HABITAT MAPPING OF BLUE SHARK IN THE EASTERN MEDITERRANEAN SEA: APPLICATION OF GENERALIZED ADDITIVE MODELS ON COMMERCIAL FISHERY BY-CATCH

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Abstract

Blue sharks (*Prionace glauca*, Linnaeus 1758), are repeatedly caught in the surface drifting longline fisheries throughout the eastern Mediterranean Sea. Based on a dataset derived from the Greek and Cypriot commercial fisheries, targeting swordfish during 1998-2005, we applied an information theoretic generalized additive model approach, modeling separately: (1) the probability of making a catch and (2) the positive catch rates. Analyses suggested the presence of intra-annual variations in their abundance and revealed interesting associations with some environmental features. GAM selected models can serve as an indication of preference or association for the selected environmental variables. Based on these associations, an indirect identification of the blue shark potential habitat was delivered, mapping the probability of occurrence as well as the relative abundance in the eastern Mediterranean region.

Keywords: *Prionace glauca*, habitat, distribution, GAM.

1. Introduction

Blue shark (*Prionace glauca*, Linnaeus 1758) is a large pelagic oceanic species of the family Carcharhinidae that inhabits clear and deep waters in tropical, subtropical and temperate areas. While blue shark is among the most abundant, widespread, fecund and faster growing of the elasmobranchs, it is also one of the most heavily fished sharks in the world (Castro *et al*., 1999). Highly migratory in nature, it is known to make seasonal reproductive migrations following changes in water temperature and currents (Nakano, 1994; Stevens, 1999). Blue sharks constitute a major by-catch of long-line fisheries targeting swordfish or tunas, much of which is poorly documented and where data are rarely incorporated into national and international statistics (Gilman *et al*., 2007). In Greece, about 250 vessels are involved occasionally from February to the end of September, mostly during summer months (ICCAT, 2011). Blue sharks comprise a significant portion of the total catch, reaching as much as 4% in the Greek fleet (Megalofonou *et al*., 2005a, b). Applications of non-parametric generalized additive models (GAMs), incorporating environmental data to analyze fishery performance trends, have determined that blue shark catch rates are significantly affected by spatial, temporal and environmental parameters (Bigelow *et al*., 1999; Damalas and Megalofonou, 2010). Such GAM selected models provide an indication of preference or association for the selected environmental variables. In this paper, based on GAM derived models we deliver an indirect identification of the potential occurrence and distribution of blue shark in the eastern Mediterranean Sea, which may serve as an early habitat proxy defined from the available data.

2. Materials and Methods

This study is based on the models derived for eastern Mediterranean blue sharks in the recent work of Damalas and Megalofonou (2010). Recapitulating the methodology therein, during the period 1998-2001 and 2003-2005, 36 Greek and 2 Cypriot commercial longlining fishing boats were followed throughout their fishing grounds in the south-eastern Mediterranean Sea (Figure 1, Table 1).

Table 1. Number of ports, vessels, fishing sets, hooks deployed, bluefin tuna and swordfish caught by fishing gear in the eastern Mediterranean Sea, during 1998-2001 and 2003-2005 (ports and vessels overlap between fishing gears).

Fishing Gear	No Ports	No boats	Fishing sets	No of hooks deployed	Average hooks per set	Blue sharks caught	% of total catch	Swordfish caught	% of total catch
SWO-LL$_T$	12	12	283	289,110	1021.6	17	1.12	1299	85.2
SWO-LL$_A$	16	32	978	494,609	505.7	146	2.06	5562	78.4
Total	22	38	1261	783,720	621.5	163	1.89	6861	79.6

The longline gears deployed were surface drifting longlines targeting swordfish (SWO-LL$_T$: traditional swordfish longline; SWO-LL$_A$: American type swordfish longline). Fishing period was March to September. Observers stationed on-board the vessels, recorded during each fishing-set the following operational data: date, location (determined from GPS), number of hooks, gear configuration, and bottom depth. Whenever placement of on-board observers was not possible, the aforementioned information was gathered at the landing locations, by interviewing the skippers and consulting the boats unofficial logbooks. Sea surface temperature (SST), Lunar index, Bathymetry, Distance from coast, SST frontal energy (SST gradient), temporal change in SST (DSST), temporal change in frontal energy (DSST gradient), and distance from thermal fronts (distance.front) data were assigned to all fishing sets corresponding to the exact date and coordinates. Nominal catch per unit of effort (CPUE) was calculated as the number of fish caught per 1000 of hooks deployed.

