilitate the interpretation of fisheries data, which are used for stock assessment models (Miller, 2007).

The aim of the present paper was to study the influence of spatial, temporal and environmental factors on blue shark catch rates from longliners based in Santos, São Paulo State, Brazil, which operate in the Southwestern Atlantic Ocean. The results hereby obtained might help to assess part of the blue shark stock in the South Atlantic Ocean, allowing the implementation of more adequate management measures for its conservation.

MATERIAL AND METHODS

Catch and effort data

The catch and effort data analyzed in the present paper were obtained from logbooks of tuna

longliners based in São Paulo State, which operated off southeast Brazilian coast. They were available by the “Laboratório de Referência em Controle Estatístico da Produção Pesqueira Marinha” of “Instituto de Pesca/APTA/SAA/SP”, through ProPesq® system (Ávila-da-Silva *et al.*, 1999). A total of 6,445 longline fishing sets from 1998 through 2006 were analyzed (Figure 1). Logbook data included individual records containing the vessel identification, fishing location, longline setting and retrieval time, number of hooks deployed and number of fish caught by species. Data were distributed in 1°x1° squares, considering the initial position of the set by day, month, year, latitude and longitude. Catch rate was expressed using the nominal catch per unit effort (CPUE), as number of blue sharks/100 hooks.

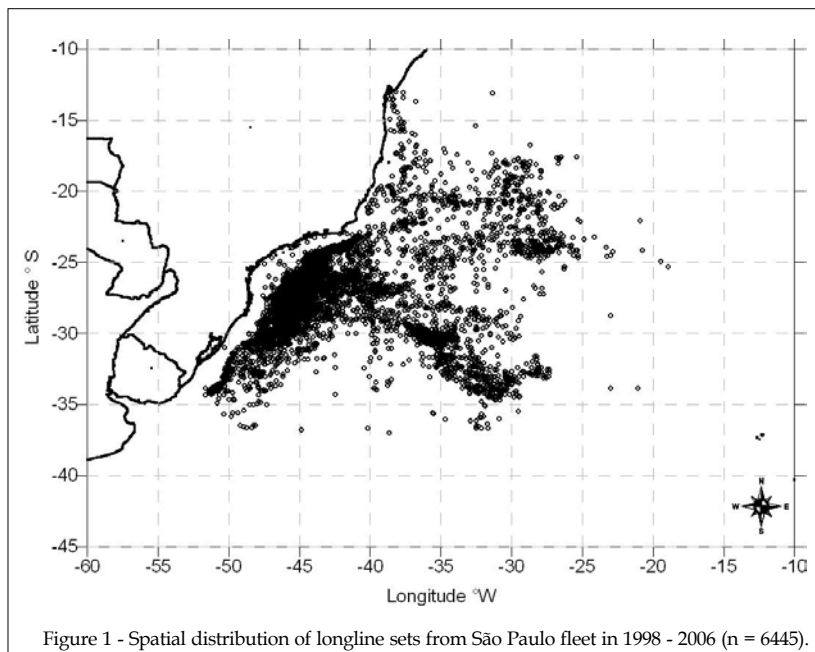


Figure 1 - Spatial distribution of longline sets from São Paulo fleet in 1998 - 2006 (n = 6445).

Environmental data

The environmental variables selected for the analysis were: a) Chlorophyll-a concentration (mg/m³); b) Sea Surface Temperature - SST (°C); c) Wind speed (m/s⁻¹), and d) Ocean depth (m). The temporal series of Chlorophyll-a concentration were obtained from SeaWiFS images, provided by “SeaWiFS Project”, from Goddard Space Flight Center/NASA for the period 1998-2006. These images were turned into numerical data with the GDRA2XYZ program provided by the Phoenix Training Consultants. Sea surface temperature, the zonal and meridional wind components, measured by satellite sensors, were obtained for the entire area, for the same period,

from the Physical Oceanography Distributed Active Archive Center “Jet Propulsion Laboratory” / NASA. Wind speed (m/s^{-1}) estimates were obtained for each fishing location by the equation: wind speed = $\sqrt{[(\text{meridional wind}^2 + \text{zonal wind}^2)}$ (Bigelow *et al.*, 1999). The ocean depth at the location of the longline sets was collected from the National Geophysical Data Center (ETOPO5- Earth Topography 5 min). These data, with an original resolution of $0,5^\circ \times 0,5^\circ$, were used to construct data bases of $1^\circ \times 1^\circ$, by month, year, latitude and longitude, which were then matched with the fisheries data bases. These four environmental variables were selected due their likely functional relevance to blue shark distribution. For example, water temperature determines the rate of metabolic processes, decisively influencing reproduction and feeding migrations, while wind speed can have an effect in the horizontal and vertical disposition of the longline, thus affecting gear catchability (Goñi & Arrizabalaga, 2005; Bigelow *et al.*, 1999 and 2006; Hazin & Erzini, 2008).

