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Assessing swordfish distribution in the South Atlantic from spatial predictions

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Abstract

Generalized Regression Analysis and Spatial Prediction (GRASP) was used to map the spatial distribution of swordfish (*Xiphias gladius*) in the South Atlantic. Generalized additive models (GAMs) were used to relate catch to environmental predictor variables. Catch information from 38,000 Brazilian pelagic longline sets from 1980 to 2000 and size frequency data from 5000 longline sets from 1982 to 2000 were obtained from International Commission for the Conservation of Atlantic Tuna (ICCAT). Results highlight the importance of environmental variables for the fishery and for the spatial distribution of different size classes of swordfish (small, intermediate and large). The distribution of swordfish was closely associated with convergence zones (inter-tropical and sub-tropical), especially in the months of greatest convergence intensity. Spatial distribution patterns differed for the three studied size classes. The smallest size classes were found mainly in coastal zones and in areas with a shallow mixed layer (<20 m). In contrast intermediate-sized swordfish were mostly associated with the inter-tropical convergence and mixed layers of more than 20 m depth and large swordfish were often found in the vicinity of the sub-tropical convergence zone and in areas with mixed layers of less than 25 m and greater than 60 m.

Keywords: GAM; GRASP; Spatial distribution; South Atlantic; Swordfish; *Xiphias gladius*

1. Introduction

Given the importance of swordfish (*Xiphias gladius*) in the South Atlantic fishery, their highly migratory nature and significant trans-boundary movements, the International Commission for the Conservation of Atlantic Tuna (ICCAT) recommended measures to ensure a sustainable exploitation (Anon., 2002). To aid conservation and management, the commission recommended to propose baselines in the research on the identification of the main areas of occurrence of different size classes of the species, as well as on the factors influencing the species distribution in the South Atlantic.

Models for spatial prediction of relative abundance are an important tool for a better understanding of the relationships between a given resource and its ecosystem, and serve to establish baselines for conservation and management. Spatial species-environment models have traditionally been used in terrestrial ecosystems (e.g. Ferrier et al., 2002; Lehmann et al., 2002; Zaniewski et al., 2002), with relatively few applications in the marine environment (e.g. Garza-Pérez et al., 2004; Leathwick et al., 2006). This is due in part to the lack of adequate data and the often complex and non-linear relationships between fisheries and environmental variables.

Recently, a new tool for spatial prediction based on statistical models has been developed. GRASP (Generalized Regression Analysis and Spatial Prediction) models statistical relationships between response variables such as species distribution and environmental variables, so, spatial predictions can then be made based on the spatial pattern of the environmental predictor variables (Lehmann et al., 2002). Generalized additive models (GAMs) are used to fit the response variables to the environmental explanatory variables using a non-parametric smoothing function (Hastie and Tibshirani, 1990). Other widely used spatial prediction techniques that estimate surfaces directly in

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geographic space by interpolation are highly data intensive. GRASP, however, accomplishes the same goal in environmental predictor space while requiring fewer data. GRASP is therefore ideally suited to generate spatial predictions from sparsely distributed data, which is often the case for fisheries, especially those of large pelagics with wide distributions and highly migratory behaviour.

In this context, the objective of the present paper is to study the spatial distribution pattern of swordfish catches in the South Atlantic in relation to environmental variables based on swordfish catch per unit effort (CPUE) data and catch size frequency distributions. The results constitute a novel contribution to the management of swordfish resources and may be useful in reducing operational costs in the commercial fishery.

2. Materials and methods

Data regarding the fishery area, nominal effort and catches (in number of fish) were obtained from onboard logbooks of longline vessels stationed in Brazil (national and lease fleet) operating between 10°N and 60°S (Fig. 1). Data were grouped in $1° \times 1°$ quadrants, considering the initial position of the set, by day, month, year, latitude and longitude, from 1980 to 2000.

Data on length frequency (Lower Jaw Fork Length—LJFL in cm) were obtained through the ICCAT *Data Record* on longline fleets directed at *X. gladius*, operating in the above-mentioned area from 1982 to 2000 in $5° \times 5°$ quadrants by month, year, latitude and longitude. A total of 5000 longline sets were available. To determine the horizontal distribution by length, three LJFL classes were established following procedures described by Arocha (1997) and Hazin et al. (2001): (a) <125 cm, immature individuals (or juveniles); (b) 125–170 cm, maturing and/or 50% of individuals having reached size-at-first-maturity (maturing/mature); (c) >170 cm, 100% mature individuals (or adults). Data were transformed into binary information (presence and absence, PA), thereby assuming a binomial distribution.

Environmental variables such as sea surface temperature (SST) and sea surface temperature anomaly (SSA), wind components and anomalies (meridional—WMC and WMCA; zonal—WZC and WZCA), deep mixed layer and anomaly (DML and DMLA) and sea surface height (SSH) and sea surface height anomaly (SSHA) were obtained for the entire study area from the satellite sensors from the Physical Oceanography Distributed Active Archive Center "Jet Propulsion Laboratory"/NASA (1992–2000). The time series used (1980–1991) were complemented using data predicted from modelling, which are available online (Geophysical Fluid Dynamics Lab/ocean data from the IRI/ARCS/Ocean assimilation and Centre ERS d'Archivage et de Traitement (CERSAT) do IFREMER). These data, with an original resolution of $0.5° \times 0.5°$, were used to construct data bases of $1° \times 1°$ and $5° \times 5°$ resolution, by month, year, latitude and longitude, that were then matched with the fisheries data bases. The ocean depth at the location of the longline sets (Bath) was collected from the National Geophysical Data Center (ETOPO5—Earth Topography 5 min). These data, which had an original resolution of $0.5° \times 0.5°$, were aggregated to constitute a base with a resolution of $1° \times 1°$ by day, year, month, latitude and longitude.

