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Lara Loureiro de Sousa

Vulnerabilidade de *Prionace glauca (L.)* à pesca de superfície no NE Atlântico

Vulnerability of *Prionace glauca (L.)* to longlining in the NE Atlantic

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Biologia Marinha, realizada sob a orientação científica do Professor Doutor António Múrias dos Santos, Professor do Departamento de Biologia da Universidade do Porto e co-orientação do Professor Doutor Victor Quintino do Departamento de Biologia da Universidade de Aveiro

Dedico este trabalho à minha mãe
por todo o apoio, paciência e imensurável incentivo.

O Júri

Presidente	Professor Doutora Maria Ângela S.D.A. Cunha Professora Auxiliar do Departamento de Biologia, Universidade de Aveiro
Vogal – Arguente Principal	Professor Doutor João Pedro Santos Correia Professor auxiliar da Escola Superior de Turismo e Tecnologia do Mar, Peniche
Vogal - Orientador	Professor Doutor António Múrias dos Santos Professor Auxiliar do Departamento de Zoologia da Faculdade de Ciências da Universidade do Porto
Vogal – Co-Orientador	Professor Doutor Victor Manuel dos Santos Quintino Professor Auxiliar do Departamento de Biologia da Universidade de Aveiro

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Palavras-chave Palangre de superfície; Tubarão azul; Distribuição Potencial; Sistema de Monitorização Contínua; Exploração

Resumo A Pesca de Palangre de superfície é uma prática pouco selectiva e encontra-se implementada em todos os Oceanos do planeta, perturbando e removendo espécies chave dos ecossistemas marinhos. Este estudo revelou a possibilidade de quantificar a extensão da sobreposição desta actividade com a distribuição da população de tubarão azul no Atlântico Nordeste. Assim, com o Maxent foi possível mapear e validar áreas de adequabilidade ambiental para tubarão azul. Modelos de distribuição potencial gerais e sazonais foram desenhados com um elevado nível de precisão (AUC=0.936 para os dados gerais em análise). Tal como já seria esperado a variável ambiental mais explicativa desta distribuição foi a temperatura à superfície do mar, em particular os seus valores mínimos. Analisando os modelos sazonais foi possível observar um alto grau de compatibilidade entre a distribuição e as movimentações sazonais da população previstas para o modelo e as descritas em estudos anteriores. Examinando os desembarques oficiais da Pesca de Palangre Portuguesa confirmou-se a importância de espécies de tubarões para esta Pesca comercial. A análise dos dados de MONICAP de barcos a operar no Atlântico Norte permitiu o mapeamento das áreas onde esta actividade é mais intensa. Estas áreas são definidas por 20-44ºN e 8-35ºW. A sobreposição de parâmetros ambientais com estas áreas sugere que a actividade pesqueira é sobretudo influenciada pela temperatura a superfície do mar, a batimetria e as anomalias de temperatura a nível geral, e a batimetria a nível sazonal. Com este estudo 40% da área potencial prevista para a distribuição do tubarão azul no Atlântico nordeste encontra-se sob severa exploração. Sazonalmente, a sobreposição ronda os 30-40% à excepção do Verão, onde desce para cerca de 15%. No entanto, é no Inverno que se dá a maior sobreposição, sendo também nesta altura que a pesca atinge maior intensidade. Estes valores são alarmantes, tendo em conta que a frota analisada é apenas uma das que operam na zona, pelo que quaisquer medidas tendentes a minimizar os efeitos da pesca de Palangre terão de ser desenvolvidos a nível internacional.

Keywords Longlining; Blue shark; potential distribution; VMS; Exploitation

Abstract Longlining is a non-selective fishing technique implemented in all major Oceans in the planet, moreover is disturbing and removing keystone species from the marine ecosystem worldwide. The present study aimed to assess the extent to which this fishing activity overlaps the distribution of blue shark in the northeast Atlantic. Thus, with Maxent it was possible to map and validate areas of environmental suitability and appropriate niche for blue shark. Both general and seasonal models for this top predator were predicted with a high level of accuracy (AUC=0.936 for general training data). As it was already expected the main feature influencing this distribution was sea surface temperature, particularly its minimum values. Analysing the seasonal models it was possible to observe a general agreement between the predicted distribution and seasonal movements of blue sharks and data previously described. Scrutinizing Portuguese longlining landings it was confirmed the magnitude of shark species to this commercial fishery. Data from Portuguese longlining landings confirmed the magnitude of shark captures by this commercial fishery. The analysis of Portuguese VMS records of the longline vessels operating in the North Atlantic Ocean allowed the designing of a map indicating areas subject to a constant exploitation. These areas are defined by the coordinate's 20-44ºN and 8-35ºW. The ecological analysis of these areas revealed sea surface temperature, bathymetry, and SST anomalies as the main drivers of longlining exploitation both in general and seasonal analysis. With the present study 40% of the potential distribution area of blue shark in the northeast Atlantic population is under severe longlining exploitation. Seasonally, the overlap is around 30-40%, with the exception of the summer, where it falls to 15%. However, the highest overlap is in the winter, precisely when the fishery's activity is the most intense. These values are alarming, considering that the longline fleet studied is not the only one operating in the area. Therefore, any mitigation measures to reduce effects of bycatch by longlining should be implemented at the international level.

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1| INTRODUCTION

INTRODUCTION

1. Fisheries: longlining and bycatch

Conservation of marine ecosystems requires a complete understanding of biodiversity patterns within fisheries' areas. In particular, understanding the association between marine species' behaviour and environmental features in their occurrence areas is extremely important as it shapes populations' distributions and influences potential availability to fisheries exploitation (Sims et al. 2001). This knowledge can reduce non-target bycatch, one of the biggest threats from current industrial fisheries. After recognizing the problem of the ecological impact on ecosystems resultant from incidental captures, few comprehensive assessments of bycatch effects have been conducted (e.g. Lewison et al. 2004, Gilman et al. 2008, Soykan et al. 2008). According to the Food and Agriculture Organization (FAO) report on the state of world fisheries and aquaculture (2007), between 71% and 78% of the world's major fish stocks were depleted, overexploited, or fully exploited.

It is known that longlining has contributed to the overfishing of fish stocks around the globe, increasing their vulnerability to environmental variation (e.g. Gilman et al. 2008). Implemented in all major oceans, longlining is a practice that involves a long stretch of line with thousands of baited hooks. In pelagic longlining, the most pervasive fishing gear used in the open ocean (Baum et al. 2003), the mainline is suspended from floating buoys, spaced at intervals along it, that drift on the sea surface (Ward et al. 2008). The vessel advances along a specific course while the mainline is spooled out from the ship's stern. Boat and longline then drift for 2–24 hours allowing the lines to fish until the mainline is hauled back on board. As the mainline is being retrieved and a fish is encountered on a stem line, crewmen pull it onboard selecting a desired size or species. Otherwise, the fish (or other marine animal) is discarded, frequently injured or already dead (e.g. Coelho et al. 2005). Every day, up to 4000 hooks are estimated to be deployed on branch lines attached to mainlines (Ward et al. 2008). In theory, longline fisheries focus on one or a few target species but the number of endangered species caught by longliners is rather superior (e.g. Santos et al. 2002, Garza-Gil & Varela-Lafuente 2005). Nonetheless, for target species, catch rates are generally as low as one or a few fish for every hundred hooks set (e.g. Hinman 1998, Damalas et al. 2007). According to Gislason et al. (2000) the world's demand for fish will rise above the present supply. To sustain this increasing demand for commercial marine resources, like tunas or swordfish, longline fleets are operating everywhere and few protection measures for marine fauna are being applied, notwithstanding of several studies developed for ecosystem and fisheries' management (e.g. Sainsbury et al. 2000, Hartley & Robertson 2006, Soykan et al. 2008). Understanding the catchability or efficiency of the fishing gear is of primary interest if effective management and conservation plans are to be deployed. The first step is to determine the distribution and behaviour of marine species, either targeted or bycatch, in relation to the fishing practices and gear (Ward et al. 2008). Information on the extent to which fisheries overlap with different components of many species' populations in space and time can be used to reduce the observed high rates of fishing-induced mortality, which are unsustainable in the long-term.

Populations of large pelagic fish such as bluefin tuna (*Thunnus thynnus*), blue and white marlin (*Makaira nigricans* and *Tetrapturus albidus*), and sharks, such as blue and mako, are being heavily overfished (Maguire et al. 2006). Bycatch can modify biodiversity by removing top predators and prey species at unsustainable levels (Gilman et al. 2008), raising ecological concerns. Baum et al. (2003) claim that only in the past half century, as fishing fleets expanded rapidly in the open ocean, large marine predators have been subject to this intense exploitation. These authors also recognized large declines in many coastal and oceanic shark species, over a short period (Baum et al. 2003). Pelagic sharks represent a large bycatch of global high-sea longline fisheries targeting tuna and billfish, and are retained primarily for their highly prized fins (Stevens et al. 2000). Some fisheries of large oceanic teleost species catch more sharks as bycatch than their aimed species (Camhi et al. 1998). Shark bycatch resulting from longlining is of primary conservation concern, since shark populations' are particularly sensitive to increased mortality above natural levels, due to their life history traits. But longlining activity is also affecting many other species such as seabirds (Tudela 2004) or sea turtles (Gilman et al. 2007, Brazner & McMillan 2008). Thus, scientific research should aim to provide information useful for a reduction of bycatch of marine megafauna on a global scale (Soykan et al. 2008).

2. *Prionace glauca (Linnaeus 1758)*

Probably the widest ranging shark species (Figure 1), blue shark *Prionace glauca* inhabit oceanic waters in temperate and tropical regions (Stevens 1990, Skomal & Natanson 2003).

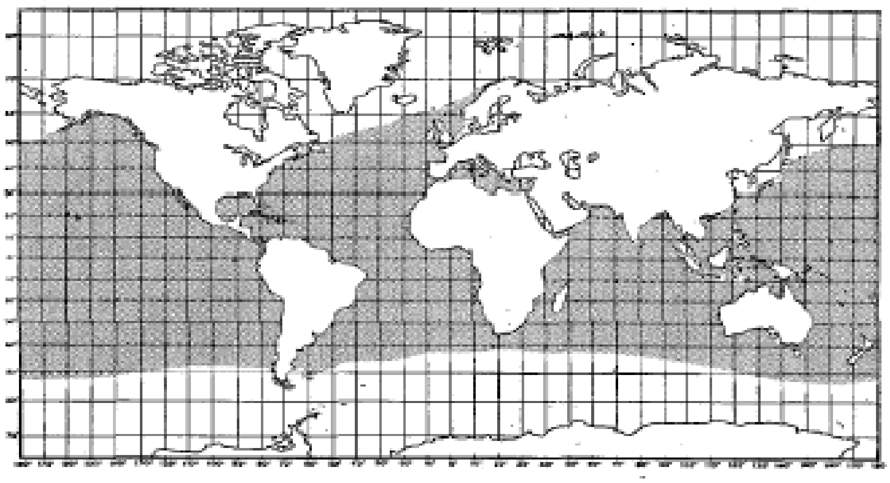

Figure 1 *Prionace glauca (Linnaeus, 1758)* global distribution. (Map source FAO species catalogue Vol.4, 1984)

Occurring all over the Atlantic Ocean, *P. glauca* ranges from Newfoundland to Argentina in the west and from Norway to South Africa in the east (Compagno 1984). It is relatively fast-growing and fecund for a large shark, maturing in 4–6 years and producing average litters of 35 pups, with an intrinsic rate of population increase at maximum sustainable yield of 6% per annum (Gibson et al., 2008). According to Compagno (1984) this species occurs in a thermal range from 7ºC to 21ºC and from the surface to 350m depth, although recent satellite tracking studies have demonstrated deeper dives to ~1200m for this species (N. Queiroz, D.W. Sims unpub. data). In the Northeast Atlantic Ocean several studies suggest the existence of north-south migrations of the blue sharks population between the Iberian Peninsula and Southeast England and Ireland (Stevens 1976, Casey 1985, Stevens 1990).

Blue sharks play a key role in the pelagic ecosystem due to their worldwide distribution and their complex and efficient reproduction (Mejuto & García-Cortés 2005). The inherent vulnerability of sharks and other elasmobranchs to overfishing and stock collapse is well documented, and according to Musick (1999) most elasmobranch populations decline more rapidly and recover less quickly than do other fish species, mostly due to their low fecundity and late age of sexual maturation. Despite being one of the best-studied elasmobranchs, assessment of the global status of the blue shark was hindered by its wide geographic range throughout the world's oceans and by the paucity and/or poor quality of demographic and catch data (Dulvy et al. 2008).

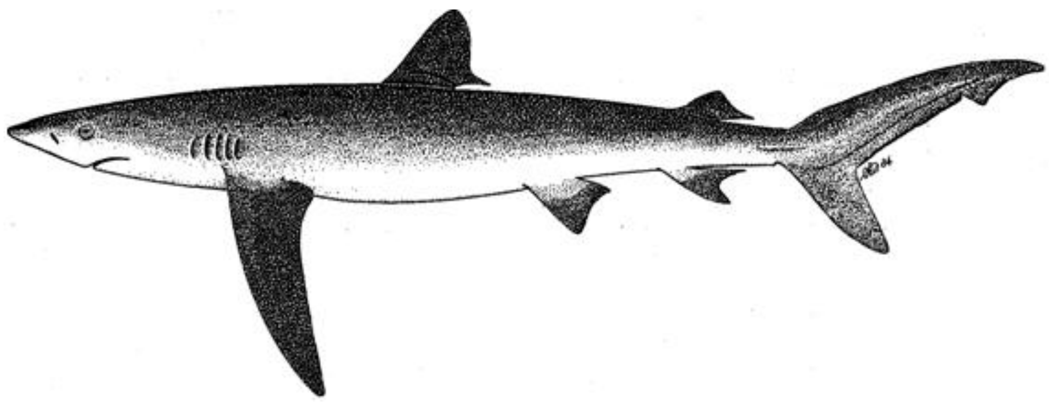

Figure 2 Blue shark (*Prionace glauca*, Linnaeus 1758), source FAO species catalogue Vol.4, 1984.

The blue shark is one of the most captured fish species in the world and there is a thought that this species is the most heavily fished shark, taken in large numbers mainly as bycatch (Dulvy et al. 2008). According to data published by Baum et al. (2003) the North Atlantic population of *P. glauca* has decreased more than 60% in the last 20 years. Many tag and recapture studies have used information collected by sport-fishermen in tagging and release programs (e.g. Stevens 1976, Casey 1985, Queiroz et al. 2005) or bycatch data recorded in commercial fleets (e.g. Henderson et al. 2001). Historically, these worldwide known captures have become more intense in the 1960s with the advance of technology (Mejuto & García-Cortés 2005). Blue sharks are usually captured as bycatch from the fishery targeting swordfish, *Xiphias gladius* (Mejuto et al. 1992, Mejuto et al. 2003, Mejuto et al. 2004). Moreover, Buencuerpo et al. (1998) observed for the period of 1 year that the capture of blue sharks is largely dominated by immature individuals. According to the International Commission for the Conservation of Atlantic Tunas (ICCAT), during 2005 Portuguese Atlantic longline fleets caught, in 2005, 14806 t of fish, of which 11767 t (approximately 80% of all catches) were shark species. It appears that the shark longline catch is now more important than the swordfish and should not be categorized as bycatch. In the case of the Spanish pelagic longlining fleet, both sharks and swordfish are targets, with sharks comprising over 70% of the catches in the North Atlantic (Mejuto et al. 2004). Hence, scientific work is required to assess the status of shark populations (particularly pelagic species with a key role in the pelagic ecosystem), to improve species' specific data collection, and ultimately to develop techniques able to reduce shark bycatch.

3. Objectives

In a global analysis longlining is responsible for the overexploitation of several key-stone pelagic species (Baum et al. 2003, Myers & Worm 2005). The Northeast Atlantic Ocean, in particular, is a region explored by just a few countries, including Portugal (Gibsom 2006), but recent data suggest that a intense chondrichthyan fishery is occurring in the region (e.g. Buencuerpo et al. 1998, Correia & Smith 2004, Mejuto et al. 2004). Being a non-selective fishing technique, longlining is involved in many species' captures: swordfish and tunas as target species and pelagic elasmobranchs as secondary captures. Proper management of such different species requires a deep understanding of their ecology, notably in terms of use and partitioning of pelagic habitat and resources.

Blue sharks are officially the third most heavily fished species by Portuguese longliners. Management actions aiming to preserve this species and to diminish its impressive bycatch are still lacking, not only in the Northeast Atlantic, but also worldwide. This is a global problem with no apparent solution. First, effective species conservation plans require accurate estimates of their spatial distributions (Hernandez et al. 2006). Furthermore, for species that are being commercially exploited, or that are being affected direct or indirectly by anthropogenic activities, it is mandatory to have quantitative assessments of the distribution of such activities, at both spatial and temporal scales. The two sets of data can be superimposed to analyse the extent of their overlap which, in turn, can be used as a first measurement of a species' vulnerability to a given commercial activity.

The present study aims to assess blue shark vulnerability to longlining fisheries' practice in the Northeast Atlantic by using two different sources of information: species' distribution models (SDMs), to infer the distribution of *P. glauca* in the area, and vessel monitoring system (VMS) data, which can be used to estimate relatively unbiased spatial descriptions of fishing effort, although it was specifically designed for fisheries control and marine policies enforcement (Mills et al. 2006). Information on the extent to which fishing areas overlap with different components of the blue shark population's distribution in space and time is extremely valuable for conservation measures, and should complement more traditional analyses based on landings' data (e.g. Stevens et al. 2000, Correia & Smith 2004).

3. 1) Blue shark distribution model

The potential distribution model for *P. glauca* in North Atlantic can be determined, for a delimited area, analysing commercial fisheries data records. Several tagging studies suggest the existence of a single population of blue sharks in this region (Casey & Kohler 1992), which is also supported by recent molecular evidence (N. Queiroz, unpub. Data). However, given the extent of the area (e.g., the Northeast Atlantic) and the highly mobility of this species, records taken by conventional observation techniques are scarce and sparsely distributed, allowing just a raw picture of its distribution. Modelling the occurrence of *P. glauca* in the area is essential to obtain much higher resolution maps of its distribution.

In modelling studies where absence data are difficult to obtain, it is advantageous to use algorithms that accept only presence data (e.g. Graham & Hijmans 2006). This is the case for *P. glauca,* since it is a free-ranging pelagic species, and it is extremely complicated to obtain a significant number of absences. Moreover, even if absence data are available, they frequently appear with a very low reliability level. Maxent software (Phillips et al. 2006) employs the maximum entropy algorithm to establish deterministic models of distribution, assigning values to probability distribution based on limited information (Wu & Stengos 2005). According to Peterson et al. (2007) this potential distribution map describes the area where the conditions are appropriate to a species' sustainability, that is, the area that supplies the conditions of its fundamental ecological niche. Comparing to other methods in ecological modelling based just in presence data, Maxent is one of the most effective for predicting species distribution (Elith et al. 2006). To develop this model, ecological features such as temperature, chlorophyll *a* and bathymetry will be analysed, since such parameters are known to directly influence the pelagic sharks' distribution (Lutcavage et al. 2000, Sims et al. 2000, Sims & Southall 2002, Sims et al. 2003, Queiroz et al. 2005).