Generalized Additive Model (GAM)

The relationships between CPUE and the spatial, temporal and environmental factors are very likely nonlinear (Swartzman *et al.*, 1992; Swartzman *et al.*, 1994; Salthaug & Godø, 2001; Bigelow *et al.*, 1999; Maury *et al.*, 2001). GAMs are nonparametric generalizations of multiple linear regressions, being thus less restrictive in the assumptions about the underlying statistical distribution. Therefore, they differ from more conventional models in that they can easily incorporate complex nonlinear effects from multiple sources (Hastie & Tibshirani, 1990). The nonlinear effects in GAMs are expressed as a smoother function of each variable in the predicted value of interest (Hastie & Tibshirani, 1990), such as the blue shark CPUE. The general formulation of GAM can be expressed as follows:

$$\text{CPUE} = a + \text{year} + s(\text{latitude}) + s(\text{month}) + s(\text{longitude}) + s(\text{chlorophyll-a}) + s(\text{sea surface temperature}) + s(\text{wind speed}) + s(\text{ocean depth}) + e$$

where the response variable CPUE, is the number of blue shark caught per 100 hooks, a is a constant, s is the effect of the smoothing “Spline” function (*natural cubic*) (Cleveland & Delvin, 1988) with 3 df for independent variables and e is the random error derived from the Poisson distribution, with a logarithm link function. The choice of 3 df for each predictor variable to use as a smoothing function was based on visual inspection of smoothing graphs and exploratory analysis. Such approach allows the detection of major effects and reduces

spurious patterns that can arise from overfitting data (Maravelias *et al.*, 2000). All independent variables were numeric, except *year*, which was expressed as a nine-level factor (1998-2006). The selection of variables was evaluated by a stepwise method, with forward entry from null model. The decision on entry or exclusion of the predictors was based on the lower value of Akaike Information Criterion (AIC) (Akaike, 1974) and F -test, with 95% of confidence ($p < 0.05$). The consistency of the final model was evaluated in terms of the pseudocoefficient of determination [pseudo $R^2 = 1 - (\text{residual deviance} / \text{null deviance})$] (Swartzman *et al.*, 1992) and by checking the distribution of residuals (Ortiz & Arocha, 2004). The effects of the various independent variables were, then, depicted by plotting the fitted contribution of each variable to the total deviance, as a *spline* function.

Standardizing CPUE

Assuming that the year effect can reflect changes in annual abundance (Maunder & Punt, 2004), the inter-annual variation of blue shark GAM standardized CPUE was evaluated using the year coefficients back-calculation, through the inverse of the link function, to construct annually standardized CPUE values.

RESULTS

Longline sets per year varied from 261 to 1,149. On the other hand, blue sharks caught per year ranged between 7,615 to 16,707. For the period 1998-2000, blue shark comprised approximately 25% of the total catch, with its importance increasing strongly from 2001 onwards, to an average value of 50%. The percentage of sets that caught at least one blue shark (positive catches) was relatively high, comprising 94% for the overall period (Table I).

Table I - Number of fishing sets, mean number of hooks deployed in each set, blue shark catch (in number), percentage of blue shark in total catch and proportion of positive blue shark catches, from São Paulo longline fleet, in 1998 - 2006.

Year	Gear sets	Hooks/ set	Blue shark catch	% of total catch	Positive catches (%)
1998	1078	1084	11037	23,46	87,76
1999	1149	1067	9446	21,30	89,47
2000	997	1043	11043	29,43	92,18
2001	782	1071	16707	47,27	96,55
2002	547	1120	10497	52,18	95,80
2003	556	1091	8025	49,06	92,81
2004	620	1115	8904	49,46	97,42
2005	455	1114	7615	57,22	99,56
2006	261	1113	11300	57,69	96,93
Total	6445	1083	94574	37,58	93,06

GAM analysis and standardizing CPUE

The fitted model explained 42% (pseudo- $R^2 = 0,42$) of CPUE variability and all candidate predictors were significant (F test, $p < 0,05$), with the minimum AIC value found with the full model. All variables added, caused a decrease in residual deviance. The spatial-temporal factors accounted for 91,5% of cumulative explained deviance by the model. The latitude and year effects were the most important (43,5% and 32,5% of the explained deviance respectively). Among the environmental factors, chlorophyll-a was the most important, accounting for 2,7% of the variability, followed by

sea surface temperature (2,5%), wind speed (2,2%) and ocean depth (1,3%) (Table II).

The residuals distribution for the fitted model showed that the variance remained virtually constant (homocedastic), with the average residuals around zero. It indicates that the fitted model provided a good fit, not being biased (Figure 2).

The 95% confidence intervals of the standardized CPUE series were relatively narrow (Figure 3), considering the high variance usually associated to CPUE series. The overall standardized CPUE pattern indicates a relative stability, with two peaks, in 2001 and 2006, which were also followed by a higher variance.

