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Environmental, spatio-temporal and operational effects on long-line swordfish catch rates in the Eastern Mediterranean Sea

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Generalized additive models (GAMs) were applied to examine the relative influence of environmental, spatio-temporal and operational factors on swordfish catch rates in the Greek swordfish long-line fishery during the period 1998-2004. GAM analysis accounted for 56% of the variance in nominal Catch-Per-Unit-Effort expressed in number of fish per 1000 hooks. Stepwise GAM building revealed the relative importance of nine variables ranked by decreasing magnitude: fishing gear type, sea surface temperature, month of year, bottom depth, distance from land, year, longitude, lunar index and latitude. Long-lines having deeper, thicker and more resilient branch lines with illuminated fish attractants yielded significantly higher swordfish catches. CPUE peaked at the sea surface temperatures 17o and 28o C, during the last quarter of the fishing season, at depths greater than 3000 m, around a buffer zone ten nautical miles distant from the coast and when the lunar disc illumination was high. Elevated relative abundance was observed in southern latitudes and eastern longitudes, corresponding to the Levantine region. No obvious indication of a decline in swordfish abundance was detected throughout the six years.
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INTRODUCTION

Broadbill swordfish, *Xiphias gladius*, is a large pelagic oceanic marine species, sometimes found in coastal waters, which is distributed worldwide (except the polar regions). It is a highly migratory species, migrating toward temperate or cold waters in summer and back to warm waters in fall. Swordfish as a species has proven to be very sensitive in detecting (preferring) certain environmental features and tends to concentrate near converging oceanic fronts, strong thermoclines or underwater features, such as seamounts and shelving banks (Ward *et al*., 2000).

In this study, we present a preliminary attempt to examine the relative influence of various environmental, operational and spatio-temporal factors on swordfish catch rates and catch sizes of the Greek swordfish long-line fishing fleet operating in the Eastern Mediterranean Sea.

MATERIALS AND METHODS

During the period 1998-2004 a network of sampling ports throughout the eastern Mediterranean was developed, so that to cover a wide range of fishing grounds, fleets and gears. The sampling areas were the following: Ionian Sea, Aegean

Sea and Levantine basin (Figure 1). Fleets were targeting swordfish. Two fishing gears were studied: swordfish long line (SWO-LL) and "American type" swordfish long line ($SWO\text{-}LL_A$). Data derived from records taken by observers stationed both at pilot fishing ports and on board commercial fishing vessels. Fishing and operational data series concerned: name of fishing boat, gear used, days of each trip, fishing effort for each fishing day (number of hooks), number and weight of fish caught per fishing day. Spatio-temporal variable data concerned: date and geographical coordinates of each fishing set. Catch rates were expressed using the nominal catch per unit effort (CPUE) which is a fishery performance index representing the success of fishing from commercial fishery statistics. CPUE values were calculated as number of fish/1000 hooks. Daily sea surface temperatures (*SST*) were obtained indirectly from satellite-derived estimates (NOAA's[1] AVHRR), daily *lunar index* was calculated based on the illuminated % of the face of the moon, ranging from 0 (new moon) to 1 (full moon), *Bathymetry* at each fishing location was estimated using a bathymetric map of the region, *Distance from coast*, was estimated for each fishing point, applying a MATLAB (*Mathworks Inc.*) script on a digitised grid map which locates the nearest land pixel (bottom depth >0).

Fishery performance (CPUE) was modeled in S-PLUS software package (*Insightful Inc.*) as a function of categorical and continuous effects using Generalized Additive Model (GAM) approaches (Hastie & Tibshirani, 1990). Identification of the underlying probability distribution for the errors in the dependent variable (nominal CPUE data) was done following the methodology described in Ortiz and Arocha (2004). Explanatory factors influencing catch rates were identified applying a stepwise GAM model building. Adding or removing a new term was based on the reduction of *AIC* selection criterion. Nine variables were considered for inclusion in the model: *Latitude*, *Longitude, SST, Bathymetry, Distance from coast, Lunar index, Month, Year* and *Fishing gear type*, the first six being continuous and the remaining ones categorical. GAM model was fitted in the following way:

$$g\,(\text{CPUE}) = c + f_1(Latitude) + f_2(Longitude) + f_3(SST) + f_4(Bathymetry) + f_5(Distance\ from\ coast) + f_6(Lunar\ index) + Month + Year + Fishing\ gear\ type + \varepsilon$$

where g is the link function, f_i smoothers or simple transformations of the explanatory variables, c a constant and ε a random error term.

RESULTS AND DISCUSSION

Between April 1998 and September 2004 the observers reported a total of 5523 swordfish as part of the swordfish long-line catch in 1001 fishing days of sampling. Swordfish reached an overall 79% of the total catch (in number). Comparison among deviance tables and regression diagnostics identified the Poisson as the most suitable error distribution model and the predictor variables that best explained variability in the data. The final model took the following form:

log(CPUE + 1) ~as.factor(*Fishing gear type*)+*lo*(*SST, span*=0.2)+ as.factor(*Month*) + *lo*(*Bathymetry, span*=0.2) + *lo*(*Distance,span*=0.2) + as.factor(*Year*) + *lo*(*Longitude, span*=0.2) + *lo*(*Lunar, span*=0.2) + *lo*(*Latitude, span*=0.2)

[1] National Oceanic And Atmospheric Administration

where *lo* stands for locally weighted polynomial scatterplot smoother (*loess*) and *span* for the number of observations in the neighborhood of the *loess* regression that should be taken in account (e.g. 0.2 is 20% of surrounding data). The detailed deviance table for the applied model is shown in Table 1.