3.2) Vessel Monitoring System

To manage fisheries activity and preserve marine ecosystems, European Union Commission for Fisheries implemented a new program in fishery activities control, Vessel Monitoring System (VMS), based on integrated Global Positioning System (GPS) equipments on board of the majority of the vessels operating in the open ocean.

According to the E. U. Common Fisheries Policy, all community vessels exceeding 15 meters overall length are subject to VMS, apart from those which are used for aquaculture and operating inside the baselines of Member States. Vessels for which VMS is mandatory are those that use a range of fishing techniques to exploit demersal and pelagic fish species, which includes pelagic longliners.

VMS data supply patterns of fisheries activity as they have good temporal and spatial coverage, independently of the catch-book or vessel-master. Such information may provide ecosystem management plans seeking to achieve sustainable fisheries while minimizing putative risk to non-target species and habitats of conservation concern. With multilateral cooperation, VMS technologies may offer an important solution to quantification and management of ecosystem disorder, particularly on the high-seas (Witt & Godley 2007). In Portugal, the project of monitoring vessels by satellite, MONICAP (Monitorização Contínua das Actividades da Pesca) is regulated by Direcção Geral das Pescas e Aquicultura (DGPA). Implemented in 1990 and operative since 1993 (Marques 2003), MONICAP assures that Portuguese vessels with length above 15m are supervised and the areas with effective fisheries effort can be described and ecologically characterized.

Data from Portuguese longliners' VMS allows the examination of the areas where the fisheries mainly occur. Scrutinizing these areas by describing the primary ecological features known to influence top marine predators' distribution allows an ecological study over the areas that are constantly exploited. This study may be a key in future management plans to avoid the extinction of many endangered species implicated in longliners non-target bycatches in the North Atlantic Ocean. The environmental features that will be described here are temperature, primary productivity and frontal boundaries. All these parameters are known to influence directly the distribution of many marine predators as their movements are correlated with presence/absence and the extent of these variables (e.g. Lutcavage et al. 1999, Cotton et al. 2005, Queiroz et al. 2005). In parallel, data from the Portuguese VMS program will be used to correlate the fishery effort with the distribution of a top pelagic predator, *Prionace glauca.*

2| METHODOLOGY

METHODOLOGY

1. Study area

The Northeast Atlantic extends from the coasts of mainland Europe eastwards to the Mid-Atlantic Ridge. Large topographic features such as the Mid-Atlantic Ridge dominate sections of the seabed in this part of the Atlantic. There are also extensive relatively flat and featureless areas, such as in the Iberian Abyssal Plain. Main water masses and circulation patterns have also been identified in the Northeast Atlantic. The North Atlantic current carries warm water from low latitudes on the western side of the Atlantic to the western coasts of Europe. Other hydrographic features include gyres, eddies and frontal boundaries (Gubbay 2003). The present work was undertaken in a geographic area in the Northeast Atlantic Ocean delimited by the latitude 20º and 55ºN and the longitude 00º and 35ºW (Figure3).

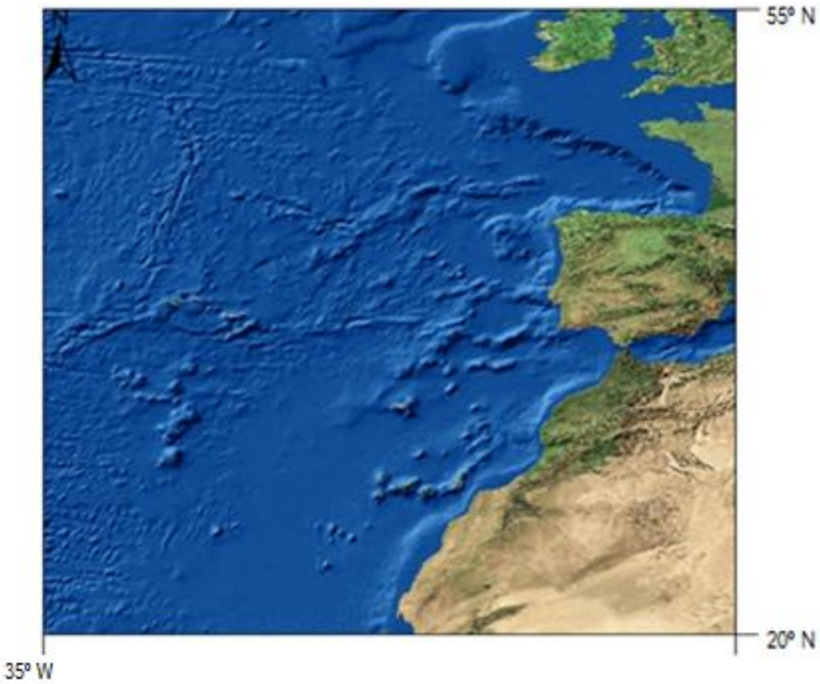

Figure 3 Study area.

2. *Prionace glauca* distribution modelling

2.1 Data Acquisition

Data from blue shark's accidental captures in commercial fishing vessels was assembled for this study. A total of 573 records were gathered from an observer logbook in different periods of fisheries' practice in North Atlantic, from March 2003 until July

2006. This dataset was first divided into seasonal datasets and then fed to GIS (ESRI® ArcGIS® 9.3) middle points from the spooled lines of the fishing fleet were retrieved. These points were then used to fetch the environmental variables needed for modelling the distribution of P. glauca in the NE Atlantic. Seasons were defined as spring (March to May), summer (June to August), autumn (September to November) and winter (December to February).

2.2 Environmental variables

Sea surface temperature (SST), chlorophyll *a* and bathymetry were adopted as explanatory variables. SST was selected as temperature is known to be a major driver of *Prionace glauca* distribution and movements (e.g. Queiroz et al. 2005). According to the latter author bathymetry can also sway the permanence and movements of these animals, in the study area. In addition, chlorophyll *a* was selected for this assessment as an indirect indicator of primary production (Sims et al. 2003). Monthly values of SST were gathered by Modis Aqua satellite, on the website PODAAC Ocean ESIP Tool (POET)[1] of the Physical Oceanography Active Archive Center (PO.DAAC), NASA Jet Propulsion Laboratory. Monthly data from chlorophyll *a* was collected with Level-3 Standard Mapped Images, by the SeaWiFs satellite[2]. Bathymetry data was gathered from ETOPO2 [3]. For the first two variables, data were collected for the period between 2003 and 2006. Monthly data was then associated according to the respective season and using GIS it was possible to compute maximum and minimum values of SST and Chlorophyll *a*, overall and per season. In addition standard deviations at one and five degrees sides were computed on Bathymetry, to better depict the topographic variations and explain their possible influence on blue shark distribution. All environmental layers were re-scaled to the minimum resolution among them (chlorophyll *a* resolution: 9Km). Finally, these 19 features were converted into ASCII format (.asc) and imported to Maxent software.

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[1] http://poet.jpl.nasa.gov
[2] http://oceancolor.gfsc.nasa.gov
[3] http://www.ngdc.noaa.gov/mgg/global/global.html

2.3 Prionace glauca distribution model and seasonal analysis

Maxent[4] was used to build a predictive model of the distribution of *Prionace glauca* in the Northeast Atlantic, based on known occurrence sites and their respective environmental conditions. In a standard binomial analysis (e.g., logistic regression) not only an equal number of presences and absences are needed but also a significant confidence level in the absences is fundamental. In this study, from 573 records 545 accounted for blue shark presences. Furthermore, given that blue shark has a widespread distribution, including the whole studied area, the absences here cannot be considered as a lack of sharks in the area, but only as non- captures. So, it is advantageous in this case to use a modelling algorithm that that only uses presences. In comparison with other established methods used in ecological modelling, based in presences-data only, Maxent appears to be the one with better performance (e.g. Elith et al. 2006, Peterson et al. 2007).

The maximum entropy concept, in which Maxent is based, refers to an optimal probability for the distribution of the species in a given area. As the second Thermodynamic law suggests, and without any external influence (except the one associated to each explanatory variable selected), the system (or in this case the species' distribution) has a propensity for equilibrium, in the way to maximize the entropy. This concept stipulates that among all distributions that satisfy certain momentary constraints on the population, we should choose the one that maximizes the entropy (Wu & Stengos 2005). Thus, for a given area, and with the controlled external constraints (explanatory variables), it is possible to determine the geographic area for the potential niche of occupation of the population, to which is associated a balanced distribution. This area could match the total area occupied by the population, when the generality of the influent variables are considered. In the Receiver Operating Characteristic (ROC) curve achieved in set with the distribution's map, the Ys' axis match with the sensitivity of the model, the proportion of observed presences correctly predicted. The Xs' axis represents the equation *1-specificity,* which is the proportion of observed absences incorrectly predicted by the model. The area below the ROC curve, called "area under the curve" (AUC), measures the performance of the model, independently of the confidence level used in the analysis. The value of AUC varies between zero and one, and when it assumes a value equal or greater than 0.5 we are ahead of a random

[4] *http://www.cs.princeton.edu/~schapire/maxent/*

forecast. As the value approaches to 1, the better the model fits the data on the distribution of the species (Phillips et al. 2006). The data were partitioned into halves, one for building the model and the other used in the validation phase (Graham & Hijmans 2006). Maxent was run using the default parameters including the employment of its “auto features”. Using “auto features” the program was able to select a set of features suitable for the analysis of the restricted number of presence records. Layer data was then imported into Maxent, which produced individual colour-coded (depicting log likelihood of occurrence) distribution maps and Jackknife analysis of variables. The software also provided detailed results on the influence of each explanatory variable in the distribution of *P. glauca.* In addition to a general predictive model, seasonal models were also performed to examine the influence of seasonal variables on this species' distribution.

3. Vessel Monitoring System-Monicap

3.1 Data Acquisition

The Vessel Monitoring System (VMS) is a program of fisheries surveillance and a computerized method of recording the location of fishing vessels at sea (Witt & Godley 2007). Each unit consists of a global positioning satellite (GPS) receiver, a satellite transmitter and a power backup. The Portuguese fisheries’ monitoring system (MONICAP) comprises shipboard equipment responsible for location, time and route records. The geographic position of the vessel is updated every 10 minutes (Marques 2003). In MONICAP communications’ system two satellite are involved, a GPS receiver to record the vessel position and an Inmarsat-C transceiver, created by International Maritime Satellite Organization (INMARSAT) and responsible for transmitting data to the control centre.

VMS data, from 2006 to 2008, was provided by the Central Commercial Fisheries authority and Inspection Centre of the Portuguese government (Direcção-Geral das Pescas e Aquicultura, CCVP - DGPA). To assure that only surface longlining practice was analysed, the official Portuguese landed records were first examined. From all the Portuguese records of fishing vessels provided by DGPA, those with reported pelagic captures were selected for VMS analysis. The VMS dataset contained records gathering geographic coordinates in decimal degrees (World Geodetic System 1984 format) and an accompanying time stamp in UTC (Universal Time Coordinated).

Information as date and time was also present in the dataset. All records received for this study are anonymous with respect to their vessel registration numbers, dimensions and administrative ports. The anonymity of the data was maintained as the name of each vessel was converted into numbers by the DGPA personnel.

3.2 Mapping fisheries activity

Fishing trips were reconstructed using Geographical Information System. The start and finish of each trip were determined when a vessel moved out of and back into a given zone, with respect to time. All movements between fishing locations were ignored retaining data only from fishing activity. The dataset was then converted to equal time, using the MBA Track Analysis software and a two-hour pattern was selected, which also allowed the distinction between fishing from steaming or near-stationery movement. This was required to minimize degree of visual editing of data, given its size, while maximizing the retention of VMS data (Witt & Godley 2007).

Fisheries activity was gridded at a spatial resolution of 3×3 km by summing the number of VMS derived data points coincident to each pixel over monthly and annual scales, using GIS. The information gathered on every record was then represented over the study area, as well as the probability density function of fishing effort, which was represented graphically with a *Kernel density* estimator. Kernel density analysis, in this study, assumes that the positions of vessels are measured at even time intervals and that this interval does not change within the fleet (Worton 1989).

To investigate the existence of a seasonal pattern in fisheries activity the dataset was separated by months and then aggregated according to the respective season. Again, seasons were defined as spring (March to May), summer (June to August), autumn (September to November) and winter (December to February). As for the general analysis, maps representing the fishing effort on every season were drawn over the study area.

3.3 Characterization of fisheries' areas

The areas where the fisheries mainly occur were depicted in relation to environmental variables known to influence directly the distribution of top pelagic predators. In addition to SST, chlorophyll a, and bathymetry, SST anomalies derived from SST layers were also used. SST anomalies (deviations to local averages) can be used to detect frontal boundaries at the sea. These, in turn, are regions where foragers accumulate and are used as passageway by sharks (Lutcavage et al. 2000, Cotton et al. 2005). Data gathering and processing of these features was made in a similar way as for *environmental variables* in blue shark distribution modelling (1B). Monthly data was then grouped according to the respective season and using GIS (ESRI® ArcGIS® 9.3) it was possible to compute mean values of SST, SST anomalies and Chlorophyll *a*. To minimize possible failures on spatial coverage a *kriging interpolation* was performed on the resulting layers of these different ecological features. Longliners' VMS positions were mapped on remote-sensing images of these environmental variables, in both general and seasonal analysis. Pearson correlations were established between longlining practice and environmental features.

3.4 Analysis of species' landing data

Data from official landed captures in Portuguese commercial ports was acquired along with VMS dataset, from DGPA. This dataset was gathered to complement the ecological scrutiny of this fishing practice, and to better understand the regularity of shark species' captures in this fishery and the yearly trends of these captures. Thus, graphical analyses were performed comparing the pelagic species captures' frequencies.

4. Overlap of blue shark distribution and longlining effort

To assess the vulnerability of blue sharks to longlining fishery activities, its potential distribution derived by Maxent was overlaid on the maps of longlining fisheries' effort. Because predicted distribution data is mapped on a continuous scale (0-1) it was converted to binary format (presence/absence). All cells with predicted probability equal or above 0.5 were considered as presence and the remaining considered as absences. Maps were overlaid in GIS, either using data for the whole study period as well as per season. Percentages of overlap between areas where estimated by using the total number of pixels denoting presence of blue shark and longliners, divided by the sum of all pixels denoting blue sharks or longliners.

3| RESULTS

RESULTS

1 *Prionace glauca* distribution model

1.1 The model

Data for blue shark distribution in the Northeast Atlantic was gathered from a logbook of an observer program for the management of commercial pelagic longline fisheries targeting swordfish in the North Atlantic, from 2003 to 2006. A total of three years of records of blue shark bycatches was used. This dataset comprised records of 573 lines of which only 28 did not retrieved presences/catches of *Prionace glauca*. This, alone, shows that the abundance of blue shark in the area is in itself a big threat for this species' maintenance, as it is a frequent catch or bycatch in a high exploratory fishery activity. With such a small number of absences, Maxent appeared as a reasonable modelling process. Thus, the 28 absences were ignored and only 545 presence records were converted comma separated values (.csv) format. The parameters used in Maxent model are presented in table 1.

Table 1- Maxent parameters used in the analysis for modelling *P. glauca* distribution

Regularization multiplier	**50**
Output format	**Logistic**
Maximum iterations	**500**
Convergence threshold	**1.0E-5**
Random test percentage	**50**

Results for the general predictive model of blue sharks in the area studied are depicted in Figure 4. In Figure 5, ROC curves indicate that both raining and test data performed better than random prediction (AUC>0.5). The AUC was 0,929 and 0,936 for test and training, respectively, indicating 93% likelihood that a random positive blue shark occurrence and a random negative location were accurately predicted. In a presence-only modelling approach the AUC result can be interpreted as the probability that the model has correctly classified presence and background points for a given species, and values above 0.75 generally indicate adequate model performance for most applications (Graham & Hijmans 2006).

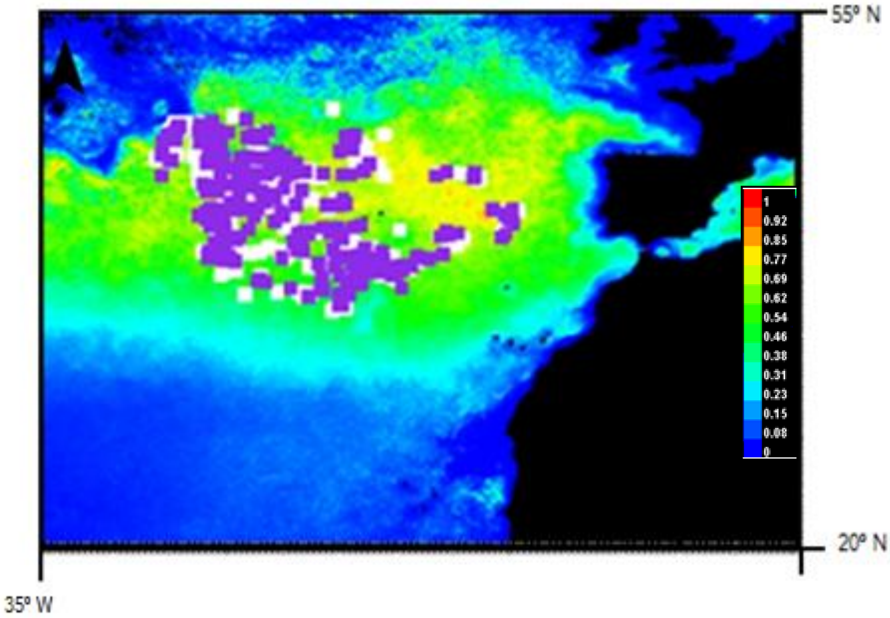


Figure 4 Illustration of the Maxent model for *Prionace glauca*. Warmer colours show areas with better predicted conditions. White dots refer to the presence locations used for training and violet dots show test locations.

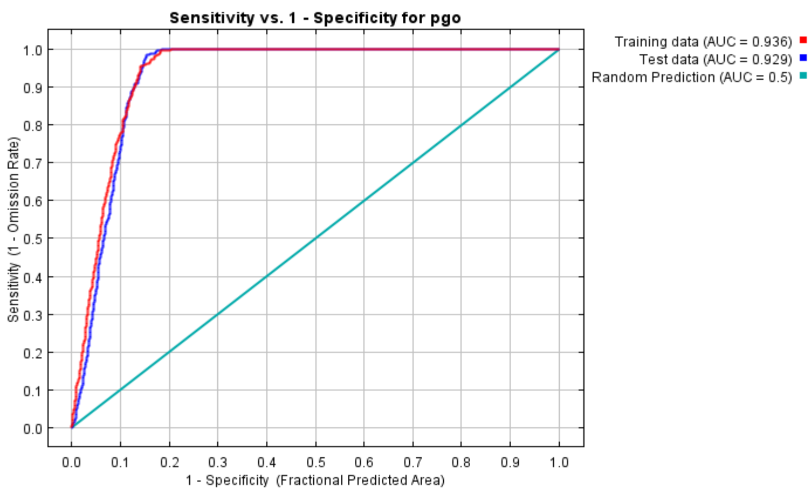


Figure 5 Receiver operating characteristic (ROC) curve calculated both on the training and on the test records. AUC values were well above the random prediction (AUC=0.936 for training data and AUC=0,929 for test data).