Table II - Stepwise of the generalized additive model (GAM) fitted to blue shark catch rates. The reduction of residual deviance (Resid.Dev), degrees of freedom (D.f), F-test, associated significance, and AIC (Akaike Information Criterion) statistic are presented for each term.

Model with structure-terms	Resid. Df	Resid. Dev.	D.f	Deviance	F.Value	Pr (F)	Explained deviance (%)	AIC statistic
Null	6444	12816.9	-	-	-	-	-	12818.9
Year	6436	11083.3	8.00	1733.62	120.9	0,000E+00	32.31	11101,3
S (latitude)	6433	8733.6	2.93	2349.64	447.7	0,000E+00	43.78	8757,5
S (month)	6430	8132.6	2.94	601.07	114.1	0,000E+00	11.20	8162.3
S (longitude)	6427	7908.2	2.93	224.31	42.7	0,000E+00	4.18	7943.8
S (chlorophyll-a)	6424	7765.9	2.89	142.26	27.5	0,000E+00	2.65	7807.3
S (sea surf.temp.)	6421	7634.3	2.93	131.70	25.1	8.882E-16	2.45	7681.5
S (wind speed)	6418	7518.3	2.94	115.99	22.0	6.173E-14	2.16	7571.4
S (ocean depth)	6415	7450.5	2.94	67.81	12.9	2.980E-08	1.26	7509.5

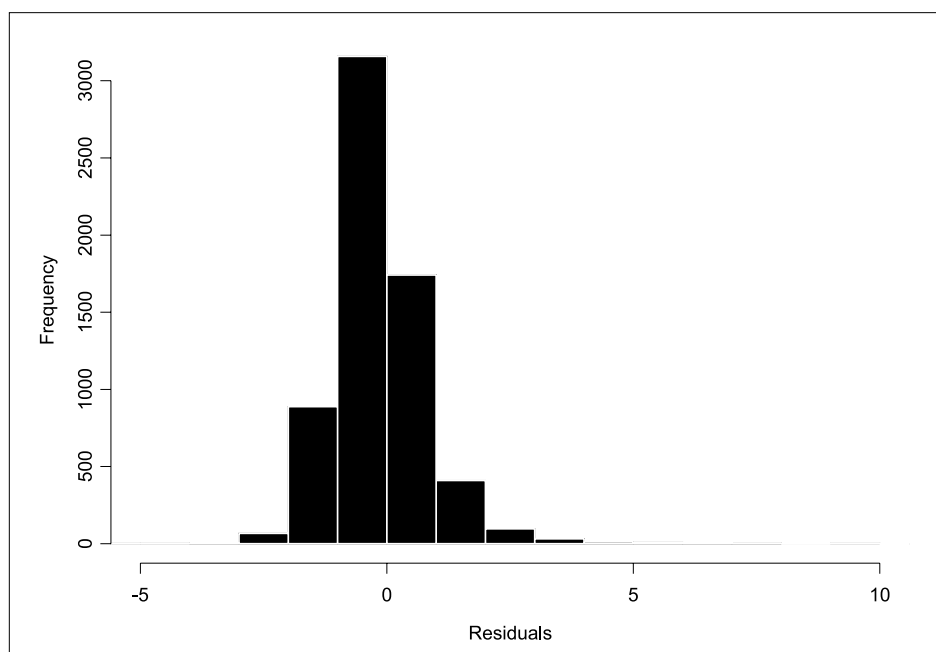


Figure 2 - Frequency distribution of residuals for generalized additive model (GAM) fitted to blue shark catch rates, from São Paulo longline fleet, in 1998 - 2006.

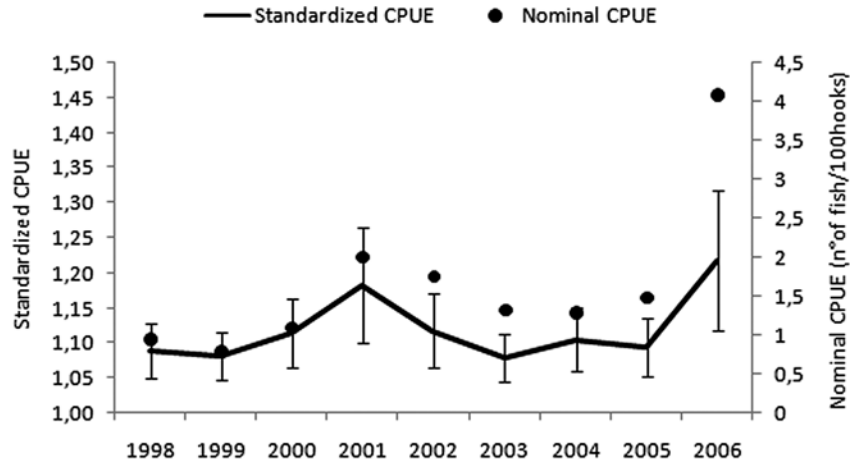


Figure 3 - Yearly standardized CPUE estimated by generalized additive model (GAM) compared with nominal CPUE of blue shark caught by São Paulo longline fleet, in 1998 - 2006. Vertical bars represent the 95% confidence intervals of standardized CPUE estimates.

