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Assessing swordfish distribution in the South Atlantic from spatial predictions

Humberto Hazin [a,*], Karim Erzini [b,1]

[a] *Universidade Federal Rural de Pernambuco-UFRPE, Departamento de Pesca, Laboratório de Oceanografia Pesqueira, Av. Dom Manuel de Medeiros, s/n, Dois Irmãos, CEP 52.171-900 Recife, PE, Brazil*
[b] *Centro de Ciências do Mar (CCMAR), Faculdade de Ciências do Mar e do Ambiente, Universidade do Algarve, 8005 - 139 Faro, Portugal*

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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

* Corresponding author. Tel.: +55 81 33206512; fax: +55 81 33206512.
E-mail addresses: hghazin@hotmail.com (H. Hazin), kerzini@ualg.pt (K. Erzini).
[1] Tel.: +351 289 800995; fax: +351 289 818353.

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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 $1^\circ \times 1^\circ$ 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 $5^\circ \times 5^\circ$ 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 $0.5^\circ \times 0.5^\circ$, were used to construct data bases of $1^\circ \times 1^\circ$ and $5^\circ \times 5^\circ$ 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 $0.5^\circ \times 0.5^\circ$, were aggregated to constitute a base with a resolution of $1^\circ \times 1^\circ$ 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

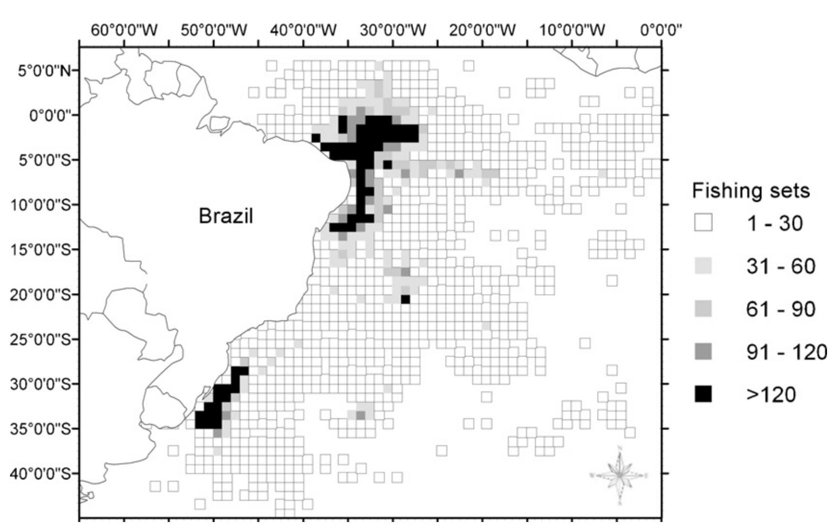

Fig. 1. Distribution of the Brazilian fishery longline sets in the Atlantic Ocean, from 1980 to 2000.