These eight environmental variables were selected for their likely functional relevance to variation in the species distributions. For example, water temperature determines the rate of metabolic processes, decisively influencing reproduction and feeding migrations. Other variable (e.g. winds) can be influential in the horizontal and vertical distribution of the longline and this affects the catchability of the gear (Goñi and Arrizabalaga, 2005; Bigelow et al., 1999, 2006). According to Bakun (1996), the utilization of the process indicators (e.g. SSA, SSHA) related to oceanic features (i.e. upwelling areas, gyres, etc.) enhances primary productivity. This is important because *X. gladius* seems to concentrate both in areas where these processes are most intense presenting high densities of plankton and prey, and in areas favorable to the reproduction process (Olson and Backus, 1985).

The spatial prediction of Catch Per Unit Effort (CPUE), calculated as the number of individuals captured by 100 hooks, of *X. gladius* for different size classes as a function of a variety

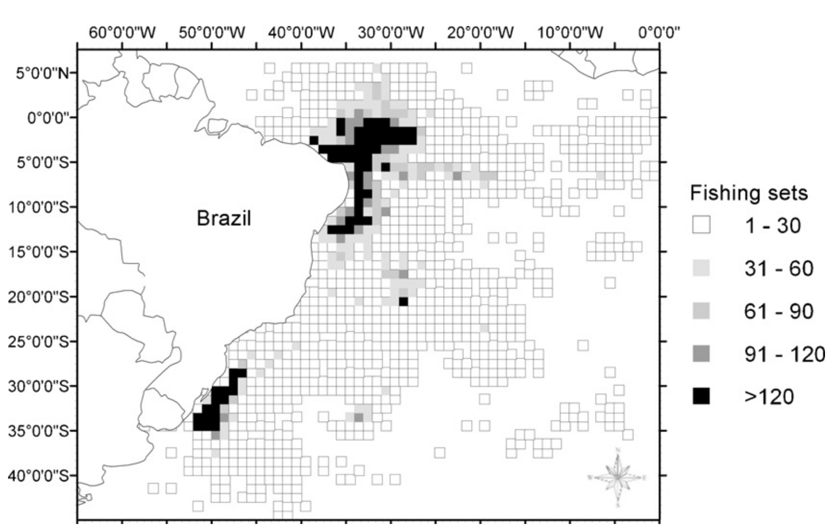

Fig. 1. Distribution of the Brazilian fishery longline sets in the Atlantic Ocean, from 1980 to 2000.

Table 1
Stepwise selected GAM models for the spatial prediction of *X. gladius* and receiver operating characteristic (ROC) values are given for the validation and cross-validation of the final models

Response variable	Final model	Validation	Cross-validation
Model for Brazilian pelagic longline fleet catch data			
ln(CPUE + 0.1)	(Month, 4) + s(Bath, 4) + s(SST, 4) + s(SSHA, 4) + s(DML, 4) + s(WZC, 4) + s(WZC, 4)	0.28	0.30
P/A	s(Month, 4) + s(Bath, 4) + s(SST, 4) + s(SSHA, 4) + s(DML, 4) + s(WZC, 4) + s(WMC, 4)	0.73	0.73
Model for the ICCAT size class data			
Juveniles (P/A)	s(Bath, 4) + (SSA, 4) + s(SST, 4) + s(DML, 4) + s(Month, 4) + s(WZC, 4)	0.77	0.85
Maturing/mature (P/A)	s(Bath, 4) + s(SST, 4) + s(DML, 4) + s(Month, 4)	0.69	0.72
Adult (P/A)	s(Month, 4) + s(Bath, 4) + s(SST, 4) + s(SSHA, 4) + s(DML, 4) + s(WZC, 4) + s(WMC, 4)	0.73	0.77

The 's' is the spline smoother and 4 is the corresponding degrees of freedom. CPUE is catch per unit effort in number of swordfish caught per 100 hooks.

of environmental variables was modelled using GRASP v3.2 (Lehmann et al., 2002)[2]. It produces spatial predictions from Generalised Additive Models (GAMs) fitting the relationships between a response variable, here CPUE or presence/absence (P/A) of swordfish, and selected predictor variables, here environmental site conditions.

In a simplified form, GRASP functions in the following manner:

(1) Two types of databases are separated: (a) the original database of the explanatory variables (e.g. sea surface water temperature) encompassing the entire study area (10°N and 60°S); (b) a sample is removed from the original database—in our case, fishery deployments and length frequencies, with the duly grouped explanatory variables;
(2) GAM is used to analyze the relative influence of various environmental factors (predictive variables, PV) on the nominal CPUE and/or the presence and absence, PA (response variables, RV);
(3) the effect of the RVs is estimated for each quadrant (1° × 1°, in the present paper) based on the PV pattern of the original database using the *predict.gam* function of the GAM library in S-plus;
(4) this tendency is then converted to the ArcGRID format of Arcgis 3.x., thereby elaborating the spatial maps of the RVs as a function of the PVs.

The general formulation of the GAM used in the present study is expressed in the following manner:

$$\text{PA or } \ln(\text{CPUE} + 0.1) = a + s_1(x_1) + s_j(x_j) \ldots + e.$$

where a is a constant, s_1 is the effect of the smoothing function for the independent variable x_1 and e is the random error of the function.

Two types of distributions were used: Poisson (ln(CPUE + 0.1)), with the function link log, for the Brazilian fleet CPUE data and binomial, with the function link logit, for the presence/absence (P/A) data sets. The non-linear effects of the model were adjusted by smoothing "Spline" functions (*natural cubic)*, (Cleveland and Delvin, 1988) with 4 degrees of freedom.