Effects of predictor variables

The results of the GAM models are shown as plots of the fitted contribution of each predictor variable to the total deviance, as a *spline* function on the parameter of interest, i.e. blue shark CPUE. The 95% confidence bands are also plotted around the best fitting smooths for the main effects. The x-axis shows the density of data points for each predictor variable added in the model. The y-axis reflects the relative importance of each predictor variable of the model.

The month effect on the catch rate of blue shark showed high values from January to June, with a peak in April (Figure 4). The latitude effect showed the highest CPUE values >30°S (Figure 5). With

respect to longitude predictor, the plot suggests that blue shark catch rates increase eastward (Figure 6).

The Chlorophyll-a concentration showed a positive effect on the relative abundance of blue shark until 0,9 mg/m³ and a negative effect onwards (Figure 7). Blue shark catch rate decreased from sea surface temperature (SST) of 16,0 to 23,0°C, remaining stable, in a low level, between 23,0 and 28,5°C (Figure 8). The wind speed effect was positive until 2 m/s⁻¹, becoming negative onwards (Figure 9). Finally, the ocean depth effect on blue shark CPUE was a positive trend from 0 to 1500 m, kept stable between 1500 and 4000 m and became negative from 4000 m onwards (Figure 10).

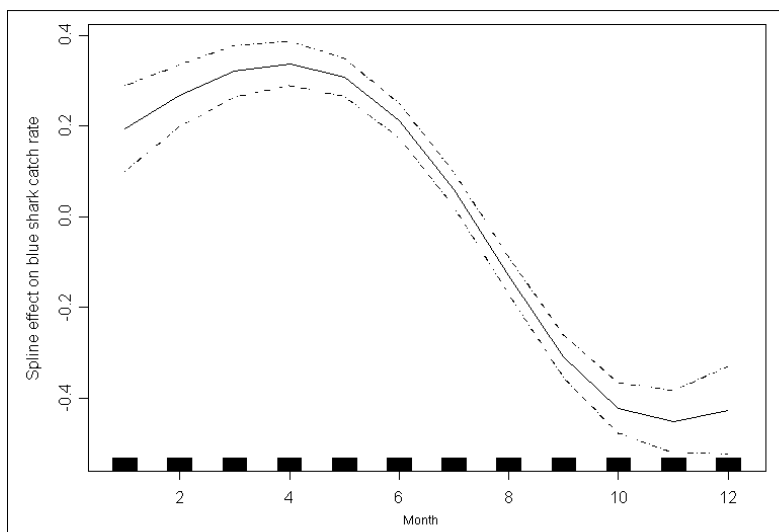


Figure 4 - Generalized additive model (GAM) derived effect of month on blue shark catch rate (n°/100 hooks) from São Paulo longline fleet, in 1998 - 2006. Dashed lines indicate 95% confidence bands and density of data points is shown by the "rug" on x-axis.

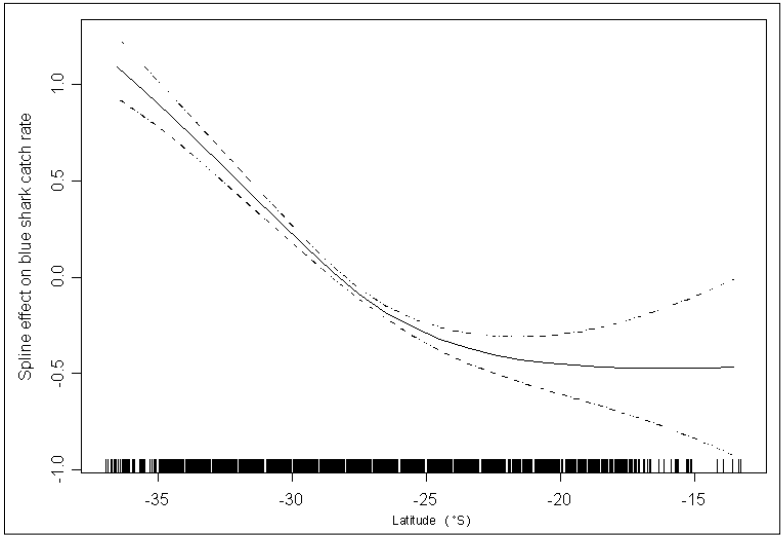


Figure 5 - Generalized additive model (GAM) derived effect of latitude on blue shark catch rate (n°/100 hooks) from São Paulo longline fleet, in 1998 - 2006. Dashed lines indicate 95% confidence bands and density of data points is shown by the "rug" on x-axis.