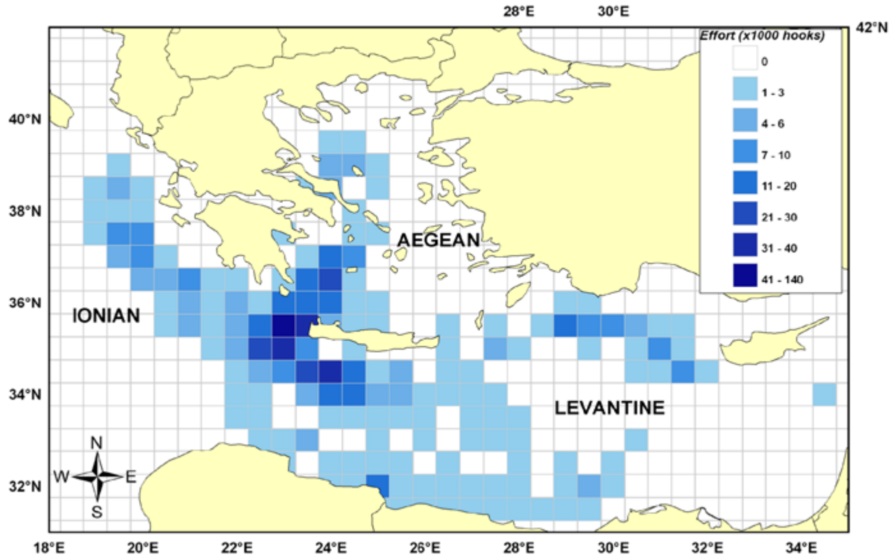

Fig. 1: Map of the studied area with spatial distribution of fishing effort during 1998–2005 in the eastern Mediterranean Sea (Note: spatial resolution of fishing effort is 1/2 of a degree; values refer to the whole study period and not individual fishing sets).

Assuming that non-linearities are most likely to occur in the functional relationships between catch rates and explanatory variables, Generalized Additive Models were applied (GAMs - Hastie and Tibshirani, 1990), using the mgcv package (Wood, 2006) in R v.2.12.0 (R Development Core Team, 2010). In a GAM, the expected values Y_i of the response variable are related to the predictor variables Zm_i according to the following general formulation:

$$f\left(E\left[Y_i\right]\right)=LP_i=c+\sum_m s_m\left(Z_{m_i}\right)$$

where the response variable is allowed to follow any distribution from the exponential family, f is the link function, LP is the linear predictor, c is the intercept, $s_m()$ is the one-dimensional smooth function of covariate Zm, and Zm_i is the value of covariate m for the i-th observation (Wood 2006). CPUE distributions were skewed, including many zero or low values and few large observations, suggesting the application of "Delta-model" approach (Maunder & Punt, 2004), modeling separately: (1) the probability of a zero observation and (2) the positive catch rates (CPUE>0). A series of 16 candidate models (plus the null model) were constructed including some combinations of the thirteen parameters under investigation that plausibly influenced species abundance. "Best" model selection was based on the generalized cross validation criterion (GCV) (Wood, 2006). Detailed description of the modeling procedure can be traced in Damalas and Megalofonou (2010).

Based on the selected models, spatial estimations of probability occurrence and positive catch rates were derived in the form of gridded matrices for the whole study area. The eastern Mediterranean region (31^o – 41^o North, 18^o – 35^o East) was gridded in a spatial resolution of 1/10 x 1/10 of a degree, concluding to a total of 11,471 grid cells (land excluded). Each one of these cells was assigned the corresponding values for each of the model parameters. E.g: a certain cell had its specific values for latitude, longitude, bottom depth and distance from nearest coast. Furthermore, for each month/year combination a value for the corresponding SST from the available satellite datasets was assigned. Implementation was done using *predict.gam*() function of the mgcv package (Wood (2006). Predicted values were accompanied by the corresponding standard error estimates, so that to assess the reliability and quality of estimates. Finally, and with the intention to visualize the results, these matrices of gridded spatial predictions, were mapped to GIS raster datasets using ESRI's ArcMap desktop GIS software.

3. Results

Between April 1998 and September 2005, the observers reported a catch of 163 blue sharks in swordfish long-line operations during 1261 fishing days, 1138 of which were sampled at landing ports and 123 onboard the fishing vessels (Table 1). Blue shark was the second most abundant by-catch (following bluefin tuna), reaching circa 2% of the total catch in number of specimens caught.