According to Neter et al. (1989), the plot of the partial residuals tends to show the nature of the relationship between the independent variables and the residuals, which were determined for each significant variable. The relative influence of each effect was judged on the basis of the values normalized with respect to the standard deviation of the partial residuals. The partial residual plots also contain the 95% confidence intervals, as well as tick marks on the abscissa showing the location of data points.

Validation of the final models (CPUE and P/A) were evaluated using two methods: the first method used linear regression between randomly chosen observed values of relative abundance and those generated by the model using the included independent variables as input (simple validation). The second method was a cross-validation of the model. Correlation between the observed and predicted values were then calculated to assess the goodness of fit of Poisson model, whereas the Receiver Operating Characteristic (ROC) test was used for binomial model (models P/A). ROC indicates the model performance independently of the apparently arbitrary probability threshold required in presence/absence models at which the presence of a target feature is accepted (Fielding and Bell, 1997).

The Pearson's correlation coefficient was used for the Poisson distribution (Lehmann et al., 2002) was used for CPUE data. The 10,000 and 5000 samples randomly chosen from the total fishing data set (CPUE) and the length frequency data sets, respectively, for this purpose were not included in the process of model generation.

Predictors were selected using a stepwise procedure, going in both directions (forward and backward) from a full model and removing predictors according to an F-test (p value = 0.05).

3. Results

3.1. Models for catch data

The starting and final selected GAM models for the Brazilian pelagic longline data set (CPUE and presence/absence) are given in Table 1. The two final models consist of the same seven variables: month, sea surface temperature (SST), sea surface temperature anomaly (SSA), sea surface height anomaly

[2] Details of GRASP are given in Lehmann et al. (2002) and the website: http://www.unine.ch/cscf/grasp/.

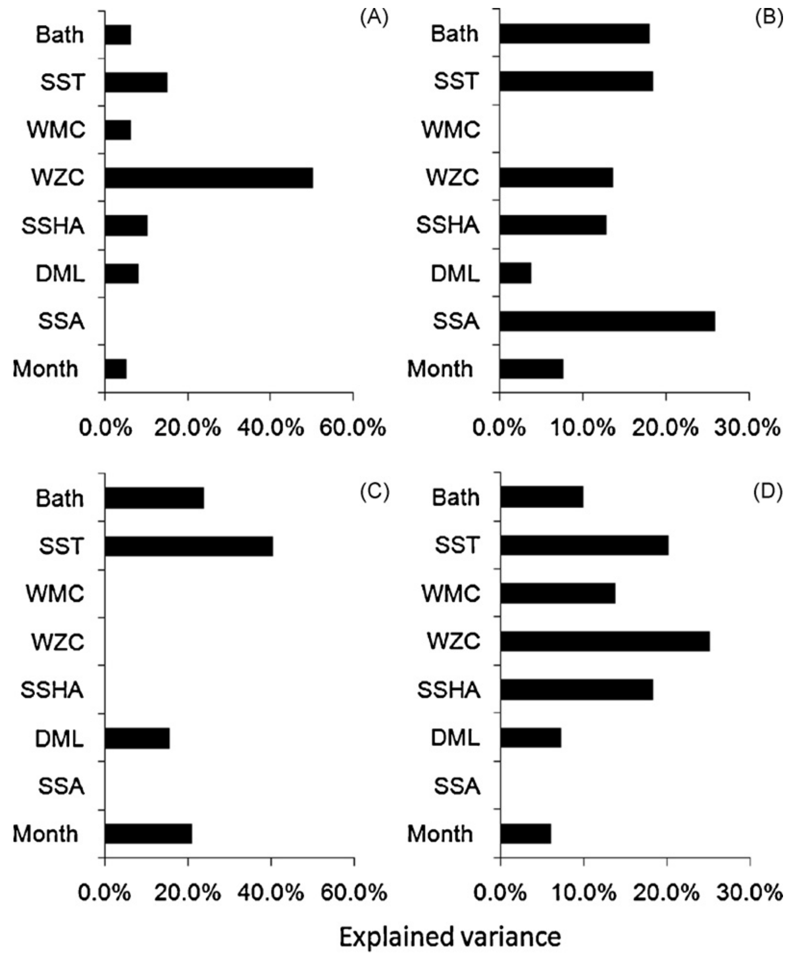

Fig. 2. Contribution of each variable added on the final model (model contribution). (A) Catch ratio data, (B) juveniles, (C) maturing/mature, (D) mature. DML, deep mixed layer; WZC, wind zonal component; WMC, wind meridional component; SST, sea surface temperature; SSHA, sea surface height anomaly; Bath, ocean depth at the location of the longline sets; SSA, sea surface temperature anomaly.

(SSHA), deep mixed layer (DML), meridional wind component (WMC) and zonal wind component (WZC).

Results of the simple and the cross-validations of the two models are also given in Table 1. Results indicate greater model stability for the presence/absence model, with the same relatively high ROC value of 0.73 for both the simple validation and the cross-validation.

The contribution of each environmental predictor variable to the final models is shown in Fig. 2. The results of model contributions by each predictor variable from the final model shows the importance of the zonal wind, sea surface temperature and sea surface height anomaly as main factors influencing distribution of the swordfish explaining with 50, 15 and 10%, respectively, of the variance explained in the final model (Fig. 2A).