1.2 Environmental analysis

To better understand how the features chosen for the analysis influence the predictions of blue shark's distribution in the study area, Maxent software provides a series of graphics scrutinizing the model in terms of environmental analysis. The contribution of each feature to the model is computed using a Jackknife technique on the test data (figure 6). Results show that all 19 environmental variables, even with low contributions, provide useful information to the gain of the model.

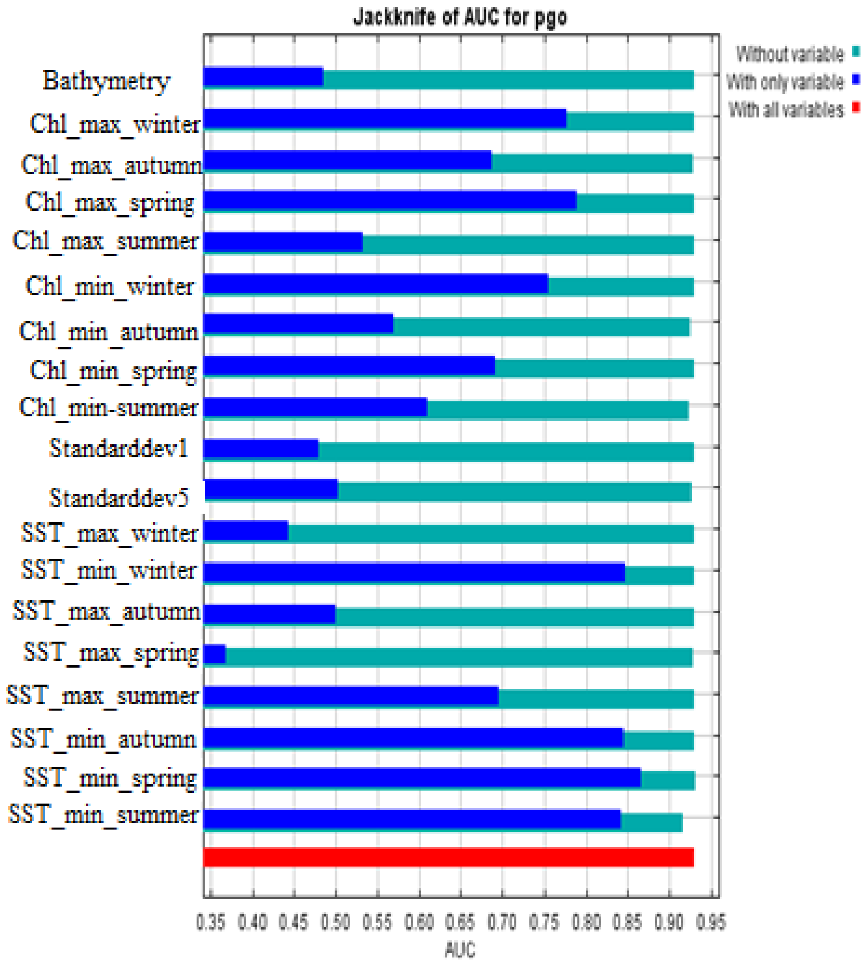


Figure 6 Illustration of Jackknife techniques on test data.

The environmental variable with highest gain when used in isolation was the minimum value of SST in spring, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted was the SST minimum value in summer, which therefore appears to have the most information that is not carried by the other variables. Regarding blue lines it is possible to verify that if Maxent uses only bathymetry, standard deviations at one and five degrees or maximum values of SST in spring, autumn and winter the model gain is low. Hence, as far as the model is concerned, these features seem not to be relevant in the determination of the distribution of blue sharks. On the other hand, the minimum values of SST both in spring and winter months contribute reasonably to the model. A detailed inspection of green lines (gains excluding a given variable) shows that no variable provides substantial information to the model that is not already represented by other variables. This means that in this model the distribution of blue sharks in the Northeast Atlantic cannot be predicted by any variable alone. A more detailed assessment of the influence of each environmental feature on the model forecasts was obtained by inspecting Log response curves, a standard output of Maxent.

The Log response curve for bathymetry (Annex I Figure A) shows that blue shark probability of occurrence is mostly independent of ocean topography. Moreover, the influence of Standard deviations of bottom topography at one and five degrees windows do not represent an effective pressure in the blue shark distribution across the North Atlantic.

The monthly maxima and minima of chlorophyll *a* were used as surrogate variables to estimate primary production within the studied area (Figures B and C, Annex I). Results show that this variable plays an important role on the distribution of blue sharks, as with the increase of chlorophyll *a* values, and its seasonal minima and maxima, the distribution of blue shark tends to decrease.

The influence of SST in the predicted distribution of blue sharks was even more remarkable (Figures D and E, Annex I). In particular, the minimum values of SST clearly restricted the occurrence of this top predator in the area. On the contrary, the maximum values of SST did not appear to be determinant for the potential distribution.

A detailed inspection of the Log response curves for seasonal SST minima (Figure D, Annex I) suggests that in winter months there is a clear preference for areas where water temperatures range between 10 and 15ºC. Also, in spring the optimal temperature range is apparently the same. In autumn, the range is still similar, but extends to 20ºC. Finally, it is in the summer months that this range presents more differences, with a sharp decrease in shark occupancy in waters with minimum temperatures above the 20ºC. In all seasons the optimal thermic range was consistent with what is already known for this species, around 16 ºC (Compagno 1984).

1.3 Seasonal Modelling

Results for seasonal models of distribution using Maxent are depicted in Figures 7-10. A star pattern has been described in the blue shark movements across the entire North Atlantic as well as North-South migrations off Iberian Peninsula during winter and summer seasons. Seasonal variations in the predicted distribution clearly mimic these patterns.

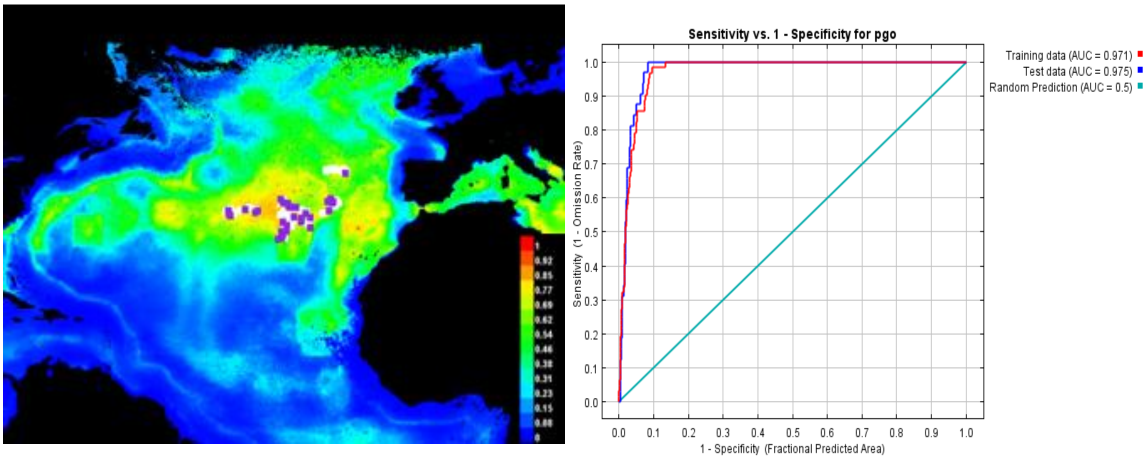


Figure 7 Winter distribution modelling for blue shark and respective ROC curve

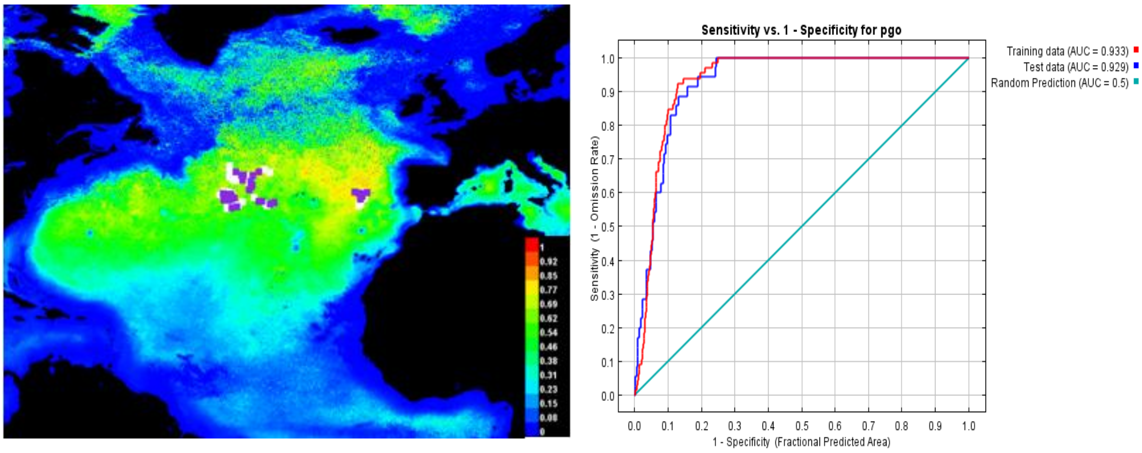


Figure 8 Autumn distribution modelling for blue shark and respective ROC curve

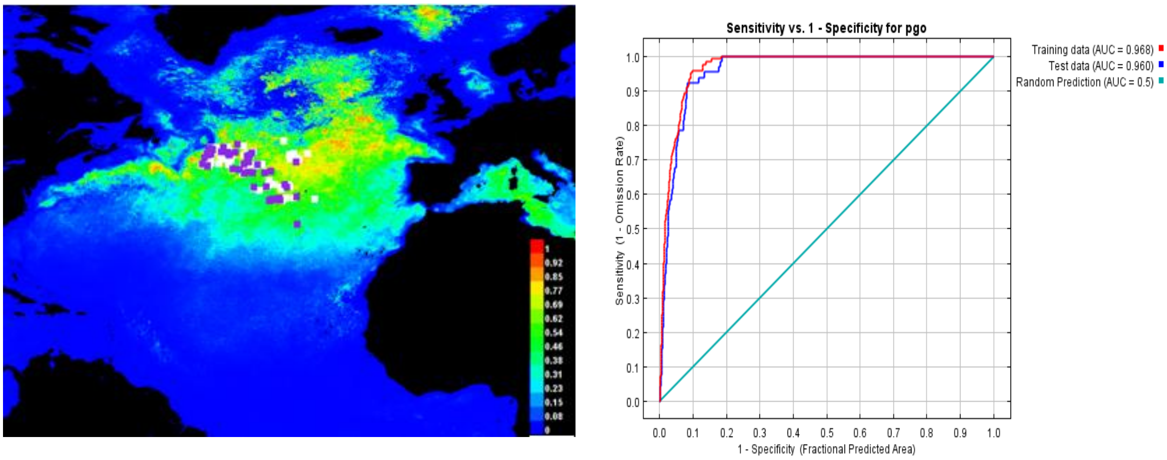


Figure 9 Summer distribution modelling for blue shark and respective ROC curve.

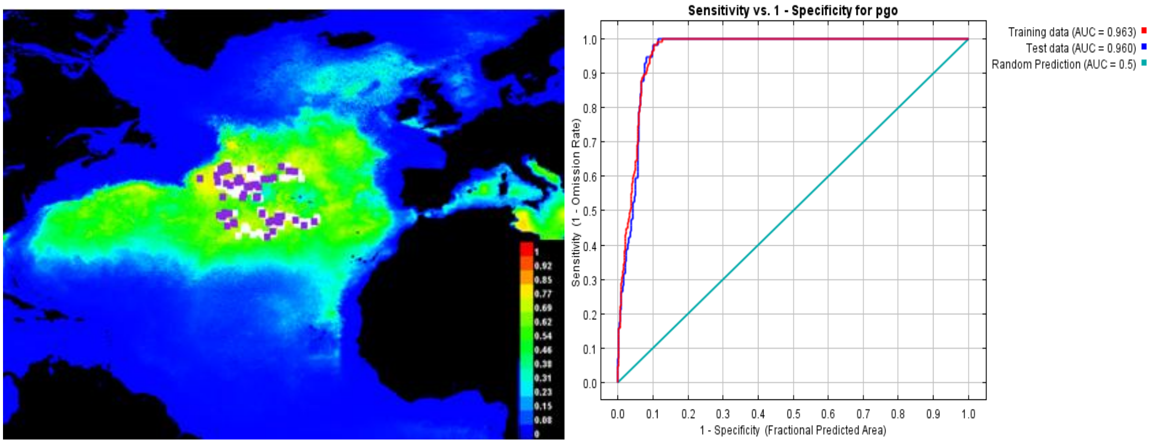


Figure 10 Spring distribution modelling for blue shark and respective ROC curve.

Focusing on the area around Iberian Peninsula, it is possible to observe a north-south migration, which may be a consequence of seasonal differences in water temperature. In the summer blue shark migrate towards the north, reaching southern UK, whereas during the winter they clearly prefer southern and warmer waters, around southern Iberian Peninsula and North Africa. In autumn and spring months the distribution is confined to the middle of the Atlantic Ocean, just offshore the Iberian Peninsula with no special north-south preferences. The AUC values for each seasonal model were high (Table 2), suggesting that they are a good approach to environmental suitability of *Prionace glauca* distribution in relation to seasonality.

Table 2 - AUC values for seasonal distributional models of *P. glauca* in the North Atlantic Ocean generated with Maxent (random AUC is 0.5).

	AUC values	
SEASON	**Training**	**Test**
Spring	**0.968**	**0.960**
Summer	**0.963**	**0.960**
Autumn	**0.933**	**0.929**
Winter	**0.971**	**0.975**

Jackknife graphics provided by Maxent for each of the seasonal models (Figure 11) show the major influence of Sea Surface Temperatures in the predicted distribution of blue sharks. All seasonal distributions predicted shared a common limiting factor, the minimum values of SST. Interestingly, the summer model was the only one that did not show this variable as giving unique information to the predictive model. In both spring and autumn the second most effective pressure factor was the maximum value of chlorophyll *a*. In winter topographic characteristics (the standard deviations at 5 degrees) assumed also some relevance. In the summer, chlorophyll *a* was together with minimum value of SST, the most important feature conditioning the distribution of *P. glauca.*

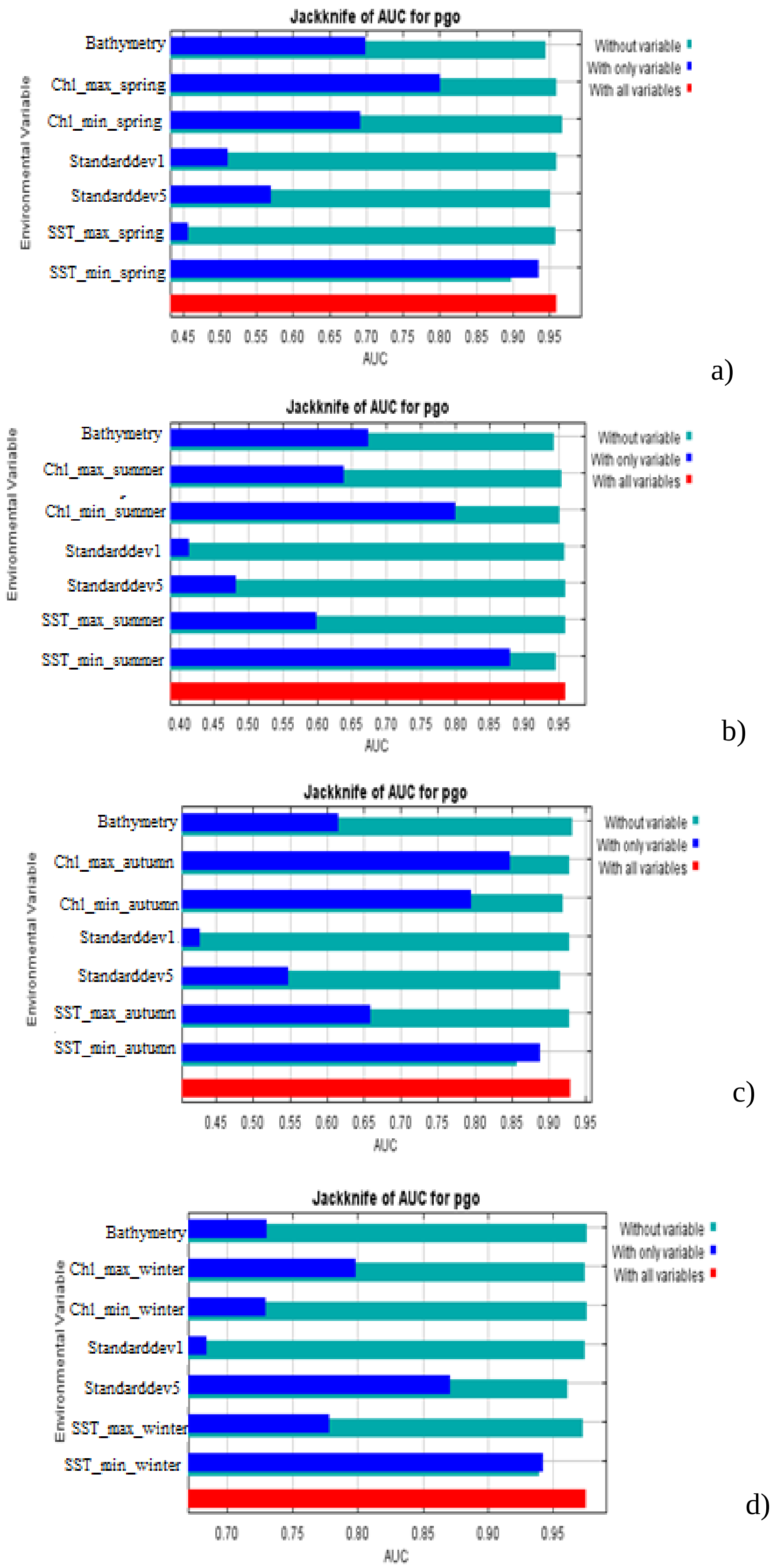


Figure 11 Jackknife representing seasonal models of *P. glauca* distribution, a) spring, b) summer, c) autumn and d) winter.