Figure 6 - Generalized additive model (GAM) derived effect of longitude on blue shark catch rate (n°/100 hooks) from São Paulo longline fleet, in 1998 - 2006. Dashed lines indicate 95% confidence bands and density of data points is shown by the "rug" on x-axis.

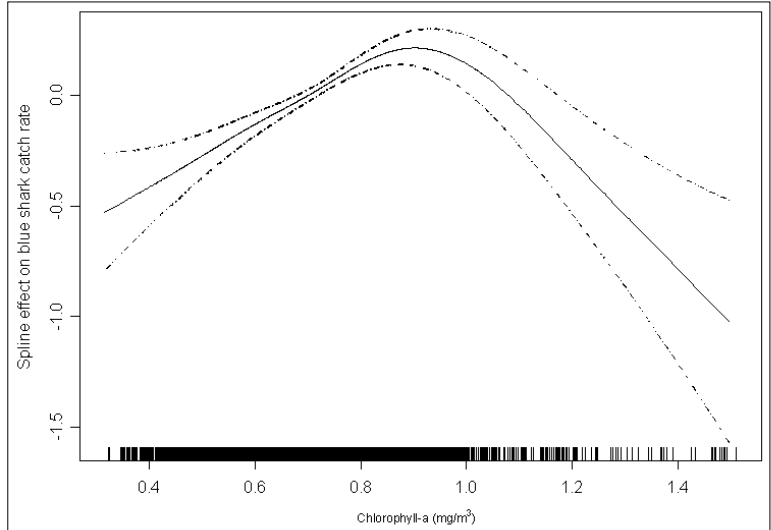
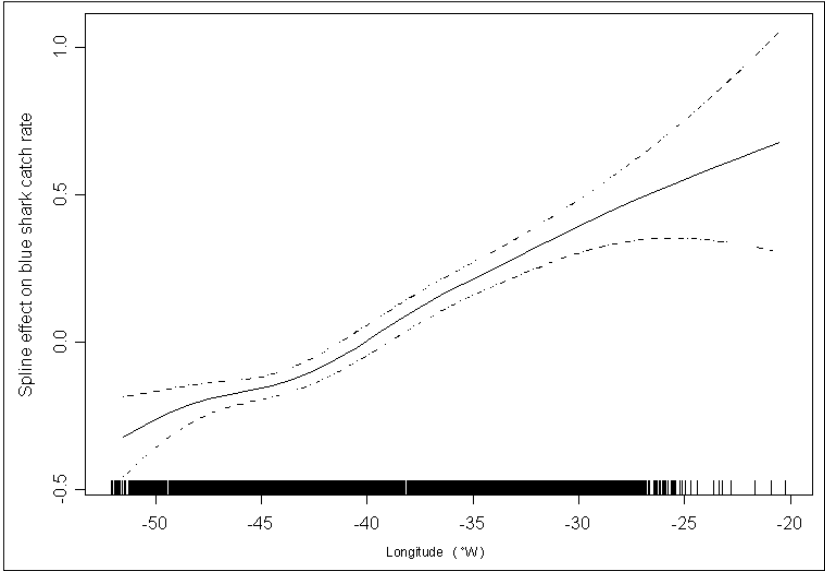


Figure 7 - Generalized additive model (GAM) derived effect of Chlorophyll-a concentration on blue shark catch rate (n°/100 hooks) from São Paulo longline fleet, 1998 - 2006. Dashed lines indicate 95% confidence bands and density of data points is shown by the "rug" on x-axis.

Figure 8 - Generalized additive model (GAM) derived effect of sea surface temperature on blue shark catch rate (n°/100 hooks) from São Paulo longline fleet, in 1998 - 2006. Dashed lines indicate 95% confidence bands and density of data points is shown by the "rug" on x-axis.