Fig. 3 shows the relationships between the partial residuals for the significant variables. Higher catch ratio values were associated with submarine banks and other topographic features (2500–3500 m depth) and deeper waters (>4000 m depth). The effect of sea surface temperature on the catch ratio of *X. gladius* is positive for temperatures higher than 22 °C. The effect of the depth of the mixed layer on catch ratio indicates that the highest catch ratio values were obtained instead when the thermocline is between 30 and 50 m of the surface. The catch of *X. gladius* is associated instead is influenced by the wind meridional component, increasing in the direction of positive values, in contrast to the zonal wind component where the effect decreases in both negative and positive directions. The catch ratio increases with more negative values of sea surface height anomaly (>−50 mm). Strong seasonality can be seen, with peaks in March–April and August.

The spatial prediction of swordfish catches in the South Atlantic based on the P/A model is shown in Fig. 4(A and B). Two main areas where swordfish are caught can be identified from the analysis; one north of 5°S and the other between 20–25°S and 15–35°W (Fig. 4B).

3.2. Size class models

The final models for the P/A of the three size classes of swordfish are given in Table 1. There is a difference in the variables selected for the three final models, with more environmental factors included in the final models for juveniles and mature individuals (adults) (Fig. 2B and C), suggesting both sizes undergo a greater influence from these variables. For the

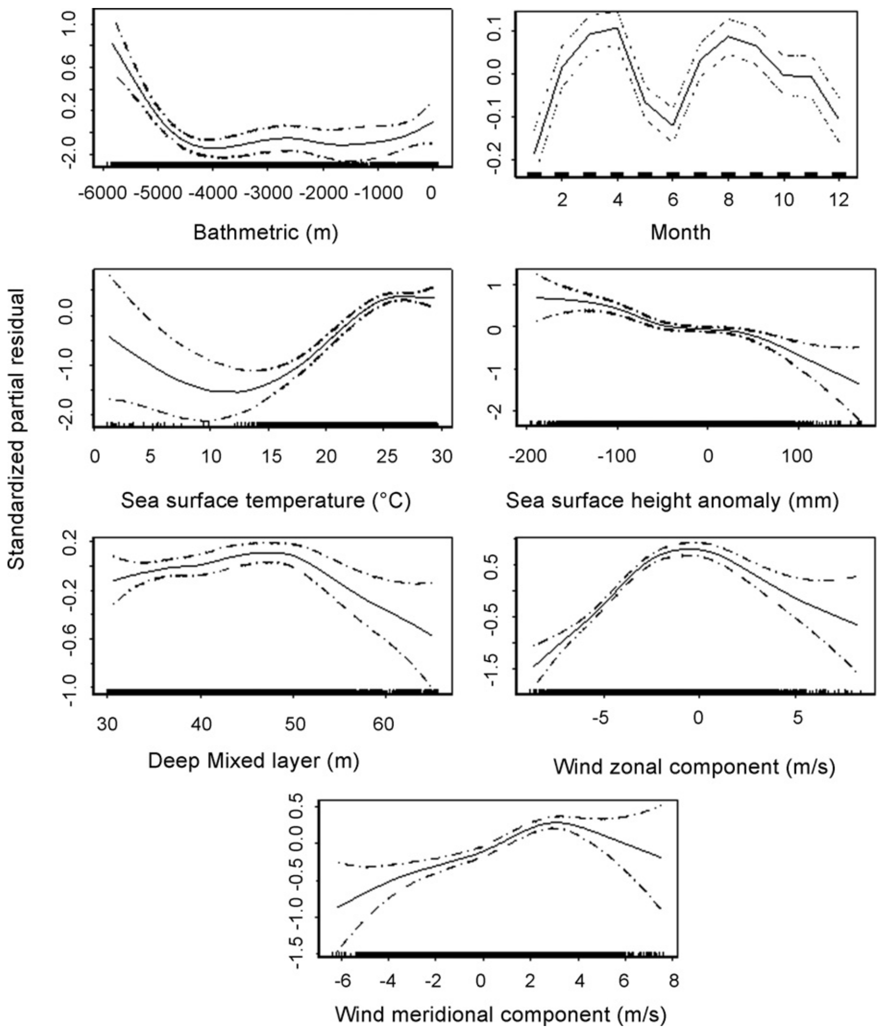

Fig. 3. Partial response curves showing the effects of the predictor variables on catch of swordfish in the South Atlantic from 1982 to 2000. Dashed lines represent the 95% confidence interval limits.

model of juveniles, SSA, SST, Bath and WZC were the factors that most influenced distribution, respectively, accounting for 27, 19, 18 and 15% of the variance explained in the model (Fig. 2B). In the model of maturing/mature individuals, SST and Bath contributed more than 50% (Fig. 2C). For the model of mature individuals, the factors that most contributed were WZC, SST, SSHA and WMC (Fig. 2D).

The simple and cross-validation results are given in Table 1, with the relatively high ROC values indicating satisfactory fits. Although there are differences between the simple validations and the cross-validations, these are minor (0.03 for the intermediate size class swordfish and 0.04 for the other two size classes), and indicate that model stability is good.

Figs. 5–7 show the partial response curves for the significant variables for the three size class models. Differences in vertical distribution between the three size classes can be seen with juveniles found especially at deep mixed layer of less than 20 m (Fig. 5). Intermediate size (maturing/mature) class individuals were also found at all depths but were more commonly associated with deep mixed layer of greater than 30 m (Fig. 6). Mature (adults) swordfish were more commonly found in areas with deep mixed layer of less than 20 m and greater than 60 m. Juveniles were more common in January and February and September to November than in other months (Fig. 5). Intermediate-sized swordfish were most common from June to August (Fig. 6), while adults occurred most frequently from January to May and from October to December (Fig. 7). Given the large confidence intervals for temperatures below 20 °C, the optimal temperatures for juveniles seem to be above 25 °C (Fig. 5).