2. Portuguese longlining VMS analysis

2.1 Longliners VMS selection and landing analysis

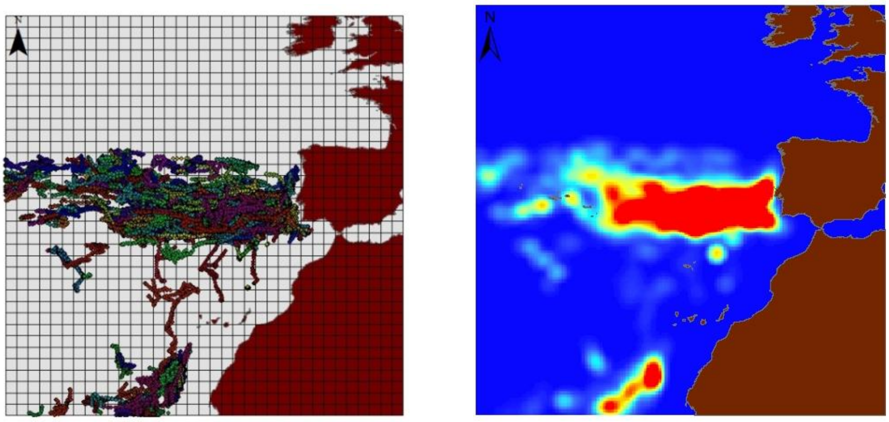
Data from Portuguese longline vessels monitoring system was analysed to map the areas where the fishing effort is higher on the North Atlantic Ocean. To choose those vessels which only operate this sort of fishing technique for the requested period (2006-2008) over the delimited area and targeting great pelagic species, every official landing record was examined. From the total of registered longliners, 28 were selected and the landings were inspected up to the species level, whenever possible. In Tables 3 and I (Annex II) it is possible to observe that the target species of this fishery were tunas and swordfish (*Thunnus spp*. and *Xiphias gladius,* respectively), but many other great pelagic species were hold and landed on Portuguese ports. Data from wet weight landings (Table I, Annex II) show that shark species, such as mako shark (*Isurus oxyrhinchus)* and blue shark *(Prionace glauca)* represent almost 40% of the total landed records, while swordfish or tunas represent no more than 19% in any year. Thus, if the analysis is done according to the number of landed specimens (Table 3) swordfish is the second major catch, behind mako sharks, which is the most captured species every year (except for 2007 when the number of tuna species captured exceeded all the others). The number and amount of these great pelagic species captures' was constant during the three-year of period of these data on fishing activity.

Table 3 - Major pelagic species' frequencies and proportion (%) landed by Portuguese ports from 2006 and 2008.

Species	**2006**		**2007**		**2008**	
	%	**Number of individuals**	**%**	**Number of individuals**	**%**	**Number of individuals**
I. oxyrhinchus	21.10%	123	18.11%	153	19.77%	120
P.glauca	19.38%	113	14.56%	123	16.14%	98
A. vulpinus	0.00%	0	7.34%	62	10.21%	62
Sphyrna spp.	0.69%	4	0.12%	1	0.16%	1
X. gladius	20.07%	117	17.28%	146	18.62%	113
Thunnus spp	10.81%	63	19.64%	166	14.33%	87
K. pelamis	6.17%	36	6.86%	58	5.44%	33
Others	21.78%	127	16.09%	136	15.32%	93

2.2 Analysis of VMS records

The analysis of VMS data depicted in Figure 12 show that the area between 20 - 44º N and 0 - 35º W is being overexploited by Portuguese longliners. The fleet remains in offshore zones to the west of the Iberian Peninsula, exploring also southern latitudes. The area covered by these vessels is roughly one third of the area encompassed in the present study (Figure 13).



a) b)

Figure 12 Portuguese longlining VMS analysed for the Northeast Atlantic Ocean region, a) vessels positions; b) longlining effort (Kernel density estimator), from 2006 to 2008

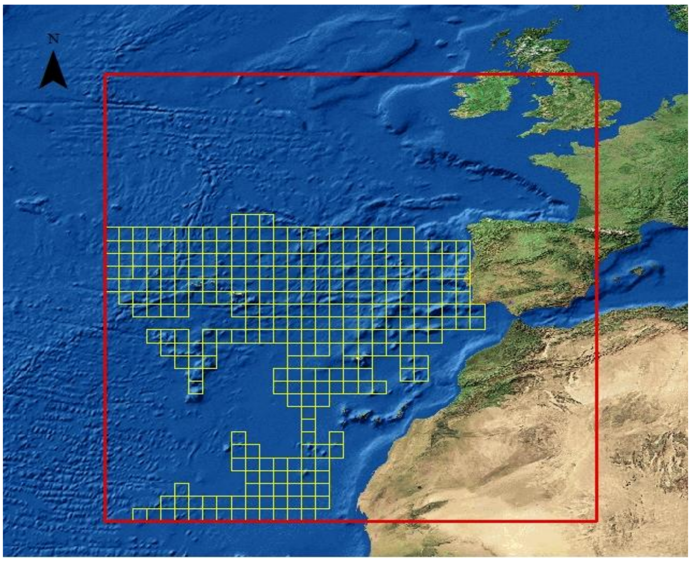
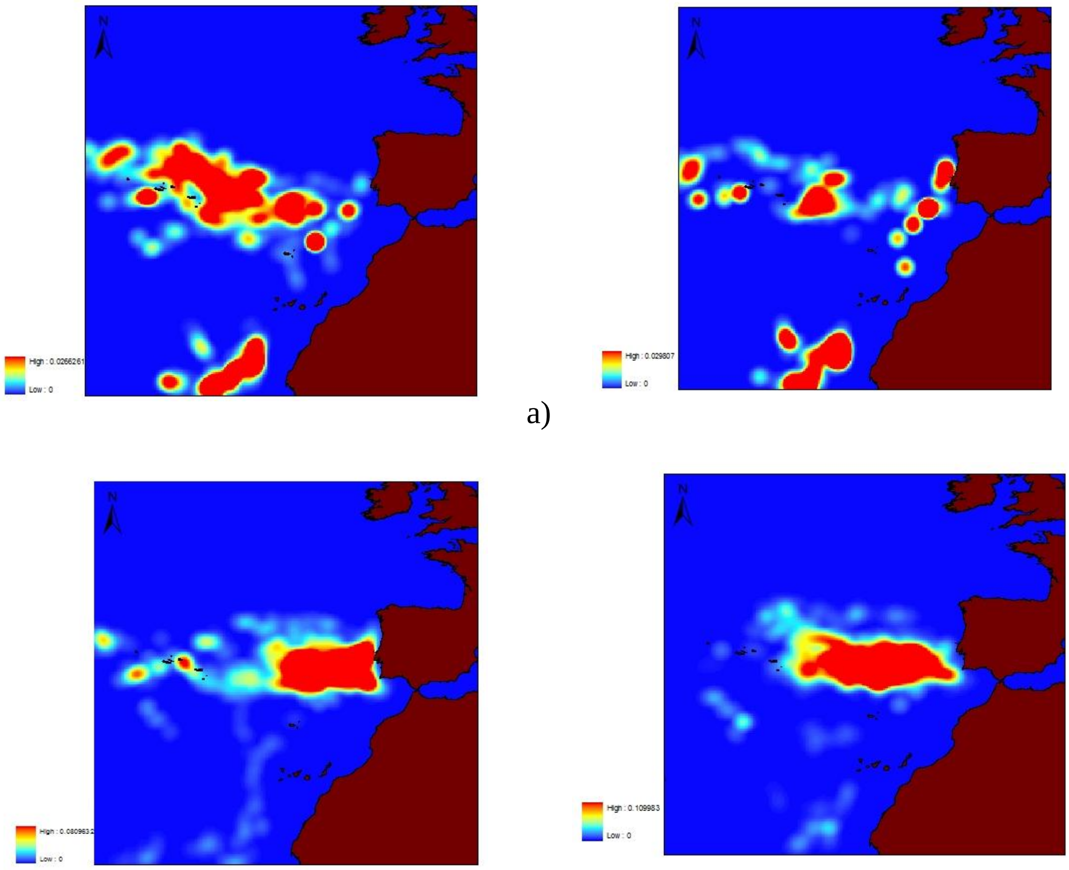


Figure 13 Portuguese longlining activity areas on Northeast Atlantic Ocean, from 2006 to 2008, red line defines study area and yellow grid represents the longlining effort area.

Figure 14 depicts the seasonal differences in patterns of fishing activity. In colder months (winter and autumn) vessels stay offshore between the Iberian Peninsula and Azorean waters. In spring and summer, they concentrate in Azorean waters, but also explore southern latitudes, reaching the Mauritanian coast. Overall, the area explored in spring and summer is larger and more scattered that the one explored in winter and autumn. Interestingly, the number of positions gathered from VMS analysis in warmer seasons is much smaller than in the colder seasons (Table 4).



a) b)

c) d)

Figure 14 Seasonal fishing effort of Portuguese longline vessels operating in Northeast Atlantic Ocean, from 2006 to 2008, a) spring; b) summer; c) autumn and d) winter.

Table 4 – Seasonal comparison of Portuguese longlining fishing effort expressed as number of fishing positions.

Season	**Number of fishing positions**
Spring	12196
Summer	4526
Autumn	20860
Winter	24634

2.3 Ecological analysis of longlining activity areas

The total area covered by longliners was mapped over each environmental feature used in the Maxent model, either as averages for the whole study period or per season (Figures 15-18). Correlation between these variables and fishing effort are summarised in Table 5. Overall, correlations vary from low to moderate values ($r<0.4$), and in many cases they were not statistically significant.

Average SST for the whole study period was positively correlated with fishing effort areas ($r=0.204407$, $p<0.05$). It is worth mentioning that the whole area exploited by Portuguese longliners is on a range of temperatures above 15.5 ºC. A detailed inspection of seasonal results (Figure A, Annex II), revealed no significant correlations between SST and longlining activity except for the autumn, where a negative but small correlation was observed ($r=-0.13901$, $p<0.05$), suggesting that during this season the fishing fleet may try to avoid warmer areas.

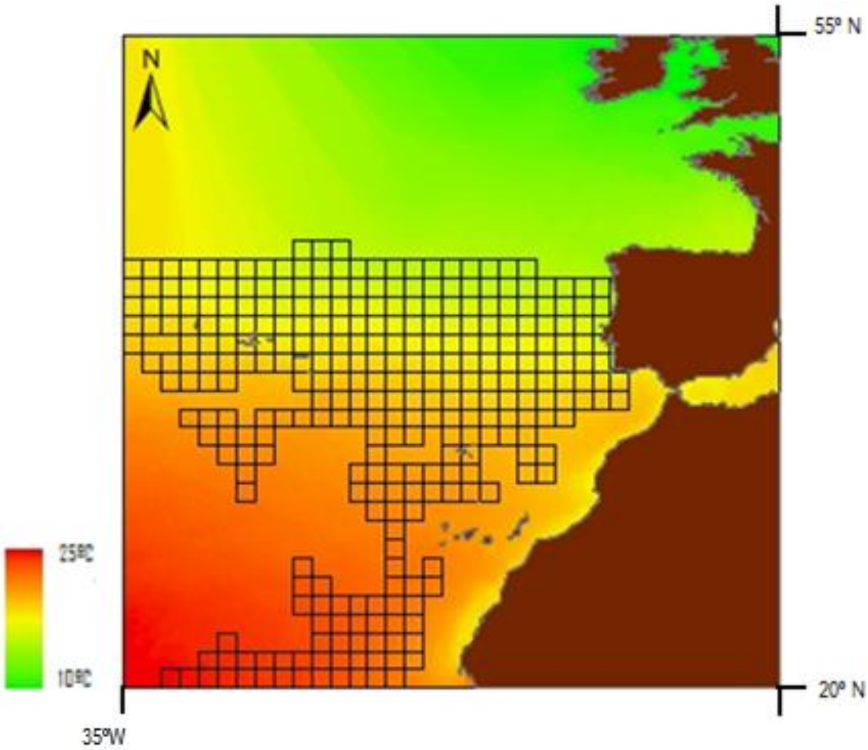


Figure 15 Portuguese longlining effort in Northeast Atlantic Ocean with respect to average Sea Surface Temperature, from 2006 to 2008.

In relation to ocean topography, results show a direct correlation between the longlining activity and bathymetry ($r=0.328071$, $p<0.05$). Although this was one of the highest correlations observed, it still is not apparent when the maps are inspected visually. Seasonal analysis of correlation between bathymetry and longlining effort (Figure B, Annex II) revealed significant statistics for all seasons but for spring ($r=0.079$, $p=0.251$). Thus, data suggests that the vessels explore preferentially zones of shallower waters which, in the middle of the ocean, are only found near seamounts and submarine canyons.

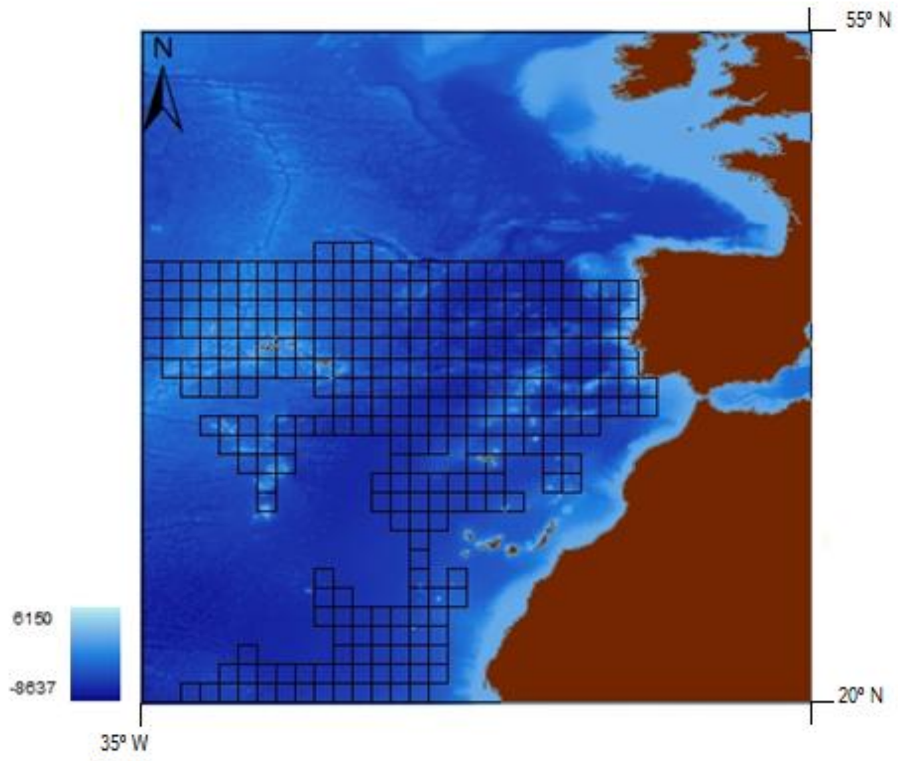


Figure 16 Portuguese longlining effort areas in Northeast Atlantic Ocean with respect to bathymetry, from 2006 to 2008.

Significant correlations between mean SST anomalies and fishing effort were obtained for the data concerning the whole study period (r=0.212, p=0.002). Superimposing fishing effort on SST anomalies' layers (Figure 21) clearly shows that the fleet is often in areas characterized by abrupt changes in sea surface temperature like fronts. At a seasonal level (Figure C, Annex II), no significant correlations were observed.

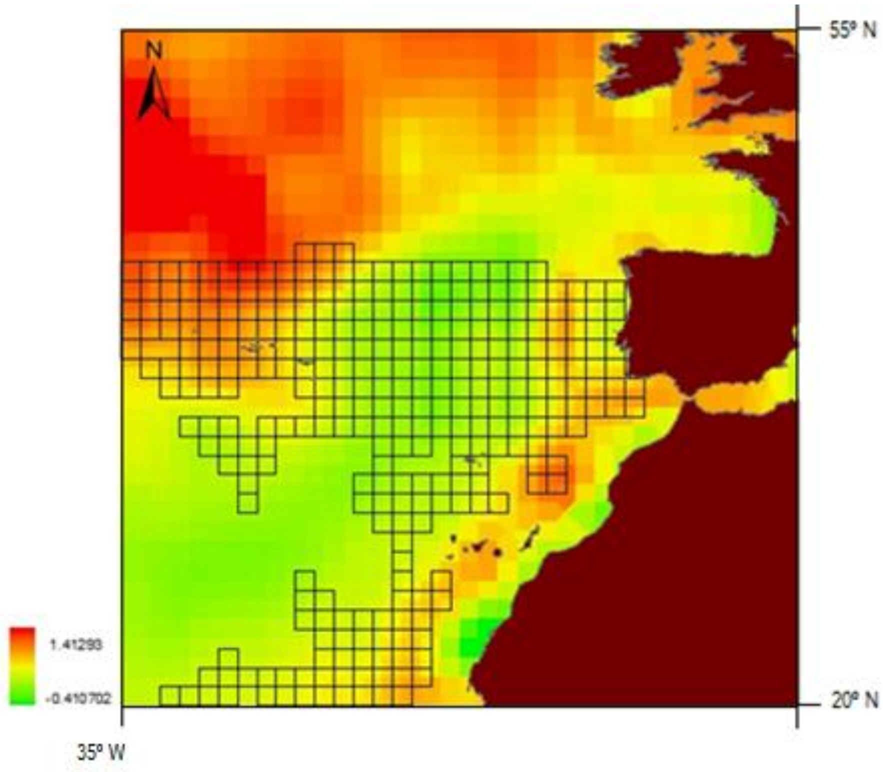


Figure 17 Portuguese longlining effort areas in Northeast Atlantic Ocean with respect to sea surface temperature anomalies, from 2006 to 2008

For chlorophyll *a*, it is clear that longlining activity is not associated with high productive areas (Figure 18). This was confirmed by the non-significant correlation between these two variables (r=0.174, p=0.170). Seasonal analyses (Figure D, Annex II) revealed only a significant and negative correlation during summer (r=-0.273, p=0.031), suggesting that in this season the fleet tends to exploit areas or regions characterized by low productivity.

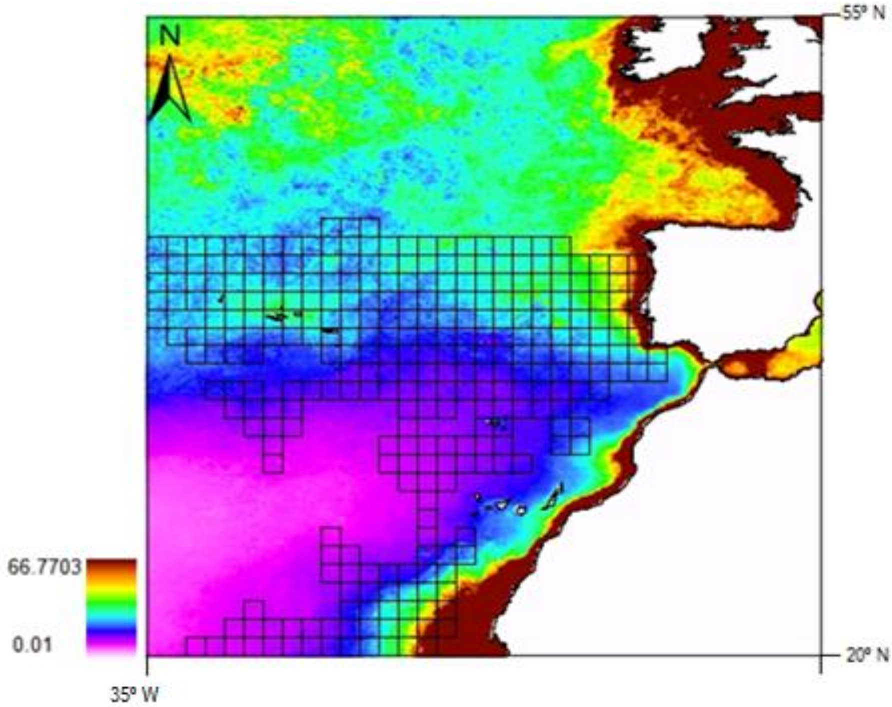


Figure 18 Portuguese longlining effort areas in Northeast Atlantic Ocean with respect to Chlorophyll *a* mean values, from 2006 to 2008.