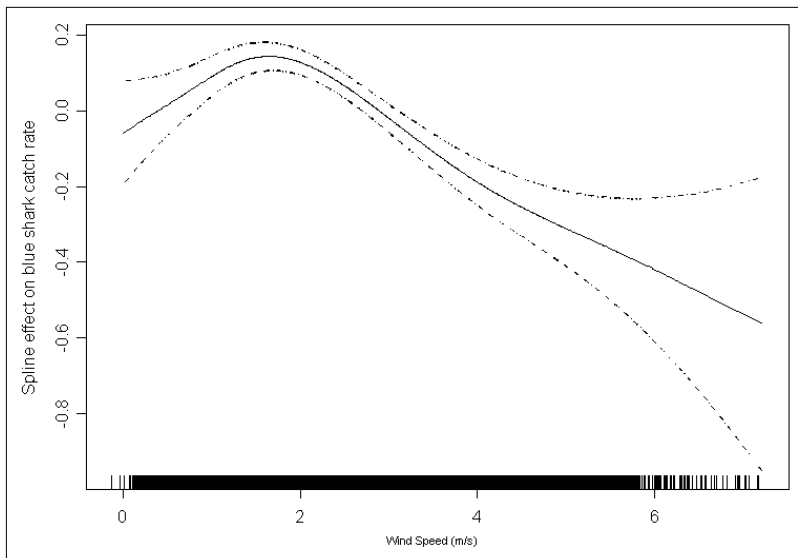
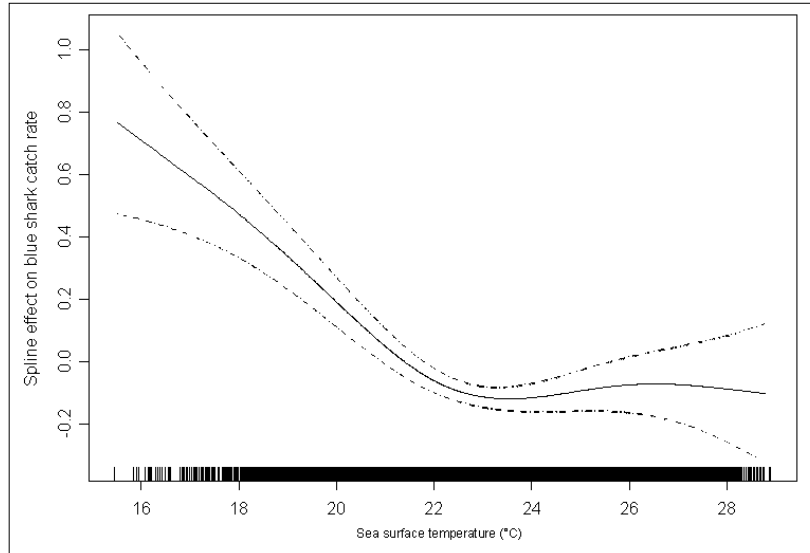
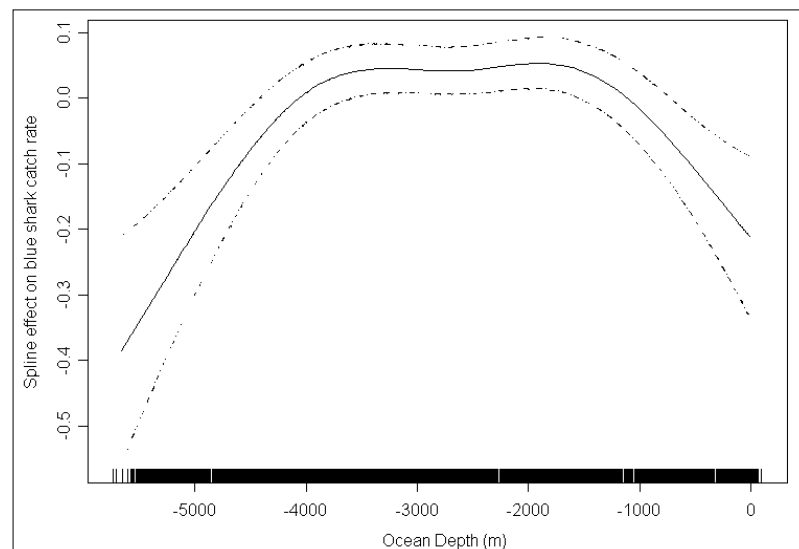


Figure 9 - Generalized additive model (GAM) derived effect of wind speed on blue shark catch rate (n°/100 hooks) from São Paulo longline fleet, in 1998 - 2006. Dashed lines indicate 95% confidence bands and density of data points is shown by the "rug" on x-axis.

Figure 10 - Generalized additive model (GAM) derived effect of ocean depth on blue shark catch rate (n°/100 hooks) from São Paulo longline fleet, in 1998 - 2006. Dashed lines indicate 95% confidence bands and density of data points is shown by the "rug" on x-axis.



DISCUSSION

Blue shark distribution and abundance is known to be affected by several factors, such as availability of prey, marine currents, thermal fronts, latitude, longitude, time of day, season, sea surface temperature, bottom depth, topography, and wind speed (Compagno, 1984; Carey & Scharold, 1990; Hazin *et al.*, 1994b; Bigelow *et al.*, 1999; Walsh & Kleiber, 2001). This paper presents, a new perspective of analysis, examining how environmental, spatial and temporal variables influence blue shark catch rate, by means of a non-linear generalized additive model (GAM).

Standardizing CPUE

Information about temporal changes in the relative abundance of fish stocks is essential to allow a proper assessment of their status, and to adopt management and conservation measures, ensuring the long-term sustainability of the resources. In this case, CPUE has been extensively employed, although their use as an index of relative abundance is criticized by several authors (Ricker, 1975; Fonteneau, 1998; Fréon & Misund, 1999; Maunder & Punt, 2004), because the factors influencing the relationship between CPUE, fishing effort and actual abundance are multiple and commonly not linearly distributed, easily leading to erroneous interpretations (Fonteneau, 1998; Maury *et al.*, 2001).