For maturing/mature individuals, there was a linear increase for sea surface temperatures above 20 °C (Fig. 6), while for adults, the optimal temperature range was approximately 16–23 °C, with a peak at 20 °C (Fig. 7). The effect of fishing depth was at a maximum at 3000 m for juveniles (Fig. 5) and between 3100 and 4500 m for intermediate-sized individuals (Fig. 6). For adult swordfish, a linear increase with depth from depths of approximately 3000 m can be seen (Fig. 7).

Sea surface temperature anomaly was only significant in the juvenile swordfish P/A model, with the presence of juveniles

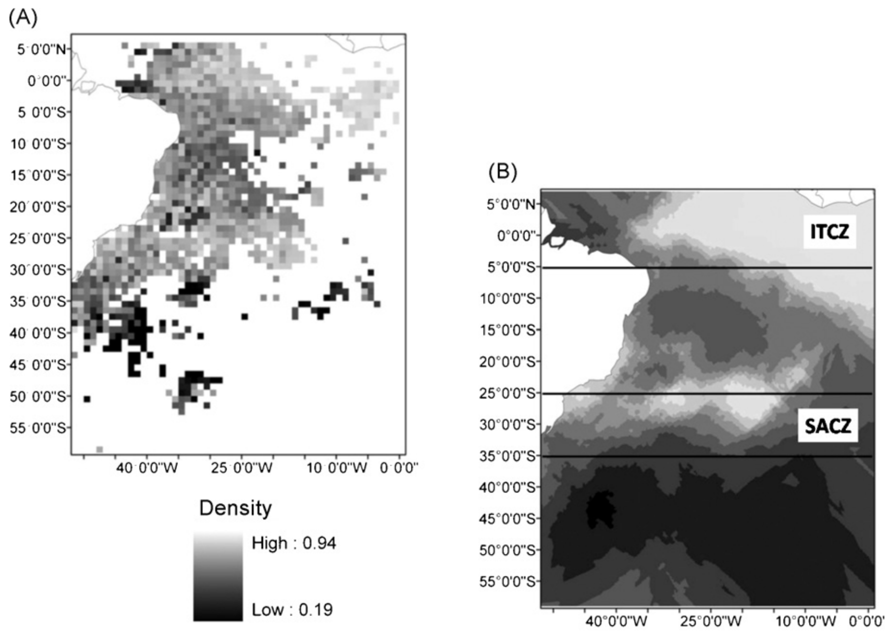

Fig. 4. Spatial prediction of *X. gladius* catches based on the GRASP approach. (A) Spatial distribution of the catches and (B) final modelled spatial distribution. Dashed lines represents the limits of the inter-tropical convergence zone (ITCZ) (Hazin, 1993) and the South Atlantic convergence zone (SACZ) (Garcia, 1997) for the months of July and September, respectively.

most strongly associated with values between −0.5 and 0.5 °C (Fig. 5), while the sea surface height anomaly showed an increase between 50 and 100 mm for adult swordfish (Fig. 7). The wind zonal component was important for juveniles and adults, with decreasing and increasing effects for values above 2, respectively (Figs. 5 and 7). For adult swordfish, the wind meridional component had a dome shape, with maximum values corresponding to approximately −1 m/s (Fig. 7).

Spatial predictions for the three size classes of swordfish are shown in Fig. 8. Distributions are clearly different with the juveniles found close to the coast, while intermediate size class individuals are located mainly in the inter-tropical convergence

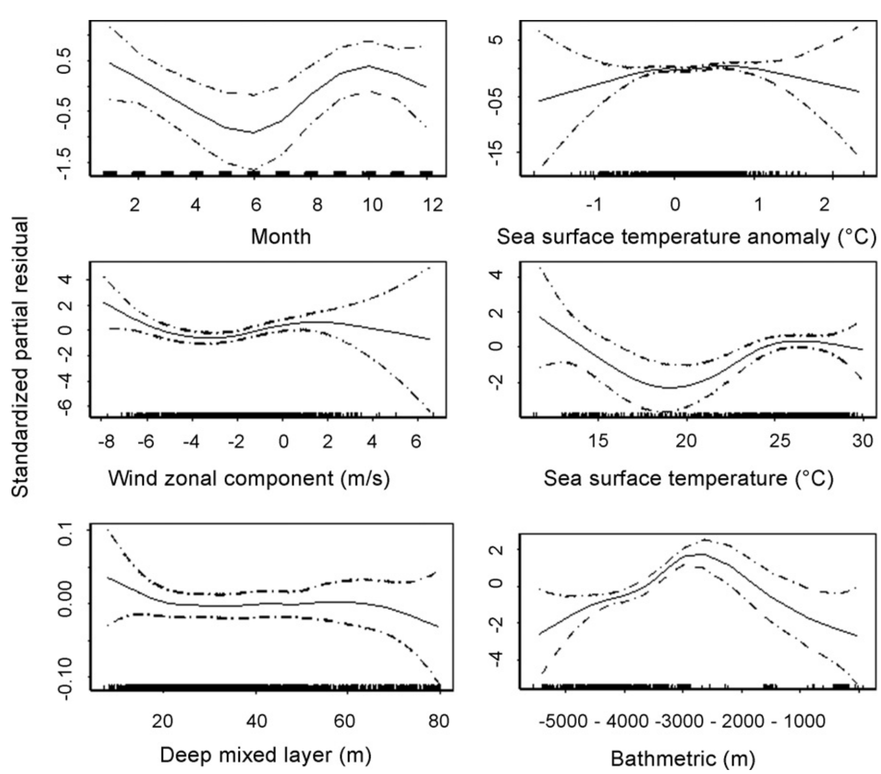

Fig. 5. Partial response curves showing the effects of the predictor variables on the presence of small-sized (juvenile) swordfish in the South Atlantic from 1982 to 2000. Dashed lines represent the 95% confidence interval limits.