Table 5 – Values of Pearson's correlations between longlining activity and environmental features, over the study period, yearly and per season. Values in bold denote a significant correlation at the 0.05 level (two-tailed).

Periods	General		spring		summer		autumn		winter	
	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*
SST	**0.204**	**0.000**	**0.003**	**0.955**	**-0.070**	**0.424**	**-0.139**	**0.048**	**0.135**	**0.066**
Bathymetry	**0.328**	**0.000**	**0.079**	**0.251**	**0.196**	**0.033**	**0.349**	**0.000**	**0.296**	**0.000**
SST anomalies	**0.212**	**0.002**	**-0.035**	**0.615**	**-0.082**	**0.378**	**-0.036**	**0.606**	**0.048**	**0.517**
Chlorophyll *a*	**0.174**	**0.170**	**0.021**	**0.871**	**-0.273**	**0.031**	**0.014**	**0.913**	**-0.057**	**0.658**

3. Overlap of blue shark distribution and longlining effort

The overlap of blue shark distribution and longlining effort is depicted in Figure 19. Longlining effort tends to be higher in areas of higher probability of occurrence of this great pelagic shark. A visual inspection of this map shows that a reasonable part of the total predicted area that satisfies blue shark ecological niche is under fishery activity. Seasonal results (Figure 20) show a more variable pattern of overlap, which is apparently smaller during summer.

Quantitative analysis of these data is summarized in Table 6 and depicted in Figures 21 (for the whole study area) and 22 (for seasons). Apparently, longlining vessels tend to exploit sharks more harshly in colder seasons. The accumulated area covered by longline vessels is around 49% of the total area considered in this study. If seasons are considered the pattern of exploitation varies between 25-29% for all seasons, with the exception of summer, where it is less intensive (14%). The blue shark occupies 44% of the study area, but if seasons are considered this occupancy is higher in colder months. Nonetheless, seasonally this area occupied remains above 30% of the total area analysed. Overall, the overlap between the potential distribution of *P. glauca* and the area explored by longliners is around 40%. Again, seasonal analysis shows a variable pattern between of 30-39%, except for summer season, where it falls to 15%.

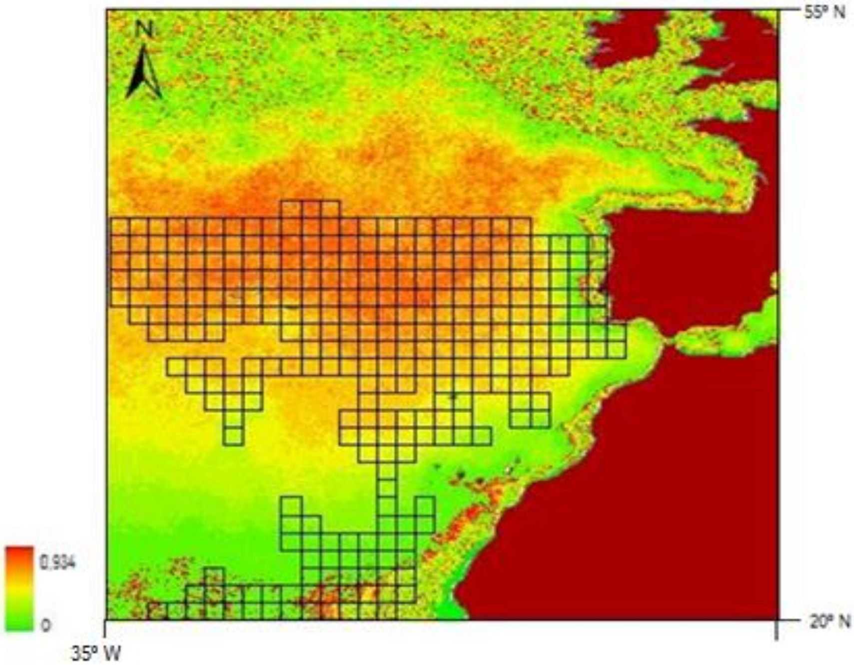


Figure 19 Portuguese longlining effort (3x3 Km square grid) from 2006 to 2008, mapped over the potential distribution of blue shark. Warmer colours represent areas with higher probability of blue shark occurrence.

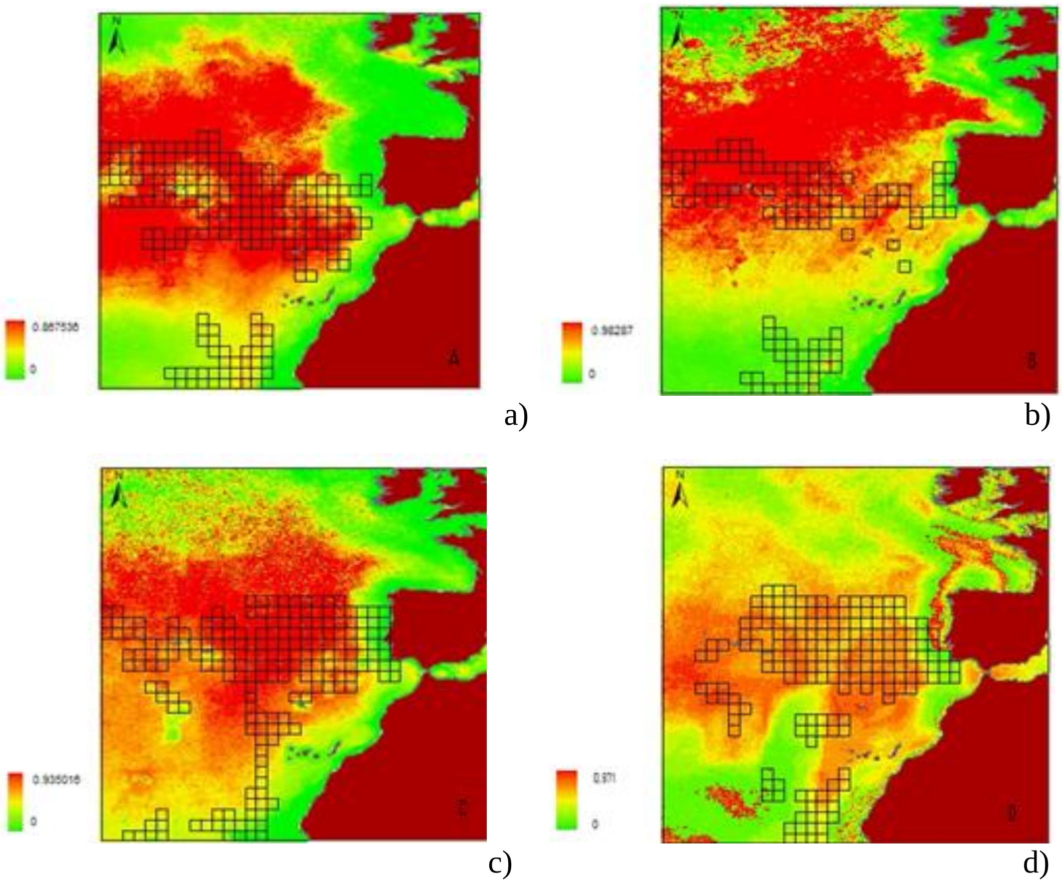


Figure 20 Seasonal longlining efforts mapped on blue shark seasonal potential distributions, a) spring; b) summer; c) autumn and d) winter.

Table 6 – Quantitative assessment of the area covered by longliners, blue shark potential distribution in relation to total area and overlap between longlining effort and predicted distribution of blue shark.

	yearly	spring	summer	autumn	winter
Area covered by longlining (%)	**49**	**29**	**14**	**28**	**25**
Blue shark occurrence (%)	**44**	**38**	**31**	**45**	**47**
Overlap (%)	**40**	**30**	**15**	**38**	**39**

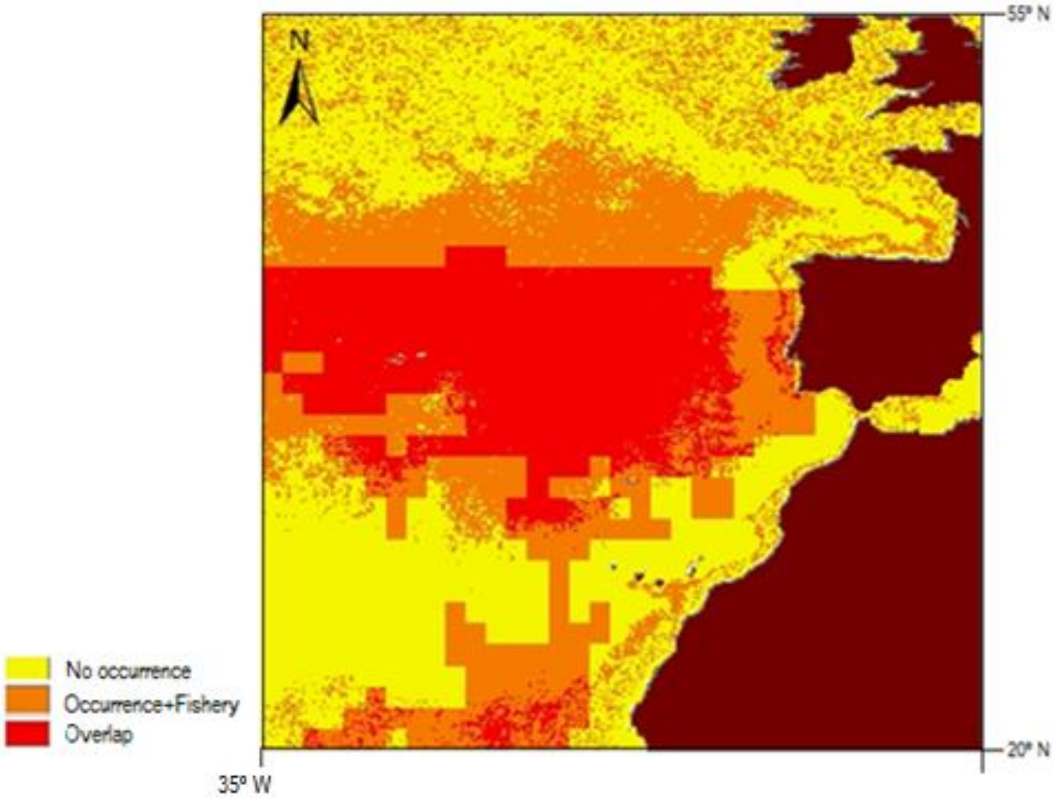


Figure 21 Representation of blue shark possible overexploitation in the Northeast Atlantic Ocean, by Portuguese longlining practice. Cells in yellow represent the absence of blue shark.

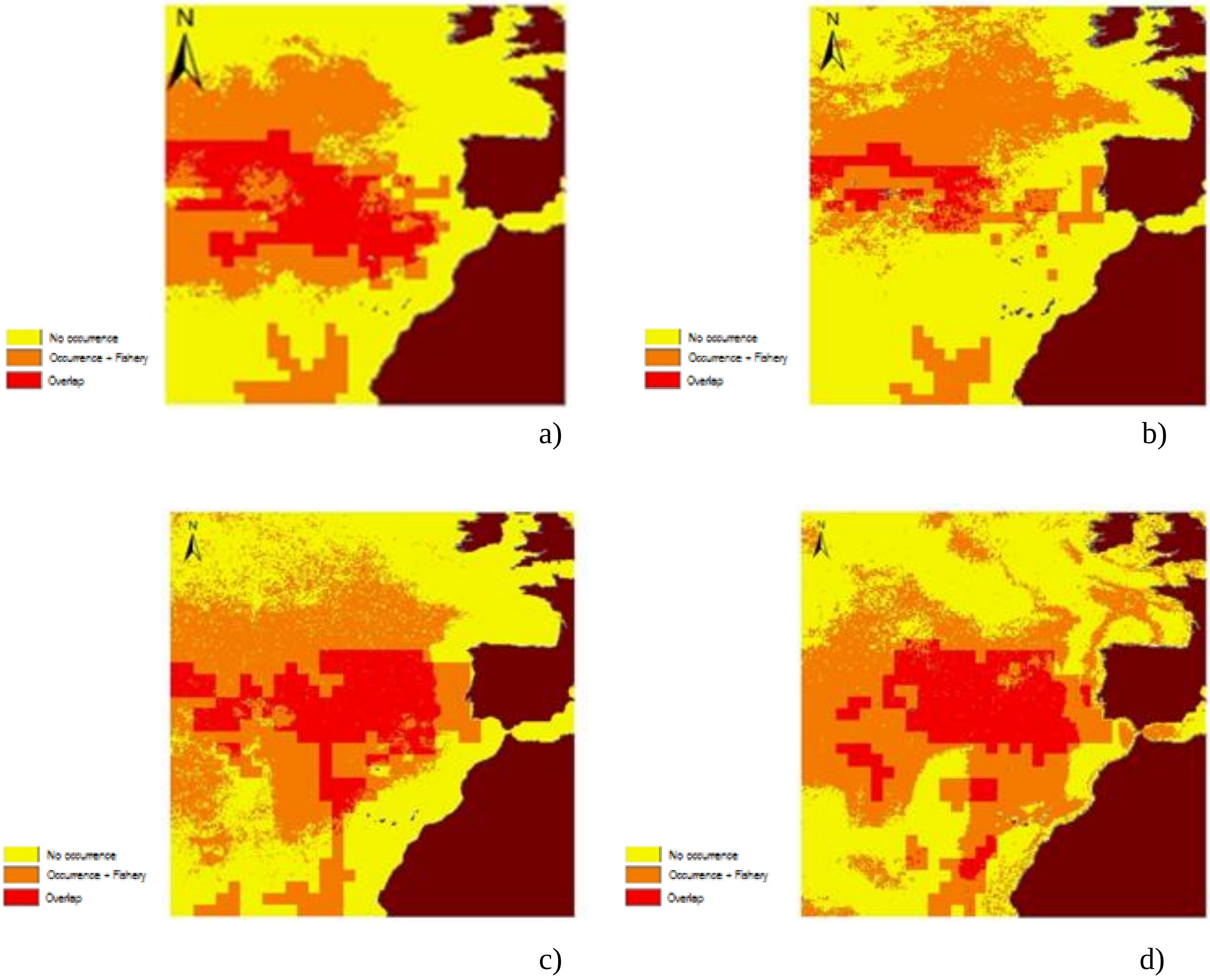


Figure 22 Seasonal exploitation proportions of blue shark in Northeast Atlantic Ocean, a) spring; b) summer; c) autumn and d) winter.

4| DISCUSSION

DISCUSSION

Raw results from longlining practice show that a large number of blue sharks are being caught by commercial fisheries in the Northeast Atlantic. In a total of 573 spooled lines used as data sources for this study, only 28 did not retrieve a blue shark presence. This information is of particular importance when there is an increased awareness about the depletion of the stocks of *Prionace glauca* in the North Atlantic. In 2000 the IUCN Red List Assessment raised the conservation status of the blue shark to Near Threatened (Dulvy et al. 2008). The overexploitation of this species, particularly in the North Atlantic, is of great concern since not much is known about the consequences of a keystone predator removal at the ecosystem level (Gibson et al. 2006).

1. Blue shark distribution model

Many research studies aiming to determine blue shark population distribution in the Northeast Atlantic have been done, based on tagging programs (e.g. Stevens 1976, 1990, Fitzmaurice et al. 2005, Queiroz et al. 2005). Conventional tags supply valuable data on stock structure, distribution of life history classes, and direct evidence of fish horizontal movements (Kohler et al. 2002). However, mark-recapture studies do not provide enough information to understand the behaviour of marine animals at small temporal and spatial scales, and to establish accurately the effects of environmental influences on their distribution (e.g. Stevens 1976).

Predictive species distribution modelling (SDM) has become an essential tool in biodiversity conservation and management (Guisan et al. 2007). Whenever the geographical area to be covered is huge, and the methods employed in direct/indirect observation are expensive these techniques may be the only way to obtain a general picture of the spatio-temporal distribution of an organism. This is precisely the case of free-ranging oceanic species, such as the blue shark, for which conventional techniques of observation (involving oceanic vessels) are prohibitive. Another problem, related with data gathered from platforms of opportunity (such as recreational boats, or even longliners) is that it is very difficult to obtain a significant or reliable number of absence records which are required by standard ecological modelling technique (e.g., linear or non-linear regression models). In the particular case of blue sharks in the northeast Atlantic, the absence of blue sharks in a longline cannot be unambiguously assigned to a local absence of this species. Fish may simply ignore the bait. Hence, according to

Guisan and Thuiller (2005) presence-only models are the most appropriate techniques to predict the distribution of highly mobile organisms.

Overall, the predictive models generated by Maxent were quite accurate, as indicated by the AUC values for both training and test datasets. Multicollinearity of environmental predictors, a problem that often arises in many modelling techniques, may render part of the results uninterpretable. The effect of multicollinearity on Maxent analysis is still a matter of debate. Unlike generalized linear models, Maxent does not need to invert the covariance or correlation matrix, an operation which result is highly affected by multicollinearity. Therefore, a good model may still be obtained even under high levels of multicollinearity, but its detailed interpretation is hampered. Whenever the explanatory variables are moderately to highly correlated, as is the case of the present study, their individual effects on the predicted distribution should be taken with caution.

Apparently, the effect of bathymetry on the predicted distribution was not significant, as the relative contributions of ocean topography variables to the model were low. However, a significant effect was expectable, since sharks often aggregate nearby seamounts, reef islands or shelf breaks (Worm et al. 2003), using them as waypoints in migration corridors (Holts & Bedford 1993). This was confirmed in blue sharks by satellite telemetry (N. Queiroz, D. W. Sims unpub. data). The exception to this pattern was the winter season. In colder months standard deviation at five degrees of bathymetry appear to have some influence on the model. Results for chlorophyll *a* also suggest that blue shark distribution is not influenced by primary productivity. Again, this was not expectable, since prey density is usually positively correlated with primary productivity. Surprisingly, only in summer was there a statistical significant correlation, and it was negative, suggesting that in this season sharks prefer low productive waters.

The influence of variables derived from SST on the distribution of blue sharks was high, as expected. As an ectothermic species, dependant on the external environment, water temperature is a major determinant of the rate of an animal's physiological processes and growth patterns (Sims 2003). Temperature is known to have direct effects on behaviour, ecology and whole performance of aquatic animals. It affects muscle function, swimming performance, metabolism and cardiorespiratory performance of both ectotermic fishes and their prey (Domenici et al. 2007). Furthermore, ectothermic fish and squid, two major preys of blue shark (Compagno

1984), are easier to catch in colder waters (Domenici et al. 2007). Not considering the high collinearity among explanatory variables, the one that contributed with most information to the model was the minimum value of SST, either generally or per season. Using these data, a pattern on the thermic preferences for the blue shark in the Northeast Atlantic was determined, and a thermal optimum was found around 15 ºC. This figure is consistent with previous studies which found a relatively cooler thermal range for this species, between 7º and 16ºC (Compagno 1984). Overall, the thermal niche and the optimization of prey encounters may be the main factors determining this great predator distribution patterns.