Analysis based on GCV, revealed that a model including only seven, out of the thirteen investigated, variables was the best to describe our data explaining approximately 10% of the variance in the probability of encountering blue sharks:

Prob. Occurrence = c + Month+ Gear + Year + s(Lat) + s(Long) +s(Lunar.index)+ s(SST).

Positive catch rates were more adequately approximated by an eight factor model, explaining an impressive 72.9% of the variance in the probability of positive blue sharks CPUE:

positive CPUE = c + Month+ Gear + Year + s(Lat) + s(Long) + s(Distance) +s(Lunar.index)+ s(SST)

For facilitating the predictive procedure, lunar index was transformed from a continuous variable to a four level categorical factor (0.00→0.25 new moon; 0.25→0.75 first & last quarters; 0.75→1.00 full moon). Taking into account the different levels of the four categorical factors, a series of 392 different combinations were drawn (2 gears x 7 years x 7 months x 4 lunar phases). Each one of these prediction matrices included estimates of occurrence probability as well as relative abundance for a certain combination of gear, year, month and lunar phase for the whole eastern Mediterranean region.

Averaging over all years studied (1998-2005) delivered a more comprehensive series of monthly maps. Such illustrations are presented in Figures 2 and 3, depicting how can such prediction matrices be visualized through a GIS environment.

Presence/Absence data – Probability of occurrence

There was an obvious longitudinal constituent, values increasing from east to west, a fact implying a strong presence of blue sharks in the Ionian waters (Fig. 2). However, this trend was more or less eased during summer. Monthly allocation of probability advocated that occurrences were expected to be more frequent during summer and autumn months. The Levantine basin comprised the most likely location of occurrence from June through September. Probability of occurrence in the Aegean Sea was always low (<20%), reaching this value only during September. The relatively small number of observations in the westernmost parts of the study area, resulted in larger confidence intervals around these estimations.

Positive catch rates – Relative abundance

Spring months (April-May) along with September were the periods during which positive catch rates peaked (Fig. 3). Spatial distribution of predictions indicated that relative abundance indices were to be higher from April to June in the Aegean, while this period was shifted to August through September for the Levantine. Attention must be drawn to the fact that predictions for the north Aegean and northeast Levantine may lack credibility, as standard errors were relatively high for both sub-regions.

As a word of notion, the large standard error predictions were consistently noticed in certain marine regions (Figs. 2 – 3). One obvious plausible reason was the low number of observations available for these areas (Fig. 1), making model predictions for the most part imprecise. However, in locations where numerous samples have been acquired, large standard errors indicate that actual observations are very dissimilar compared to model predictions. According to the best model selected, these certain regions may be characterized as areas of high or low abundance, a result not validated by the observed values. It is therefore considered as good practice to avoid drawing conclusions for these areas of ‘uncertain’ estimates.