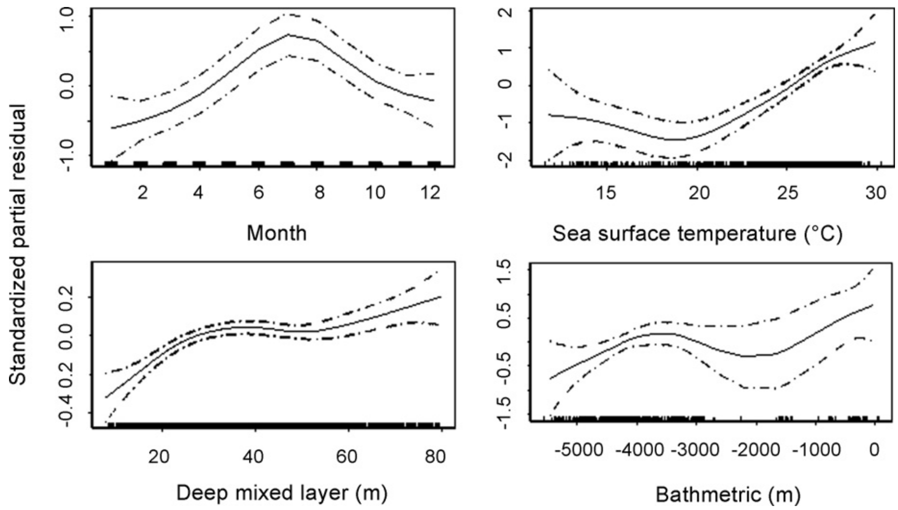

Fig. 6. Partial response curves showing the effects of the predictor variables on the presence of intermediate size (maturing/mature) swordfish in the South Atlantic from 1982 to 2000. Dashed lines represents the limits the 95% confidence interval limits.

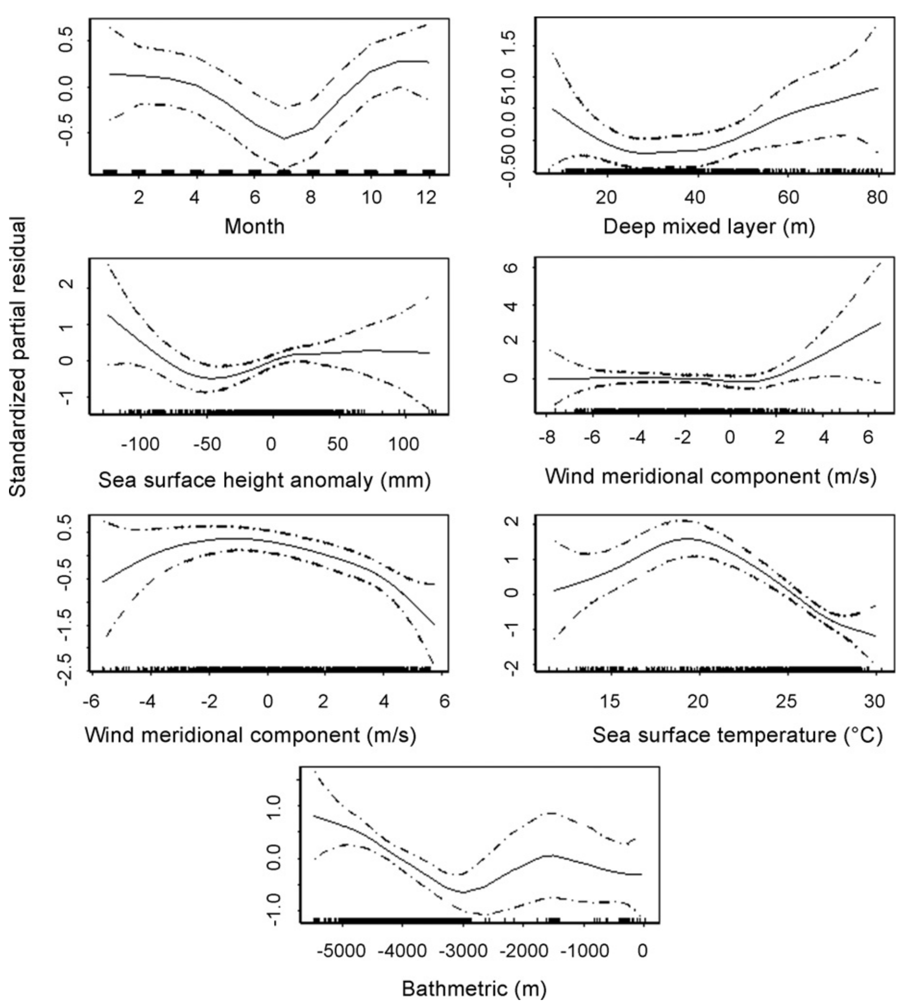

Fig. 7. Partial response curves showing the effects of the predictor variables on the presence of large (mature) swordfish in the South Atlantic from 1982 to 2000. Dashed lines represents the 95% confidence interval limits.