Both general and seasonal predictions of the distribution of *P. glauca* in the Northeast Atlantic were agreement with the known patterns of distribution for the area (Stevens 1976, 1990, Fitzmaurice et al. 2005, Queiroz et al. 2005). The cyclical movement off the Iberian Peninsula has been documented for this species (Pawson & Ellis 2005), as are the north-south movements in the eastern North Atlantic (Henderson et al. 2001). During the summer months, a northwards migration towards the English Channel and Irish waters was predicted, which agrees with data from Queiroz et al. (2005). These north-south migrations may occur as a consequence of the water temperature variations in the area, and at least partially driven by prey density. Furthermore, the area off the Iberian Peninsula, particularly off Portugal, the Mediterranean and the Bay of Biscay are also known to be areas of nursery and parturition for blue sharks (Stevens 1990, Litvinov 2006). Mating is thought to occur during spring and beginning of summer, when adult males and females are present (see Queiroz et al. 2005). The distribution model predicted a permanence of the population around the Iberian Peninsula and the Azores, the latter being known as a zone of male aggregations (Litvinov 2004). The model also predicted an offshore distribution during summer months, to the west of the Iberian Peninsula, which also agrees with trans-Atlantic movements known to occur between East and West North Atlantic (Stevens 1990, Mejuto et al. 2005). Together, these results suggest that, even under a highly multicollinearity scenario, the models derived by Maxent are quite reliable.

2. VMS data analysis

Catch data of longlining obtained by Monicap-VMS framework confirmed that marine predators are being heavily exploited by the Portuguese fleet in the Northeast Atlantic. This is of great concern, since longlining is a non-selective gear and catches are indiscriminate and therefore uncontrollable. Results from this study clearly demonstrate that the technique is quite “ineffective” with a larger proportion of non-target species being caught. Furthermore, the biggest proportion of this bycatch is made by sharks.

At a worldwide level, estimates show that 50% of the global catch of Chondrichthyans is taken as bycatch and is almost totally unmanaged (Stevens et al. 2000). In a recent study, Macguire et al. (2006) demonstrated that 21% of highly migratory tuna and tuna-like species are moderately exploited, 50% fully exploited, 21% overexploited and 8% depleted, of which swordfish stocks in the Atlantic and the southeastern Pacific are fully exploited; For highly migratory sharks species, these figures are: 10% moderately exploited, 35% fully exploited, 40% overexploited, and 15% depleted. According to these authors longlining is the main cause of overfishing and is hampering the recovery of depleted fish populations.

Results from this study also agree with those of Correia & Smith (2004), since during the three-year period under analysis, the biggest fraction of official landings from Portuguese longlining was attributable to elasmobranchs. Unfortunately, not only is there an excessive number of pelagic sharks captured and landed by Portuguese longlining vessels but these captures are relatively constant along the years, representing a total of 40% of the landings. Swordfish, the main targeted species, is the second most captured one, just after mako shark and followed by blue shark.

VMS data also showed that the areas defined by the coordinates 20-44ºN and 8-35ºW are constantly being exploited. This area is characterized by having an average SST around 15.5-24ºC. Apparently, Portuguese longlining vessels restrict their activity to the area offshore the Iberian Peninsula and southern waters. The pattern of area exploitation varies seasonally, being driven mainly by variations in SST and SST anomalies, but also bathymetry. Overall, warmer waters are preferred, probably because these are also preferred by swordfish (Nakamura 1985), and endothermic mako shark and tunas (Bernal et al. 2001, Sepulveda et al. 2004).

The active search and higher fishing effort, in low bathymetric areas confirmed results from other studies, where a strong association was found between swordfish occurrence, the longlining target species, and seamounts and nearby submarine canyons (e.g. Sedberry & Loefer 2001). These bathymetric variations have been described as having a significant high level of productivity and therefore are places where foragers accumulate (Worm et al. 2003). Sharks are also known to prefer these areas (Queiroz et al. 2005), which obviously increases the probability of being captured.

The correlation between mean SST anomalies and fishing effort agrees with various reports that have demonstrated the association of larger pelagic species, as bony fish and sharks, with oceanographic features, such as fronts and eddies (Lutcavage et al. 1999, Lutcavage et al. 2000, Sims et al. 2000, Sims & Southall 2002). These frontal areas, characterized by a sharp interface between two water masses, and therefore by a high primary productivity, are able to sustain large aggregations of predatory organisms (Olson et al. 1994). Also, fronts and eddies might be used by pelagic predators as "migration corridors" (Cotton et al. 2005) or reproduction areas (Lutcavage et al. 1999). It is worth noticing that there is no correlation between fishing effort and SST anomalies at the seasonal scale, meaning that the fleet tends to explore zones where these features vary among seasons but not those that appear at smaller time scales (within seasons).

The seasonal analyses also revealed that during spring fishing effort was not correlated with any of the environmental features used. On the other hand, longlining activity seems to clearly exploit areas with low bathymetry during the remaining seasons. In this case, as explained before, the amount of available species seems to be a driving factor for fisheries exploitation. SST has a negative correlation with autumn months, which probably reflects target species pursuit: it may occur that between September and November longliners are directing the pressure to species with lower thermic range, such as blue sharks (Henderson et al. 2001, Queiroz et al. 2005). This observation is consistent with the results obtained by Santos et al. (2002) who found that in Portuguese longlining fisheries blue shark captures tended to increase from September on.

3. Blue shark vulnerability to exploitation

On a yearly scale, the overlap between blue shark distribution in the study area (estimated from Maxent model) and longlining area covered (estimated from VMS data) was almost 40%. This figure decreases in seasonal analyses, remaining quite high during winter and autumn (around 30%), with the least overlap during summer (15%). The latter is probably a consequence of a shift in the distribution of blue sharks towards the north that is not followed by the fishing fleet, which remains scattered in more southern waters. But it is in the winter months, the most intense fishing season (with 24634 longline positions recorded), that blue sharks migrate to southern and warmer waters, off the Iberian Peninsula and the Azores. In this season, blue shark vulnerability is higher, given that the overlap between its potential distribution and fishing activity reaches almost 40%. Another concern is that this particular fleet seems to heavily explore areas spread around the Iberian Peninsula latitudes, which are thought to be used by *P. glauca* as breeding and nursery areas (e.g. Litvinov 2004). Overall, 44% of the study area may be occupied by the northeast Atlantic blue shark population. At a seasonal scale this distribution reaches roughly 30% of the area delimited for this analysis.

Compared with the other seasons, summer may be the one which presents the lowest threat for blue shark conservation, since only 15% of its potential distribution is under a severe fisheries' activity. However, these values may be misleading, because the present study did not account for the effects of the Spanish longlining fleet. This fleet is much bigger than the Portuguese (roughly three times bigger, according to the number of vessels provided by official control centres), and operates in a much wider area in the Northeast Atlantic.

Despite their low commercial value (if finning is not considered), the declines in abundance of blue sharks and their high overall exploitation rate are all indicators of excessive mortality (Campana et al. 2006). Many marine vulnerable species live in pelagic habitats, making surveys logistically complex and expensive (Lewison et al. 2004), ultimately delaying any quantitative assessment of the effects of fishing activity on their abundance and distribution. The present results show that species' distribution models and VMS data can be successfully combined to provide baseline data for fisheries management and species conservation.

5| CONCLUSION

CONCLUSION

Maxent appears to be a valuable tool to better understand population's distribution when only-presence data is available. The predicted distribution of *P. glauca* in the area studied was in agreement with previous knowledge on the occurrence of this predator in the North Atlantic, and the level of accuracy of the model itself was high (AUC=0.936). Assuming that a high level of multicollinearity among explanatory variables exists, individual contributions of each one to the whole model should be interpreted with caution. Nonetheless, sea surface temperature seems to be the main driving feature of the predicted distribution of blue shark, since the thermic optimum range derived from the results seems to be well within the known values for this species. The influence of bathymetry and productivity (chlorophyll *a*) on the predicted distribution was not significant. Overall, seasonal models were also able to retrieve known patterns of movement in the area.

With VMS data it was possible to reconstruct individual vessel trajectories and, with these, a quantitative measure of area covered during fishing activity was determined. Such information was necessary to compute the overlap between longlining activity and the distribution of blue sharks. The degree of overlap was used as a measure of shark vulnerability to this fishing technique. Values obtained ranged from 40% of overlap (for the whole study period), to 15-40% if seasons were considered. The lowest value of seasonal overlap was in the summer, and the highest in the winter. Although variable, the area covered by the Portuguese longliners is restricted to 20-40ºN. Higher values of overlap in the winter are explained by the southern migration of sharks, which is driven by colder temperatures. Unfortunately, this is the season where fishing activity is higher.

The present results demonstrate the utility of VMS records to determine the susceptibility to fisheries of free-ranging oceanic animals. On the other hand, mapping the fishing effort over remote-sensed environmental features allowed the assessment of the ecological background supporting these fisheries, independently of logbooks and/or vessel masters. In summary, Portuguese vessels actively seek areas of low bathymetry (e.g., seamounts) or regions of sharp variation of temperature (fronts, eddies) which are used by many large species as migration corridors or areas of aggregation. Overall, their contribution to the depletion of several species, including *Prionace glauca,* seems to be quite high, considering the dimension of the fleet. Management plans are urgent if the preservation of less resilient top predatory species, like the blue shark, is to be achieved. These should be deployed at a nationwide level but also at the international level, since other longlining fleets, namely the Spanish longliners, are also operating in the area, probably with a much higher fishing effort, given the number of vessels involved.

6| REFERENCES

REFERENCES

Baum JK, Myers RA, Kehler DG, Worm B, Harley SJ, Doherty PA (2003) Collapse and conservation of shark populations in the northwest Atlantic. Science 299:389-392

Bernal D, Dickson KA, Shadwick RE, Graham JB (2001) Review: Analysis of the evolutionary convergence for high performance swimming in lamnid sharks and tunas. Elsevier Science

Brazner JC, McMillan J (2008) Loggerhead turtle (*Caretta caretta*) bycatch in Canadian pelagic longline fisheries: Relative importance in the western North Atlantic and opportunities for mitigation. Fish Res 91:310-324

Buencuerpo V, Ríos S, Morón J (1998) Pelagic sharks associated with the swordfish, *Xiphias gladius*, fishery in the eastern North Atlantic Ocean and the Strait of Gibraltar. Fish Bull 96:667-685

Camhi M, Fowler S, Musick JA, Bräutigan A, Fordham S (1998) Sharks and their Relatives - Ecology and Conservation, Vol iv +39, IUCN Gland, Switzerland and Cambridge, UK

Campana SE, Marks L, Joyce W, Kohler NE (2006) Effects of recreational and commercial fishing on blue sharks (*Prionace glauca*) in Atlantic Canada, with references on the North Atlantic population. Can J Fish Aquat Sci 63:670-682

Casey JG (1985) Transatlantic migrations of the blue shark; a case history of cooperative shark tagging. In: Stroud RH (ed) Proc First World Angl Conf. World Angling Resources and Challenges, Capd'Agde, France, p 253-268

Casey JG, Kohler NE (1992) Tagging studies on the shortfin mako shark (*Isurus oxyrinchus*) in the western North Atlantic. Aust J Mar Freshwater Res 43:45-60

Coelho R, Erzini K, Correia C, Lino PG, Monteiro P, Ribeiro J, Gonçalves JMS (2005) Semi-pelagic Longline and Trammel Net Elasmobranch Catches in Southern Portugal: Catch Composition, Catch Rates and Discards. J Northw Atl Fish Sci 35:531-537

Compagno LJV (1984) FAO species catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2. Carcharhiniformes. FAO Fish Synop 125 4:251-655

Correia JPS, Smith MFL (2004) Elasmobranch landings for the Portuguese commercial fishery from 1986 to 1999. Mar Fish Rev 65:33-41

Cotton PA, Sims DW, Fanshawe S, Chadwick M (2005) The effects of climate variability on zooplankton and basking shark (*Cetorhinus maximus*) relative abundance off southwest Britain. Fish Oceanogr 14:151-155

Damalas D, Megalofonou P, Apostolopoulou M (2007) Environmental, spatial, temporal and operational effects on swordfish (*Xiphias gladius*) catch rates of eastern Mediterranean Sea longline fisheries. Fish Res 84:233–246

Domenici P, Claireaux G, McKenzie DJ (2007) Environmental constraints upon locomotion and predatorâ€“prey interactions in aquatic organisms: an introduction. Philosophical Transactions of the Royal Society B: Biological Sciences 362:1929-1936

Dulvy NK, Baum JK, Clarke S, Compagno LJV, Cortés E, Domingo A, Fordham S, Fowler S, Francis MP, Gibson C, Martínez J, Musick JA, Soldo A, Stevens JD, Valenti S (2008) You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. Aquatic Conserv: Mar Freshw Ecosyst 18:459-482

Elith J, Graham CH, Anderson RP, Dudı´k M, Ferrier S, Guisan A, Hijmans RJ, Huettmann F, Leathwick JR, Lehmann A, Li J, Lohmann LG, Loiselle BA, Manion G, Moritz C, Nakamura M, Nakazawa Y, Overton JM, Peterson AT, Phillips SJ, Richardson KS, Scachetti-Pereira R, Schapire RE, Sobero´n J, Williams S, Wisz MS, Zimmermann NE (2006) Novel methods improve prediction of species' distributions from occurrence data. Ecography 29:129-151

Fitzmaurice P, Green P, Keirse G, Kenny M, Clarke M (2005) Stock discrimination of the blue shark, based on Irish tagging data. Col Vol Sci Pap ICCAT 58:1171-1178

Garza-Gil MD, Varela-Lafuente MM (2005) The profitability of the Spanish swordfish fleet in the North Atlantic. Marine Policy 29:533–538

Gibsom QA (2006) Non-lethal shark attack on a bottlenose dolphin (*Tursiops* sp.) calf. Mar Mammal Sci 22:190-197

Gibson C, Valenti SV, Fowler SL, Fordham SV (2006) The Conservation Status of Northeast Atlantic Chondrichthyans. Report of the IUCN Shark Specialist Group Northeast Atlantic Regional Red List Workshop Peterborough, UK, 1315 February

Gilman E, Clarke S, Brothers N, Alfaro-Shigueto J, Mandelman J, Mangel J, Petersen S, Piovano S, Thomson N, Dalzell P, Donoso M, Goren M, Werner T (2008) Shark interactions in pelagic longline fisheries. Marine Policy 32:1-18

Gilman E, Kobayashi D, Swenarton T, Brothers N, Dalzell P, Kinan-Kelly I (2007) Reducing sea turtle interactions in the Hawaii-based longline swordfish fishery. Biol Conserv:19-28

Gislason H, Sinclair M, Sainsbury K, O'Boyle R (2000) Symposium overview: incorporating ecosystem objectives within fisheries management. ICES J Mar Sci 57:468-475

Graham CH, Hijmans RJ (2006) A comparison of methods for mapping species ranges and species richness. Global Ecology and Biogeography 15:578–587

Gubbay S (2003) Seamounts of the North-East Atlantic. OASIS, Hamburg & WWF Germany

Guisan A, Graham CH, Elith J, Huettmann F, Group NSDM (2007) Sensitivity of predictive species distribution models to change in grain size. Diversity and Distributions:332-340

Guisan A, Thuiller W (2005) Predicting species distribution: offering more than simple habitat models. Ecol Lett 8:993-1009

Hartley TW, Robertson RA (2006) Emergence of multi-stakeholder-driven cooperative research in the Northwest Atlantic: The case of the Northeast Consortium. Marine Policy 30:580-592

Henderson AC, Flannery K, Dunne J (2001) Observations on the biology and ecology of the blue shark in the north-east Atlantic. J Fish Biol 58:1347-1358

Hernandez PA, Graham CH, Master LL, Albert DL (2006) The effect of sample size and species characteristics on performance of different species distribution modeling methods. Ecography 29:773-785

Hinman K (1998) Ocean Roulette: Conserving Swordfish, Sharks and other Threatened Pelagic Fishes in Longline-Infested Waters. National Coalition for Marine Conservation technical report

Holts DB, Bedford DW (1993) Horizontal and vertical movements of the shortfin mako shark, *Isurus oxyrinchus*, in the southern California Bight. Aust J Mar Freshwater Res 44:901-909

Kohler NE, Turner PA, Hoey JJ, Natanson LJ, Briggs R (2002) Tag and recapture data for three pelagic shark species: blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*), and porbeagle (*Lamna nasus*) in the North Atlantic Ocean. Col Vol Sci Pap ICCAT 54:1231-1260

Lewison RL, Crowder LB, Read AJ, Freeman SA (2004) Understanding impacts of fisheries bycatch on marine megafauna. Trends in Ecology & Evolution 19:598-604

Litvinov F (2004) The dense male aggregation over submarine mounts as an integral part of species range in the blue shark *Prionace glauca*. ICES CM K:11

Litvinov FF (2006) On the role of dense aggregations of males and juveniles in the functional structure of the range of the blue shark, *Prionace glauca*. J Ichthyol 46:613-624

Lutcavage ME, Brill RW, Skomal GB, Chase BC, Goldstein JL, Tutein J (2000) Tracking adult North Atlantic bluefin tuna (*Thunnus thynnus*) in the northwestern Atlantic using ultrasonic telemetry. Mar Biol 137:347-358

Lutcavage ME, Brill RW, Skomal GB, Chase BC, Howey PW (1999) Results of pop-up satellite tagging of spawning size class fish in the Gulf of Maine: do North Atlantic bluefin tuna spawn in the mid-Atlantic? Can J Fish Aquat Sci 56:173-177

Maguire J-J, Sissenwine M, Csirke J, Grainger R, Garcia S (2006) The state of world highly migratory, straddling and other high seas fishery resources and associated species. FAO Fisheries technical paper 495

Marques A (2003) Monicap, Um caso de estudo. MONICAP@INESC

Mejuto J, García-Cortés B (2005) Reproductive and distribution parameters of the blue shark *Prionace glauca*, on the basis of on-board observations at sea in the Atlantic, Indian and Pacific Oceans. Col Vol Sci Pap ICCAT 58:951-973

Mejuto J, García-Cortés B, de la Serna JM (2003) An overview of the activity of the Spanish surface longline fleet targeting swordfish (*Xiphias gladius*) during 2000, with special reference to the Atlantic Ocean. Col Vol Sci Pap ICCAT 55:1485-1494

Mejuto J, García-Cortés B, de la Serna JM, Ramos-Cartelle A (2004) An overview of the activity of the Spanish surface longline fleet targeting swordfish (*Xiphias gladius*) during the year 2001, with special reference to the Atlantic Ocean. Col Vol Sci Pap ICCAT 56:932-939

Mejuto J, García-Cortés B, Ratkowsky DA (2005) Tagging-recapture activities of large pelagic sharks carried out by Spain or in collaboration with the tagging programs of other countries. Col Vol Sci Pap ICCAT 58:974-1000