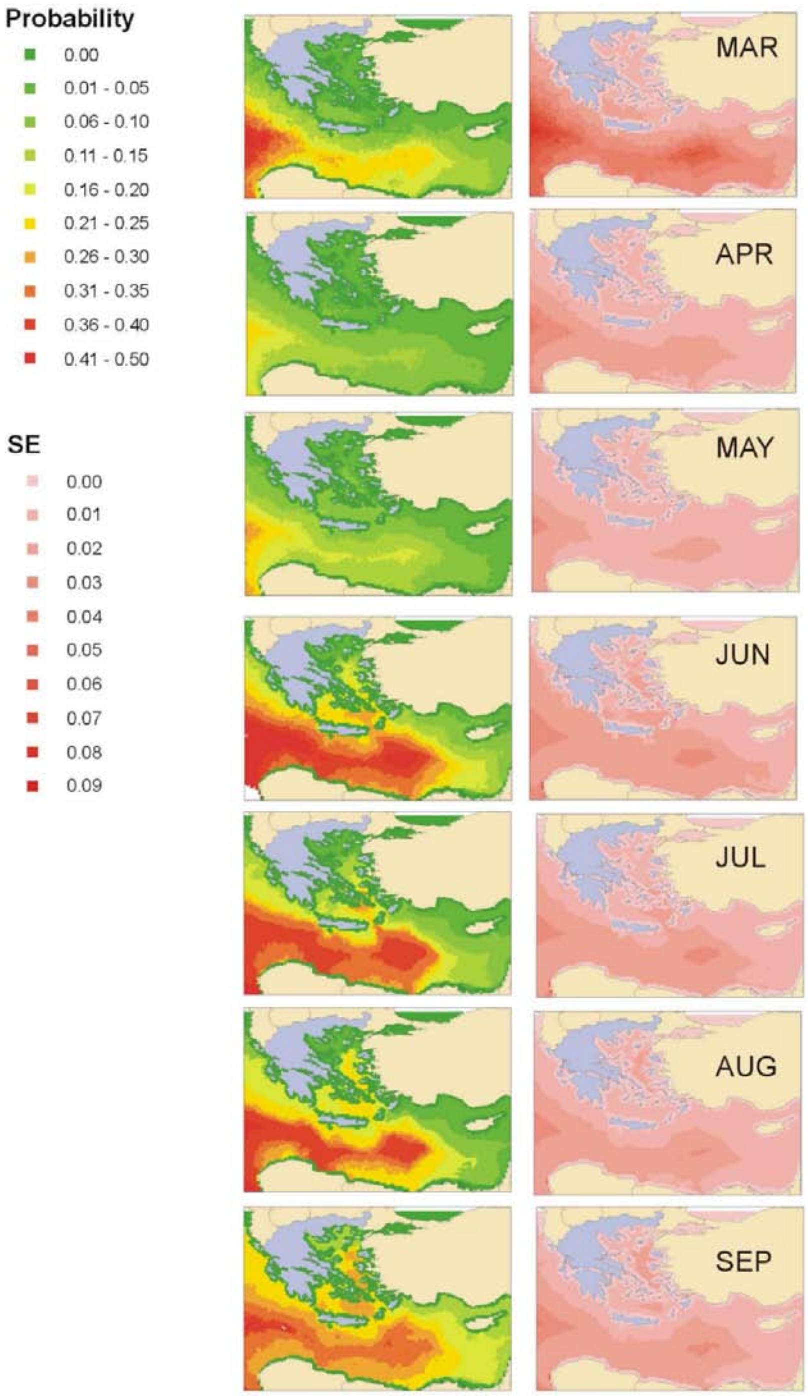

Fig. 2: Predicted monthly probability of occurrence (and Standard Errors) for blue sharks in the eastern Mediterranean sea during 1998-2005. (Predictions refer to a lunar index of 0.5 and SWO-LL$_A$ fishing gear)