Blue shark stable CPUE patterns have been documented for longline fisheries in the Atlantic (Hoey *et al.* 2002; Nakano & Clarke, 2005; Liu *et al.* 2005; Mourato *et al.* 2007) and Pacific Oceans (Nakano & Seki, 2003). The present results also showed a similar CPUE pattern in the western South Atlantic, except for the two peaks in 2001 and 2006. Although these peaks can't be properly explained by the present data, it is likely that a combination of factors related to the fishing strategy might be influencing the CPUE, in a way that the GAM was not capable of detecting. Hilborn & Walters (1992) comment that an increase in the fishing power and changes in the targeting strategy of a particular fisheries can mask the real trend of abundance of a given species, creating a false appearance of increase or decrease, when, in fact, such trends might not be actually occurring. Another important point is that the São Paulo longline fleet operates in a rather small area in comparison with the geographical distribution of the species in the South Atlantic Ocean and, therefore, the standardized catch rates generated in the present study must be analyzed carefully, and treated as a regional relative abundance only.

The stable pattern of the blue shark CPUE showed in this paper, combined with results of other analyses in the same area (Nakano & Clarke, 2005; Liu *et al.* 2005; Mourato *et al.* 2007), give support to the conclusions from the last blue shark stock assessment performed by ICCAT (*International Commission for the Conservation of Atlantic Tunas*) which suggested that the current catch levels are below the maximum sustainable yield (MSY) (Anonymous, 2005).

Although the high abundance and wide distribution of blue shark increases the resilience of the species against overfishing, South Atlantic blue shark may be threatened in the near future if all fisheries that catch the species are not effectively monitored and controlled. On the other hand, from an ecosystem approach, the blue shark is an apex predator and as such a key component of tropical and temperate open ocean ecosystems. Hence, increasing fishing pressure on them could affect the food web, throughout trophic interactions. Therefore, different countries that make use of this resource should coordinate measures for its management and monitoring.

Spatial and temporal effects on catch rate

Several studies showed that blue shark abundance is highly seasonal off southern Brazil. Amorim (1992) observed the highest blue shark catches during the period 1983 to 1986, between April and July, with the lowest values occurring from December to April. Kotas *et al.* (1999) also noticed higher CPUE values in June and July, followed by a decline in September and October. Legat (2001) observed, as well, the highest blue shark CPUE values in July and August. Azevedo (2003) found higher blue shark CPUE values in the second and third quarters, between 1997 and 2000, while in 2001 and 2002 the highest values occurred in the first quarter. Our results showed agreement with most of the studies above, with high blue shark abundance occurring in the second and beginning of the third quarter.

With respect to blue shark geographic distribution, Hazin *et al.* (1990) noticed higher CPUE values in the southwestern equatorial Atlantic, mainly to the east of 35°W. Montealegre-Quijano (2007) also mentioned higher blue shark CPUE values in higher latitudes (>30°S), with most catches composed by juveniles and adult males, while female adults were more abundant in lower latitudes (<25°S). In the present study high blue shark CPUE values were observed in high latitudes (>30°S), with the highest southern >35°S (Figure 5), for both sex, but according to Arfelli *et al.* (1985), Amorim *et al.* (1989), Amorim (1992) and Azevedo (2003) males are predominant.

Environmental effects on catch rate

Although the spatial and temporal factors have shown the greatest influence on blue shark CPUE, the environmental effects were also significant. Similar patterns were found in the North Pacific Ocean (Bigelow *et al.*, 1999; Walsh & Kleiber, 2001). The inclusion of environmental variables in the analysis is not an easy task, often resulting in low levels of explanation, because fishing and environmental data are not obtained simultaneously (Sharp *et al.*, 1983; Brill & Lutcavage, 2001). Conversely, many species, in particular the highly migratory ones, have a life cycle strictly related to environmental conditions that affect their availability and vulnerability. The inclusion of environmental variables in the model, therefore, is relevant for an appropriate understanding of the distribution of this shark species in the southwestern Atlantic Ocean.

Several studies describe the correlation between blue shark catches and water temperature. Although blue shark prefers relatively cold waters, between 7°C and 16°C, it tolerates temperatures over 21°C (Compagno, 1984). Casey & Hoenig (1977) reported blue shark catches in the North Atlantic with SST ranging between 12° and 27°C. On the other hand, Vas (1990) noted that CPUE increased with the average annual SST in the eastern North Atlantic. In the North Pacific, recorded the presence of blue shark in areas with SST in the range of 13 - 22°C (Nakano & Nagasawa, 1996) and at 16°C (Bigelow *et al.*, 1999). In Southern Brazil, Kotas *et al.* (1999) reported the highest blue shark CPUE between 21 and 22°C SST. Hazin (1993) showed that the abundance of males in northeastern Brazil tends to decline with increasing temperature, the inverse being true of females. Montealegre-Quijano (2007), found that in the southwestern Atlantic, the CPUE tended to increase with decrease in SST, with females, though, being more abundant in warmer waters (>27°C), while the CPUE of juvenile and males were associated with relatively colder waters (<18°C).