Mejuto J, Sánchez P, de la Serna JM (1992) Nominal catch per unit of effort by length groups and areas of the longline spanish fleet targeting swordfish (*Xiphias gladius*) in the Atlantic, years 1988 to 1990 combined. Col Vol Sci Pap ICCAT 39:615-625

Mills CM, Townsend SE, Jennings S, Eastwood PD, Hooughton CA (2006) Estimating high resolution trawl fishing effort from satellite-based vessel monitoring system data. Oxford Journals

Musick JA (1999) Ecology and conservation of long-lived marine animals. Am Fish Soc Sym 23:1-10

Myers RA, Worm B (2005) Extinction, survival or recovery of large predatory fishes. Philosophical Transactions of the Royal Society B: Biological Sciences 360:13-20

Nakamura I (1985) FAO species catalogue. Billfishes of the World. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. . FAO FishSynop 5:65

Olson DB, Hitchcock GL, Mariano AJ, Ashjian CJ, Peng G, Nero RW, Podestá GP (1994) Life on the edge: marine life and fronts. Oceanography 7:52-60

Pawson MG, Ellis JR (2005) Stock identity of elasmobranchs in the Northeast Atlantic in relation to Assessment and Management. J Northw Atl Fish Sci 35:173-193

Peterson AT, Papes M, Eaton M (2007) Transferability and model evaluation in ecological niche modeling. A comparison of GARP and Maxent. Ecography 30:000-000

Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modeling of species geographic distributions. Ecol Model 190:231-259

Queiroz N, Lima FP, Maia A, Ribeiro PA, Correia JPS, Santos AM (2005) Movements of blue shark, *Prionace glauca*, in the north-east Atlantic based on mark-recapture data. J Mar Biol Ass UK 85:1107-1112

Sainsbury KJ, Punt AE, Smith ADM (2000) Design of operational management strategies for achieving fishery ecosystem objectives. ICES J Mar Sci 57:731-741

Santos MN, Garcia A, Pereira JG (2002) A historical review of the by-catch from the portuguese surface long-line swordfish fishery: observations on Blue shark (*Prionace glauca)* and short.fin Mako (*Isurus oxyrhincus*) Col Vol Sci Pap ICCAT 54(4):1333-1340

Sedberry GR, Loefer JK (2001) Satellite telemetry tracking of swordfish, *Xiphias gladius*, off the eastern United States. Mar Biol 139:355-360

Séligny J-FPd, Gumy A, Grainger R (2007) The State of World Fisheries and Aquaculture 2006 (SOFIA) FAO Fisheries and Aquaculture Department Part 1

Sepulveda CA, Kohin S, Chan C, Vetter R, Graham JB (2004) Movement patterns, depth preferences, and stomach temperature of free-swimming juvenile mako sharks, *Isurus oxyrinchus*, in the Southern California Bight. Mar Biol 145:191-199

Sims DW (2003) Tractable models for testing theories about natural strategies: foraging, behaviour and habitat selection of free-ranging sharks. J Fish Biol 63 (Supplement A):53-73

Sims DW, Nash JP, Morritt D (2001) Movements and activity of male and female dogfish in a tidal sea lough: alternative behavioural strategies and apparent sexual segregation. Mar Biol 139:1165-1175

Sims DW, Southall EJ (2002) Occurence of ocean sunfish, *Mola mola* near fronts in the western English Channel. J Mar Biol Ass UK 82:927-928

Sims DW, Southall EJ, Quayle VA, Fox AM (2000) Annual social behaviour of basking sharks associated with coastal front areas. Proc R Soc Lond B 267:1897-1904

Sims DW, Southall EJ, Richardson AJ, Reid PC, Metcalfe JD (2003) Seasonal movements and behaviour of basking sharks from archival tagging: no evidence of winter hibernation. Mar Ecol Prog Ser 248:187-196

Skomal GB, Natanson LJ (2003) Age and growth of the blue shark (*Prionace glauca*) in the North Atlantic Ocean. Fish Bull 101:627-639

Soykan CU, Moore JE, Zydelis R, Crowder LB, Safina C, Lewison RL (2008) Why study bycatch? An introduction to the Theme Section on fisheries bycatch. Endang Species Res 5:91-102

Stevens JD (1976) First results of shark tagging in the north-east Atlantic, 1972-1975. J Mar Biol Ass UK 56:929-937

Stevens JD (1990) Further results from a tagging study of pelagic sharks in the north-east Atlantic. J Mar Biol Ass UK 70:707-720

Stevens JD, Bonfil R, Dulvy NK, Walker PA (2000) The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES J Mar Sci 57:4776-4494

Tudela S (2004) Ecosystem effects of fishing in the Mediterrean: An analysis of the major threats of fishing gear and practices to biodiversity and marine habitats. *Studies and Reviews General Fisheries Commission for the Mediterranean* No 74 Rome, FAO44p

Ward P, Lawrence E, Darbyshire R, Hindmarch S (2008) Large-scale experiment shows that nylon leaders reduce shark bycatch and benefit pelagic longline fishers. Fish Res 90:100-108

Witt M, Godley BJ (2007) A Step Towards Seascape Scale Conservation: Using Vessel Monitoring Systems (VMS) to Map Fishing Activity. PLoS ONE 2(10)

Worm B, Lotze HK, Myers RA (2003) Predator diversity hotspots in the blue ocean. Proceedings of the National Academy of Sciences of the United States of America 100:9884-9888

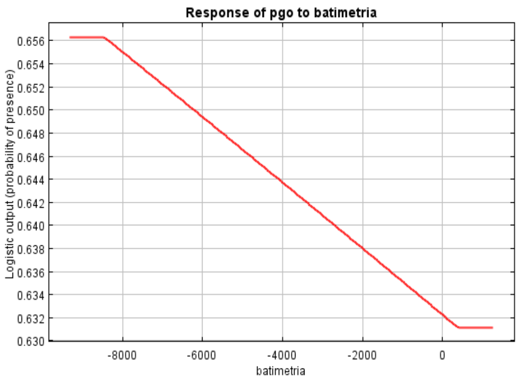
Worton BJ (1989) Kernel Methods for Estimating the Utilization Distribution in Home-Range Studies. Ecology 70:164-168

Wu x, Stengos T (2005) Partially adaptative estimation via the maximum entropy densities. Econometrics Journal 8:352-366

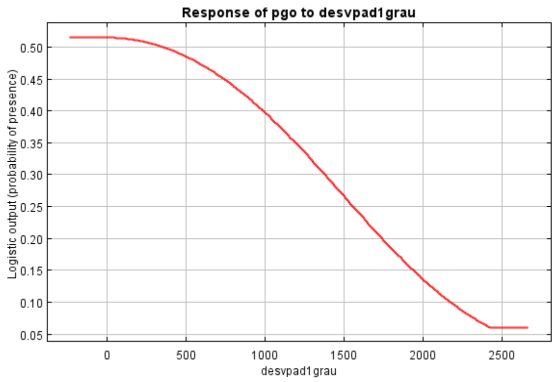
7| ANNEXES

Annex I – *Prionace glauca* potential distribution

I.1 Log response curves of blue shark distribution response to each environmental feature:



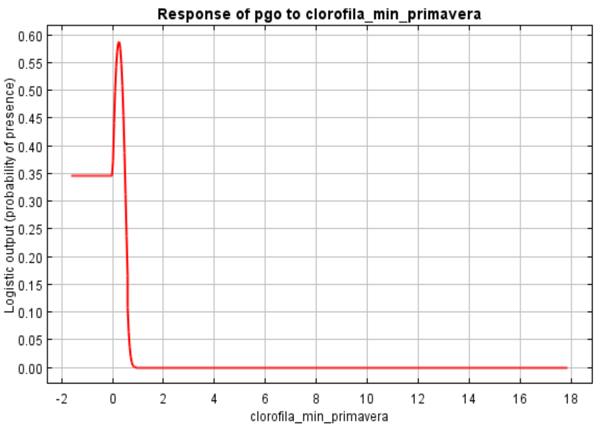
a)



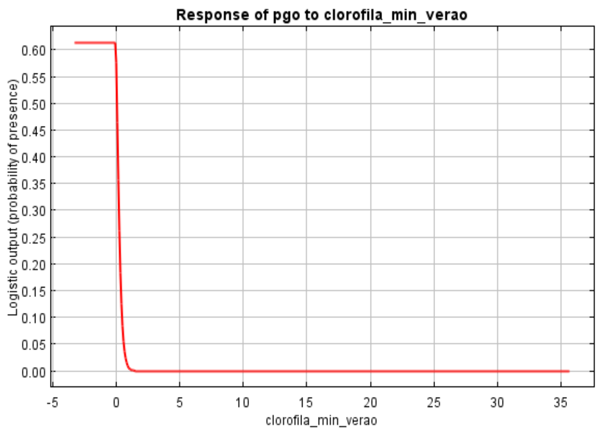
b)

c)

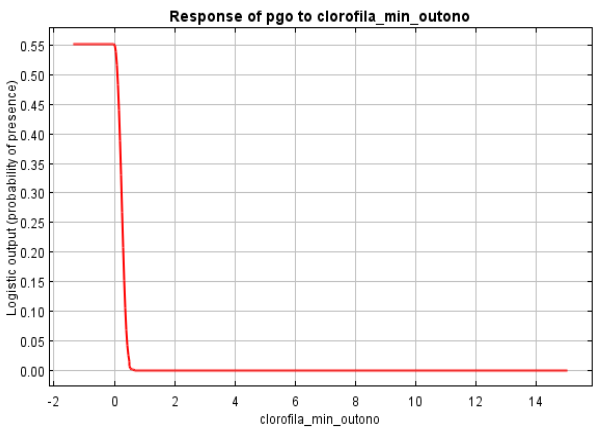
Figure A Bathymetric influences on blue sharks' distribution- log response graphics illustration. a) Bathymetry; b) standard deviation of bathymetry at one degree side window; c) standard deviation of bathymetry at five degrees side window.



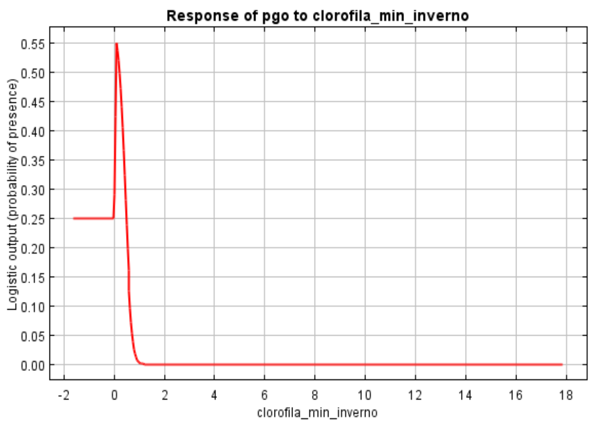
a)



b)

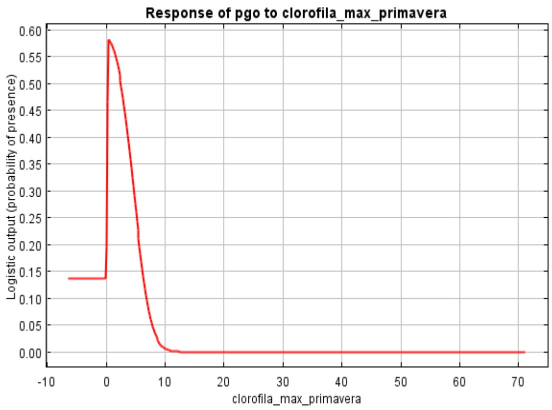


c)

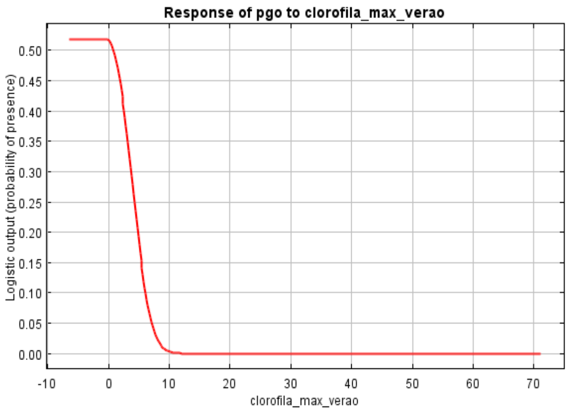


d)

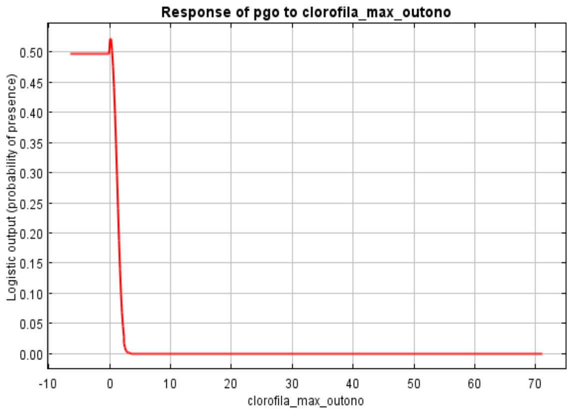
Figure B Chlorophyll *a* minimum values influences on seasonal blue sharks' distribution - log response graphics illustration. a) spring; b) summer; c) autumn; d) winter

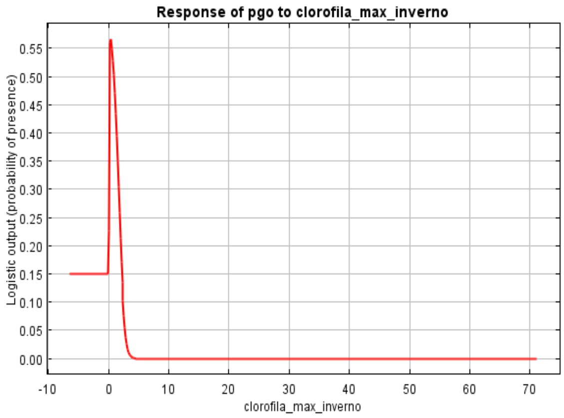


a)



b)





c) d)

Figure C Chlorophyll *a* maximum values influences on seasonal blue sharks' distribution - log response graphics illustration. a) spring; b) summer; c) autumn; d) winter

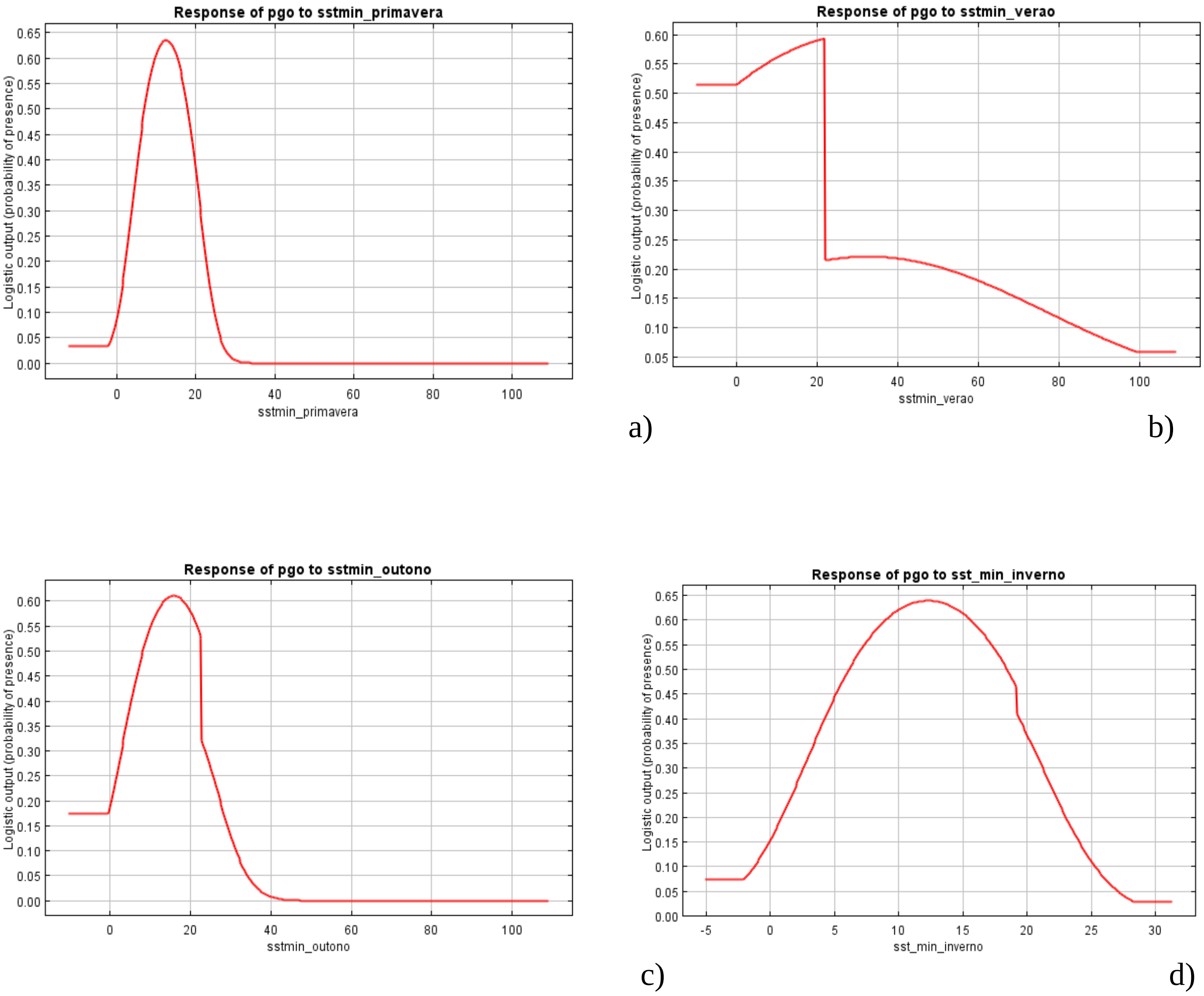
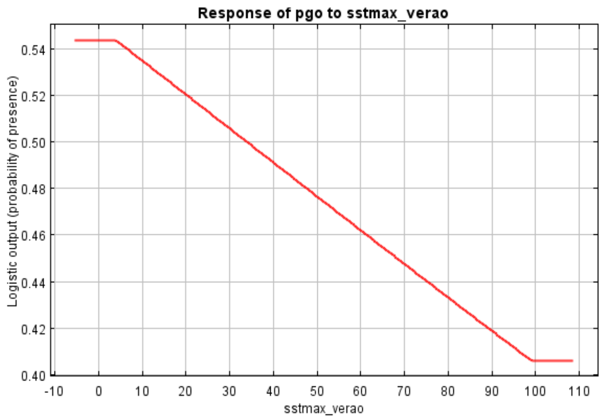
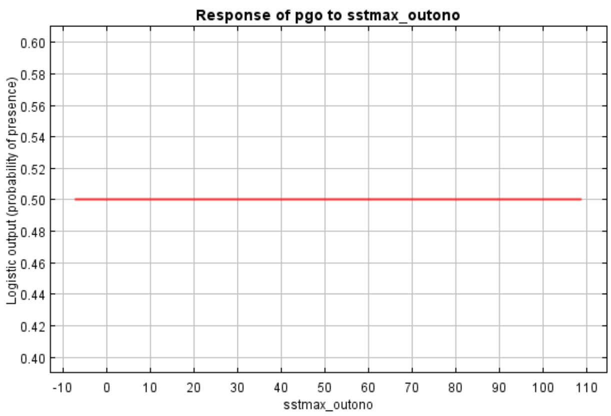


Figure D SST minimum values influences on seasonal blue sharks' distribution - log response graphics illustration. a) spring; b) summer; c) autumn; d) winter

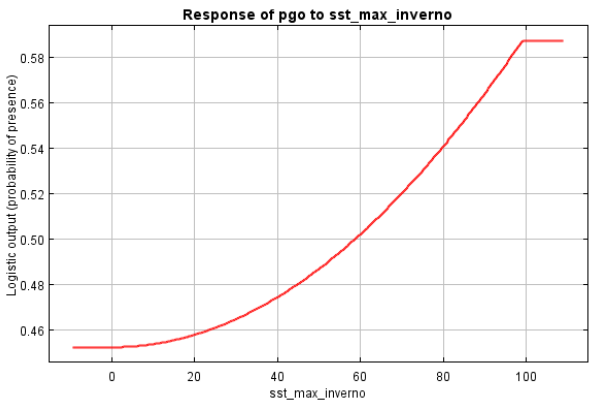
a)



b)



c)



d)

Figure E SST maximum values influences on seasonal blue sharks' distribution - log response graphics illustration. a) spring; b) summer; c) autumn; d) winter

Annex II - VMS analysis

II.1 Portuguese official landings

Table I - Species composition, wet weight and proportion (%) landed by Portuguese longline fisheries operating in the eastern North Atlantic Ocean, 2006-2008.