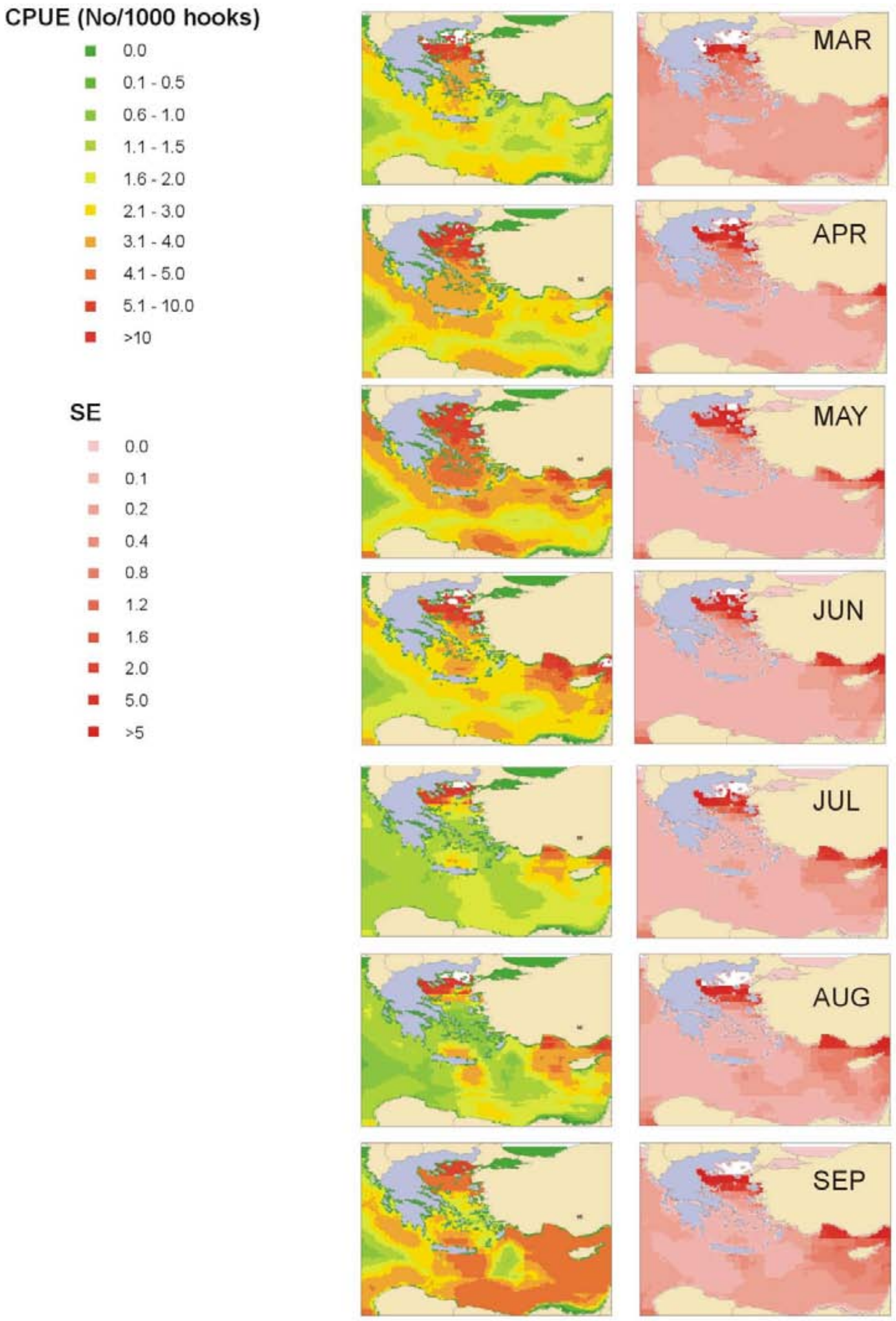

Fig. 3: Predicted monthly relative abundance (positive CPUE – Number of sharks/1000 hooks) (and Standard Errors), for blue sharks in the eastern Mediterranean sea during 1998-2005. (Predictions refer to a lunar index of 0.5 and SWO-LL$_A$ fishing gear)

4. Discussion

Modeling Mediterranean blue shark by-catches contributed in comprehending how fishery performance varied with a selection of environmental, spatial, temporal and operational factors. Subsequently it helped us generate standardized indices of commercial catch rates, which could be useful for regional planning and policy development for conservation and sustainable management of the species. Catch rates values observed in this study were very low compared to analogous values from surveys conducted in the western Mediterranean and Atlantic (Nakano, 1994; Buencuerpo *et al*., 1998; Hazin *et al*., 1998; Stone and Dixon, 2001; Nakano and Clarke, 2005). These low values can be attributed to the lower productivity of the area, or lower abundance of sharks due to regional depletion from historical fishing, or both. Furthermore, the annual effect demonstrated a continuous decline throughout the study period. These data together with other available evidence (Gilman *et al*., 2007; Soldo *et al*., 2007) point out that the Mediterranean blue shark population is in general decline and is possibly facing a worse scenario than blue shark populations elsewhere in the world

Fisheries-induced mortality of non-commercial species can affect biodiversity and ecosystems in various ways (Hall *et al*., 2000). The full effects and implications are still to be challenged in depth. There is concern that non-target species, such as blue sharks, could be severely depleted long before appropriate management policies could be implemented (Castro *et al*., 1999; Walker, 1998). This is because the fisheries are driven by the valuable target species, which are routinely assessed, while at the same time the low or non-commercial value species remain unmonitored.

In most countries, the legislation governing fisheries management is based on attempts to achieve an acceptable compromise between utilization of the fish resources and conservation of the target species, by-catch species, and the marine habitat. In order to protect and conserve species, managers urge for information on the resource distribution which will enable them to identify the areas of most suitable habitat (EC, 2007, 2008; Rubec *et al*., 1999). One way of accomplishing such a task is through long-term surveys like the one undertaken herein.

GAM selected models may serve as an indication of preference or association for the selected environmental variables. An indirect identification of the potential habitat can be delivered, based on these associations. For blue sharks there is a general lack of knowledge with regard to their ecological preferences in the Mediterranean Sea. Evidently, the current results may serve as an early habitat proxy defined from the available data. Actual habitat selection has to be based on more complex aspects such as behavioral characteristics, physiological tolerances, and predator-prey interactions.

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