In the present study, the SST effect showed the highest blue shark CPUE values in cold waters, below 20°C (Figure 8), so that its discontinuities might indicate the presence of thermal fronts (Olson & Podestá, 1987). The Subtropical Convergence (SC) is more intense during the second and third quarters (Olson *et al.*, 1988; Garcia, 1997), when lower values of SST and higher values of chlorophyll concentration are observed. The SC resulting from the mixture of tropical waters of the Brazil Current with cold water brought by the Malvinas Current, generates large variations in temperature,

producing instability in the mixture layer (Garcia, 1997). The higher CPUE during the second and third quarter of the year, off southern Brazil, and also in waters of low temperature, might, therefore, indicate an association between blue shark relative abundance and the thermal fronts of the Subtropical Convergence. A higher blue shark CPUE within the SC, however, might not be directly linked to changes in temperature and chlorophyll concentration, but to other biological factors associated with these fronts. The boundaries of water masses present in ocean fronts commonly enhance the nutrient contents in the euphotic zone (Bakun, 1983; Olson & Podestá, 1987), increasing the chlorophyll concentration, which, in turn, results in higher primary and secondary productions, a process that in the SC happens during the second and third quarters (Odebrecht & Garcia, 1997; Montu *et al.*, 1997). Consequently, during this time of the year, there is a likely increase in the amount of potential blue shark prey, such as squids (*Illex argentinus*) (Zavala-Camin, 1987; Vaske & Rincón, 1998) that are abundant in the region (Santos & Haimovici, 2002; Bazzino *et al.*, 2005). Blue shark has an opportunistic feeding behavior and is, thus, commonly attracted to regions with high concentrations of prey. It is possible, therefore, that the peak of blue shark abundance during the second and third quarters of the year, off south and southeast Brazil, be more dependent on the concentration of prey than to changes in thermal and chlorophyll gradients resulting from the SC front.

Despite the preference of blue shark for cold waters, which are usually more eutrophic, the higher band of chlorophyll concentration (>0.9 mg.m⁻³) had a negative effect on the blue shark CPUE. This could be explained by the time needed for the maturation of the water masses, i.e., time required for the energy resulting from higher chlorophyll concentration (primary production) to be transferred to higher trophic levels, up to blue shark preys, such as squid and small pelagic fish. A similar pattern was also observed by Laurs (1983) in the Northwest Pacific, where the highest catches of albacore (*Thunnus alalunga*) were observed in areas with chlorophyll concentration lower than 0.8 mg.m⁻³.

Wind speed may also affect the vertical distribution and vulnerability of blue shark, as well as the behavior of the longline. Carey & Scharold (1990) showed that this species follows a complex pattern of vertical migration, remaining near the surface at night, and carrying out vertical incursions to deep waters during the day. Bigelow *et al.* (1999) observed higher blue shark CPUEs in the North Pacific with high wind velocities and attributed this

to the longer time needed for gear retrieval, which would increase the blue shark vulnerability. Mourato (2007) found higher CPUE values when the soak time of the longline was equal to about 20 h, followed by a sudden drop from this point on. In fact, when the soak time is too long, gear saturation might happen (Engas & Løkkeborg, 1994), due to loss of baits (Shomura, 1955; Ward & Myers, 2007), reduction of their attraction power (Løkkeborg, 1990) and higher possibility of fish escape. These factors might explain the negative effect of high wind speed on blue shark CPUE that has been found in the present work.

Finally, the effect of ocean depth seems to confirm the relationship between blue shark distribution and distance from coast. Hazin *et al.* (1990) also observed its preference for oceanic waters in the Southwestern Equatorial Atlantic Ocean. Bigelow *et al.* (1999) reported a similar pattern in the North Pacific, with the highest values of CPUE of blue shark in areas with depths higher than 3,000 m. Nevertheless, in the western North Atlantic, Aires-da-Silva *et al.* (2008) analyzed fishery-independent longline surveys data and noticed that sets on shallow waters of the upper continental shelf had a strong effect on the blue shark catch rates, which seems inconsistent with the oceanic habitat preferences of this species (Compagno, 1984; Nakano & Seki, 2003).

The present results suggest that the use of commercial longline catch-and-effort data combined with spatio-temporal and environmental information, for the construction of GAM models is a suitable approach in the analysis of factors related to the availability and vulnerability of the blue shark. The GAM model has proved an adequate tool to measure the non-linear effects of variables on CPUE. The results obtained by the present work have also demonstrated the complexity of the correlation between the distribution of blue shark and the environmental factors.

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