Specie	2006		2007		2008	
	Kg	**%**	**Kg**	**%**	**Kg**	**%**
Isurus oxyrhinchus	282913.9	24.92%	433474.9	25.53%	344384.6	28.67%
Prionace glauca	446324.7	39.31%	493437.2	29.06%	305918.6	25.47%
Xiphias gladius	162630.7	14.32%	187583.5	11.05%	199863.1	16.64%
Thunnus albacores	0	0.00%	302118.7	17.80%	196152.3	16.33%
Ruvettus pretiosus	74708.8	6.58%	108858.3	6.41%	57309.1	4.77%
Sphyraena spp.	0	0.00%	2.6	0.00%	19.4	0.00%
Alopias vulpinus	0	0.00%	30777.3	1.81%	12150	1.01%
Istiophorus albicans	26610.3	2.34%	11917.6	0.70%	12605	1.05%
Thunnus obesus	66782.1	5.88%	20058.1	1.18%	2321	0.19%
Thunnus thynnus	107	0.01%	73.2	0.00%	0	0.00%
Katsuwonus pelamis	46626.8	4.11%	109301	6.44%	70184	5.84%
Seriola lalandi	0	0.00%	31.1	0.00%	104.9	0.01%
Thunnus alalunga	19687	1.73%	13	0.00%	119.6	0.01%
Makaira indica	186	0.02%	0	0.00%	0	0.00%
Sarda sarda	1529	0.13%	0	0.00%	0	0.00%
Istiophoridae	361	0.03%	0	0.00%	0	0.00%
Seriola dumerili	0	0.00%	0	0.00%	12	0.00%
Thunnus spp.	2950	0.26%	0	0.00%	0	0.00%
Sphyrna spp.	4065	0.36%	85.6	0.01%	6	0.00%
Total discharged (Kg)	1697732		1201150		1135482	

II.2 Ecological analysis of seasonal Portuguese longlining

II.2.1 SST

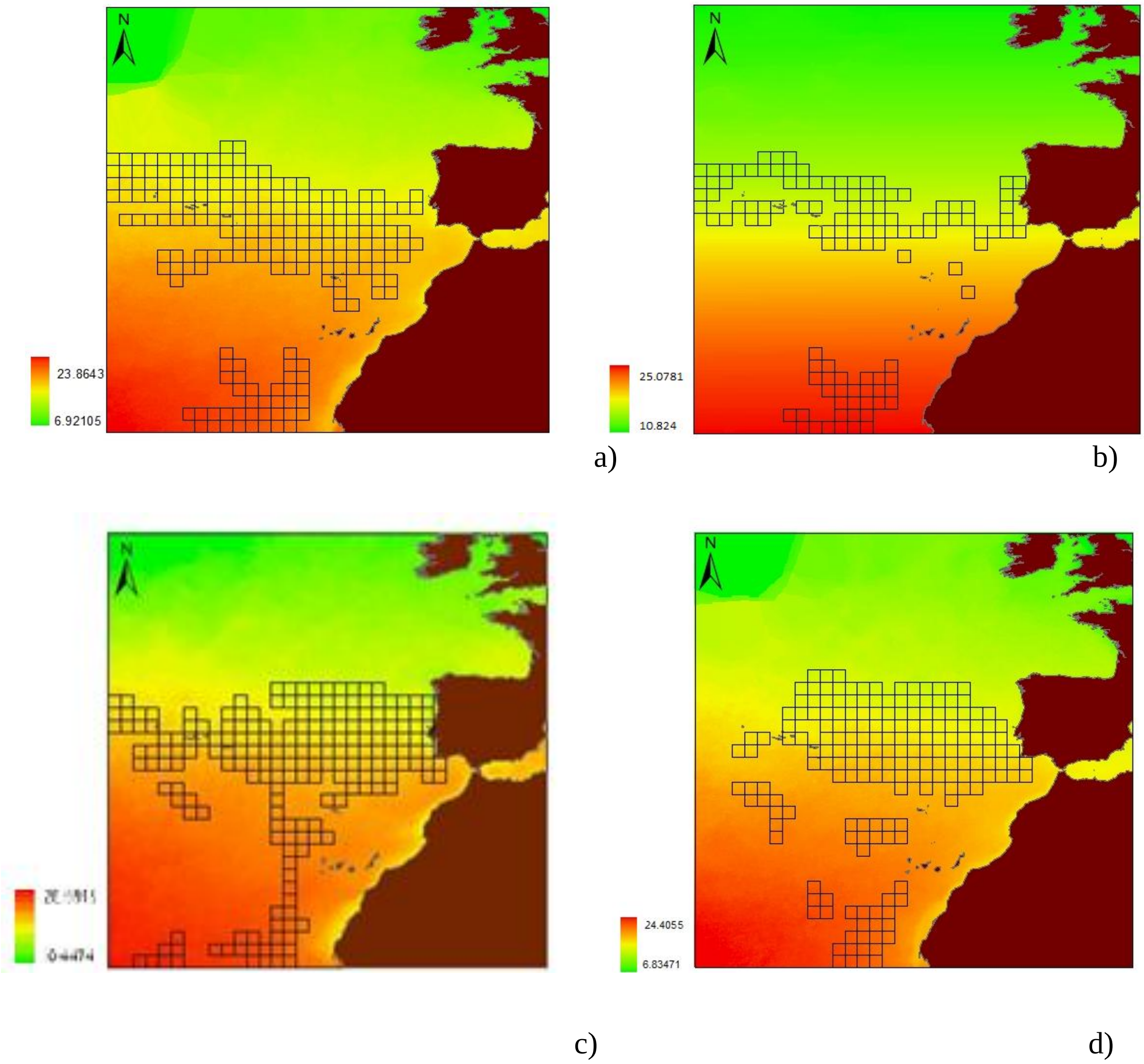


Figure A Seasonal Portuguese longlining effort in Northeast Atlantic Ocean with respect to average Sea Surface Temperature remote-sensing image for each season, from 2006 to 2008, a) spring; b) summer; c) autumn and d) winter.

II.2.2 Bathymetry

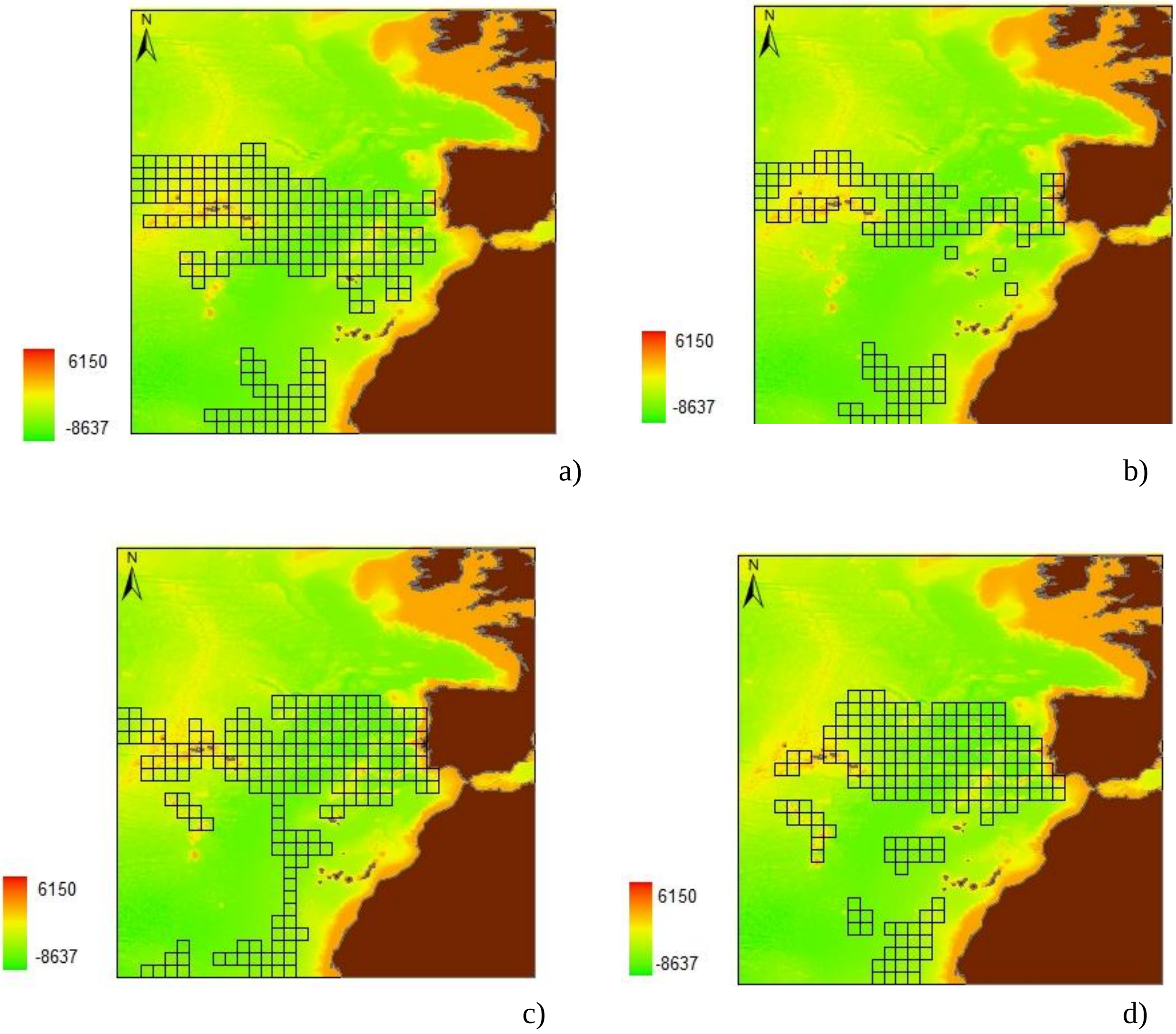


Figure B Seasonal Portuguese longlining effort areas in Northeast Atlantic Ocean with respect to seabed bathymetry, from 2006 to 2008 a) spring; b) summer; c) autumn; d) winter.

II.2.3 SST anomalies

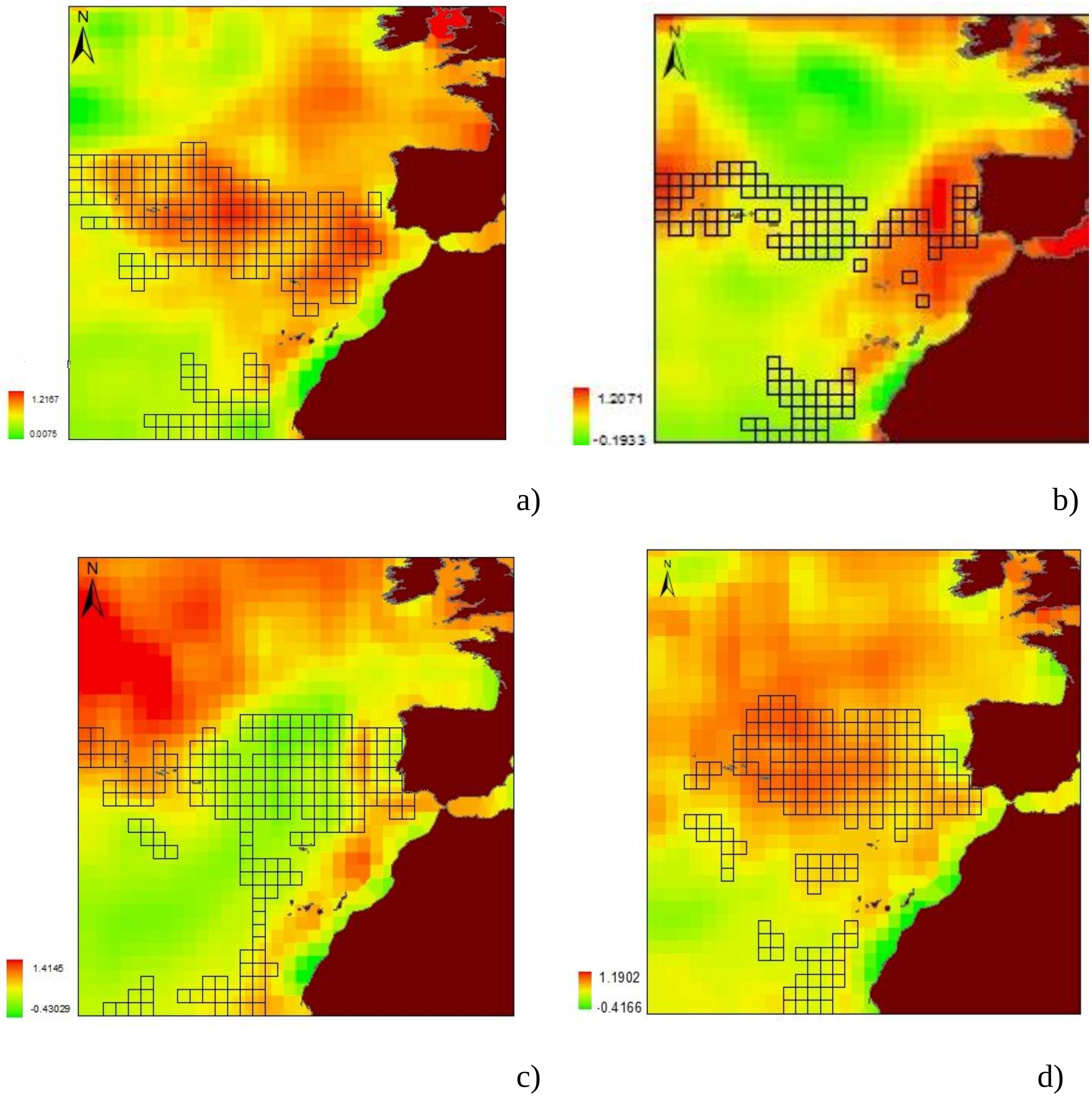
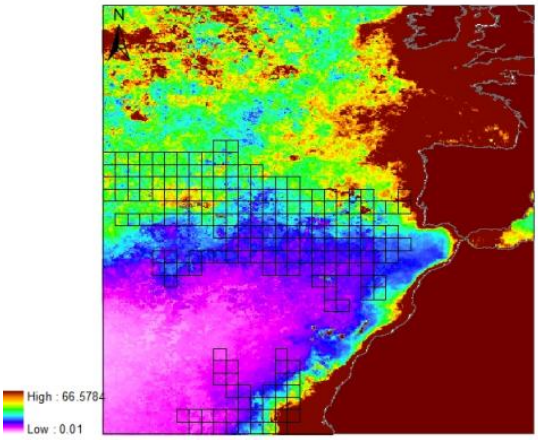
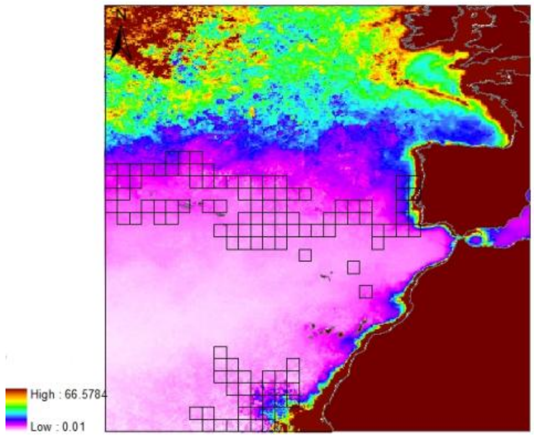


Figure C Seasonal Portuguese longlining effort areas in Northeast Atlantic Ocean with respect to seasonal mean sea surface temperature anomalies, from 2006 to 2008 a) spring; b) summer; c) autumn; d) winter.

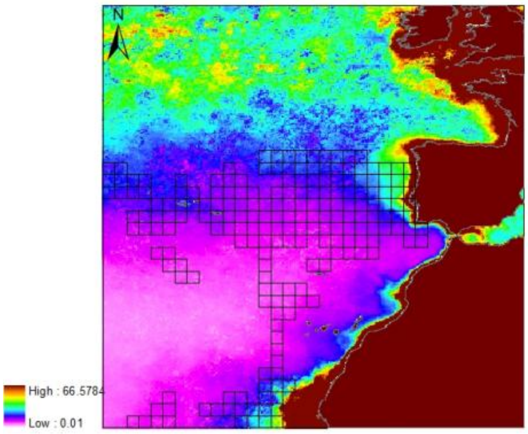
II.2.4 Chlorophyll *a*



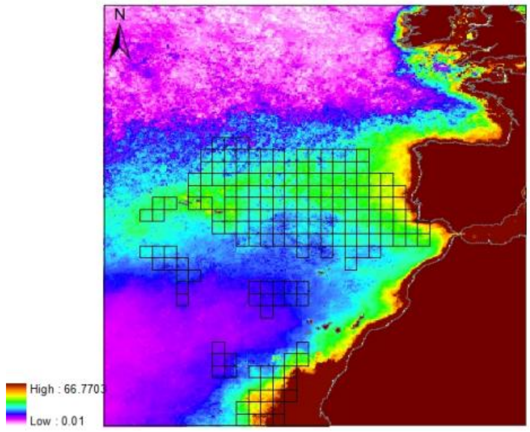
a)



b)



c)



d)

Figure D Seasonal Portuguese longlining effort areas in Northeast Atlantic Ocean with respect to seasonal minimum values of Chlorophyll *a*, from 2006 to 2008 a) spring; b) summer; c) autumn; d) winter.