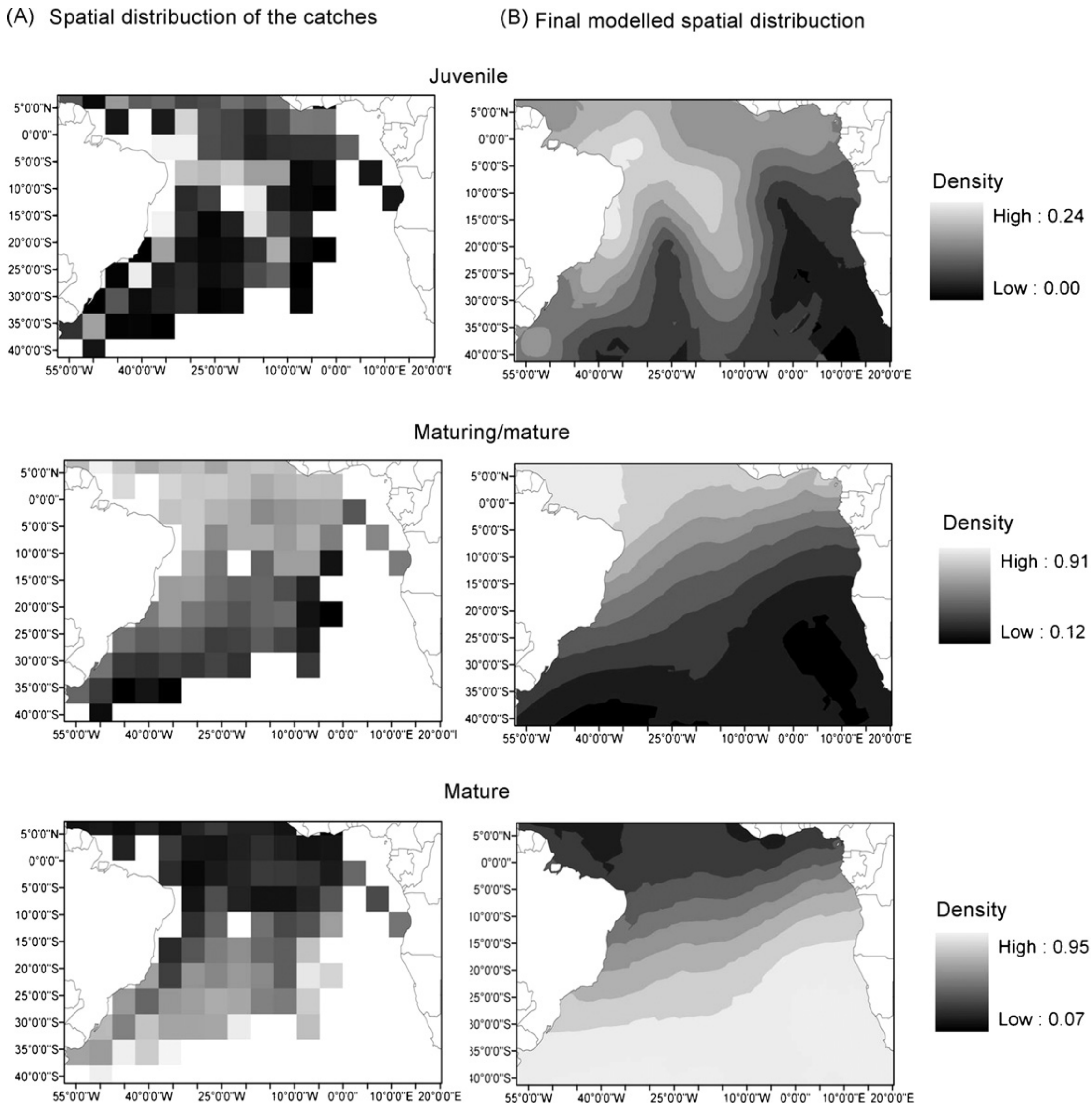

Fig. 8. Spatial prediction by stage of the maturity of the swordfish based on the GRASP approach. (A) Spatial distribution of the catches and (B) final modelled spatial distribution.

zone. Adults are found more to the south, particularly at temperatures greater than 20 °C near the sub-tropical convergence zone.

4. Discussion

GRASP has been widely used in studies concerning the conservation and management of a variety of species, including terrestrial animals (Fraser et al., 2005), plants (Lehmann et al., 2002) and coral reefs (Garza-Pérez et al., 2004). This recently developed approach combines GAM with spatial prediction (Lehmann et al., 2002), differing from surface-fitting algorithms or from geo-statistical methods that estimate surfaces directly in geographic space (Chambers and Hastie, 1993; Lehmann et al., 2002). Note that interpolation methods and statistical models can also be combined to improve model fits (Maggini et al., 2006).

In the present study, the spatial prediction of swordfish catches and P/A was very satisfactory, with more than 60% of the variation explained by the predictor variables. Compared to other studies where GRASP was used to model relationships between response and environmental variables, the cross-validations were rather high (ROC between 0.61 and 0.98), indicating satisfactory model stability (Lehmann et al., 2002; Garza-Pérez et al., 2004).

Results show a differentiated horizontal distribution by length class and the preference of the species for areas in which enrichment processes provide essential conditions for feeding, reproduction and growth. Mejuto et al. (2004) analyzed the length frequency distribution of *X. gladius* caught by the Spanish fleet in the North and South Atlantic and observed that the differentiated horizontal distribution was due to migrations into areas (higher latitudes) in which oceanographic conditions favored feeding and spawning, with immature individuals located in equatorial regions. This pattern appears to be confirmed in the present study. Results indicate three areas of species concentration located near the coast (juveniles), in the inter-tropical convergence zone (maturing/mature individuals) and in the sub-tropical convergence zone (mature individuals).

The equatorial region, particularly the western portion, is generally considered as oligotrophic (Hazin, 1993; Travassos, 1999). However, there are a number of hypotheses concerning the divergence and convergence of currents, and the interactions between these currents and underwater topography (Travassos, 1999). Interactions between ocean currents and topographical features, such as islands and submerged banks, may give rise to a complex circulation pattern resulting in the rising of isotherms (upwelling), the formation of Taylor columns and the amplification of tidal currents (Roden, 1987). According to Oxenford et al. (1983), in locations with islands and oceanic banks, there are generally vortexes and turbulence that propel nutrients from deep waters to the surface and promote an increase in primary production (phytoplankton) and, consequently, zooplankton, which is retained and concentrated in these locations. Kinkel et al. (2000) state that it is the formation of divergence along the south equatorial current that promotes the rising of cold waters and a consequent rise in the thermocline. This phenomenon is directly linked to wind forces.

Becker (2001) observed the formation of higher temperature vortex near the Aracati bank as well as various vortexes of lower temperature in the region of Fernando de Noronha banks. Travassos (1999) found a strong upwelling on one of the banks of the North Brazilian Chain. In the same area, Zagaglia (1998) reports the absence of a cold water outcrop at the surface, describing, however, the presence of transitory thermoclines and rising isotherms.

These studies demonstrate the occurrence of small isolated enrichment phenomena on the western portion of the Atlantic equatorial region related to topography, banks and oceanic islands, such as the North Brazilian Chain and the Fernando de Noronha Archipelago, in conjunction with seasonal events. These studies corroborate the present study, in which the strong effect of bathymetry in longline deployment locations was observed, especially for young *X. gladius* individuals (<125 cm) in areas near topographical features. According to Coimbra (1995), this region favors juvenile development due to greater biological productivity.

Menezes (2001) analyzed chlorophyll concentration with wind (WZC–WMC), SST and SSHA and found strong relations in the primary productivity enrichment process, whether through the outcropping or sinking of water masses, particularly in the equatorial Atlantic. The author also observed that the western portion (0° and 5°N/20°W) is characterized by strong zones of sinking masses of water, with little upwelling, whereas east of 20°W is characterized by upwelling zones.

Mello (1992) states that specimens smaller than 125.0 cm present intensive feeding activity, suggesting that this is a direct consequence of the development phase of these specimens, with the allocation of a large amount of energy to somatic growth. In tropical oceans, upwelling is one of the most important geophysical processes and is responsible for a large part of the supply of nutrients in surface waters (Brown et al., 1989).

Mejuto and Hoey (1991) state that smaller specimens are less active and more thermally dependent. It is possible that such individuals remain close to geological formations (continental slope, oceanic banks, etc.) that vary little in terms of depth and daylight hours, occurring between 10 and 60 m (Poisson et al., 2001). This appears to be confirmed by the present study, which found greater abundances when the depth of the mixed layer occurred in the first 10 m.

The concentration in the inter-tropical convergence zone (ITCZ) of maturing swordfish, in which at least 50% of the individuals had reached first maturity (125–170 cm LJFL), may be a reproductive strategy in response to the oceanographic characteristics of the area, particularly in relation to the high temperatures observed, thereby accelerating the process of gonad development (or maturity). In the period and area of greater abundance (June to August) verified in the present study, the ITCZ moves more northward and coincides with the north equatorial countercurrent formed by the looping of the North Brazil Current, producing anti-cyclonic vortexes (upwelling) from 3°N to 8°N (Zagaglia, 2003). Thus, we may consider that the greater abundance in this area is also due to a feeding strategy. Similar results were observed by Arocha (1997) for the *X. gladius* in the North Atlantic.

The presence of mature individuals in the south-southeast region of Brazil both off the coast and in more oceanic areas may be related to the concentration of food sources (Zavala-Camin, 1982; Mello, 1992; Arfelli, 1996) caused by the increased primary productivity associated with the sub-tropical convergence (formed by the Falkland current and the Brazil current) and the coastal up-swelling at Cabo Frio, though there is also evidence of the rising of deeper waters off the coast of Espírito Santo, Cabo de Santa Marta Grande, Tramandaí and along the southeast coast (Azevedo, 2003), as observed in the present study. The South Atlantic central water climbs over the continental shelf along the southeastern coast due to movement induced by the common presence of vortexes associated to the Brazil current along the shelf break (Azevedo, 2003).

Results obtained in the present paper are relevant and importance in two aspects. The first is from the commercial perspective, as fisheries directed at pelagic species have high operational costs, largely represented by the consumption of diesel fuel in the search for resources in the extensive areas of greater fishery potential. Indeed, the experience and knowledge acquired from generation to generation by the masters of the vessels are important. Nonetheless, these masters tend to commit mistakes not due to a lack of experience but to external factors, such as a lack of knowledge on the behavior of the resources, together with factors related to the environment, climatic changes, etc., which often influence operational factors, as demonstrated in Hazin (2006). The use of such predictive techniques may increase the catchability, and as consequence, the fishing mortality. This information should be taken into account when carrying out stock assessments and management.

The second important aspect regards conservation and stock management of *X. gladius* as well as the contribution toward a better understanding of the species and drafting of more efficient, precise management plans. The identification of nursery areas where juveniles are concentrated and of potential spawning grounds is important as these can lead to measures such as temporary closed areas. Although several authors have reported that the southeast region is an important feeding ground (Zavala-Camin, 1982; Mello, 1992; Arfelli, 1996) and spawning is known to take place in the equatorial region (Mejuto and Hoey, 1991; Hazin et al., 2001) where highest concentrations are found, important aspects of the spatial distribution of swordfish in the South Atlantic are still not well known.

In conclusion, GRASP proved to be useful for predicting areas of concentration and occurrence of swordfish as a function of environmental variables. This approach has many potential applications in fisheries as a tool for improving our understanding of spatial dynamics, namely in the mapping of the distribution of different life history stages and aspects such as spawning as a function of environmental variables and in the study of essential fish habitat.

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