GAM analysis indicated that *Fishing gear type* had a profound effect on catches explaining more than 23.5% of the deviance in swordfish CPUE. *Sea surface temperature* (13.4%) and *Month* (7.0%) were the next most influential parameters, while *Bathymetry* (4.9%), *Distance from coast* (2.9%), *Year* (1.9%), *Longitude* (1.6%), *Lunar index* (0.8%) and *Latitude* (0.7%) played a minor role. In total, the derived model explained more than 56% of the variance in swordfish CPUE.

The operational factor (*Fishing Gear type*) had the predominant influence, yielding significant reduction in deviance (41.3% of total). The American type swordfish long line turned out to be the most 'successful' in catching swordfish than the traditional swordfish long-line (Fig. 2 up left). This suggests that the robustness of this gear significantly affects the catch of swordfish. The use of fish attractant chemical light-sticks and thicker (more resilient) line are reasonable explanations for the increased catches of the 'American type' swordfish long line when compared to the traditional one. On the other hand, depths where fishing takes place can affect catches. SWO-LL_A targets in much deeper waters, often below 50 m while SWO-LL_T depth ranges rarely exceed 20 m. We can assume that this variable reflects the catchability of the species rather than the abundance.

The effect of *SST* on swordfish catch rates is illustrated in the upper right panel of Figure 2 as a *loess* smoothing function with 95% confidence bands. The relative density of points for different covariate values is shown by the `rug' on the x-axis. Abundance related to *SST* fluctuated through the temperature range studied, however higher CPUE values were observed in temperatures from 16 to 18^{o} C and over 27 ^{o} C. This findings are in agreement with the observations of other studies on swordfish biology. Nakamura (1985) reports values between 18-22^{o} C, Bigelow *et al.* (1999) 15-18^{o} C and Sedberry *et al.* (2001) 28^{o} C during night.

The temporal factor (*Month*) had a significant influence in the model explaining 12.3% of total deviance. Monthly allocation of catch rates revealed an overall seasonal increasing trend (Fig. 2 mid left), with fall being the most 'favourable' period, September accompanied with increased abundance. This could be attributed to the recruitment of juvenile swordfish entering the fishery. A more systematic examination of catches, incorporating supplementary aspects of the blue shark populations like size, sex and maturity would elucidate the temporal effect.

Bathymetry, explaining more than 8.7% of total deviance, when plotted against the dependent variable (CPUE) indicated that lower catch rates were more likely to occur in shallow waters. In deep waters with bottom depth over 3000 meters the catch rates increased abruptly (Fig. 2 mid right), confirming the pelagic nature of the species.

Distance from coast, embracing both spatial and environmental properties as an explanatory variable, was the succeeding term in the model (Table 1). Catch rates seem to be quite stable in the area beyond 20 nautical miles, increasing in a buffer zone around 10 nautical miles from land and dropping when moving closer to the coast (Fig. 2 low left). It should be noted that this area (10 n.m.) is where a significant portion of the fishing effort is exerted, almost 20% of fishing sets deployed in the zone between 6-14 n.m. from shoreline. So, it would be more realistic to assume that the malapportioned effort might be masking the actual situation regarding the existence of swordfish. Anyway, this is a problem all fishery dependent datasets have to deal with, since fishermen do not tend to scatter their fishing activities homogeneously in space and time.

The plot for *Year* showed no remarkable trend in catch rates, although catches decrease slightly between 1998 and 2003, followed by a burst in 2004 (Fig. 2 low right). Examining average weight of swordfish individuals caught during the study instead of catch rates, revealed a gradual decline from 30 to 23 kg. This could be a sign that over-fishing is occurring and that catch rates may not be as indicative of the population status as the average size.

The spatial predictors *Longitude* and *Latitude* explained 2.9% and 1.2% of total deviance respectively (Table 1). GAM plot (Fig. 3 up left) suggests a longitudinal constituent in the presence of swordfish, catches increasing in an easterly direction with a drop beyond 30^o E. The effect of *Longitude* to the east of 30^o E (East Levantine) is unclear because the reduced density of data points leads to larger standard error ranges. Regarding *Latitude*, elevated CPUE values could be located in lower latitudes (32^o N – North African coast Fig. 3 up right). The area of elevated catch rates (higher longitudes and lower latitudes) corresponds to the east Levantine (Fig. 1). Till recently, this region was not a traditional fishing ground of the Greek fleet. Fishing activities in this area were limited compared to the huge fishing effort exerted in the Aegean and Ionian Sea. So, the population in this region is less affected by fishing mortality, a speculation that is supported by the fact that the average size of swordfish in the area is larger (28.5 kg) than the ones caught in the Aegean and Ionian Sea (21 kg).

Although *Lunar index* was proven to be statistically significant by the GAM analysis, plotting it against CPUE showed no clear "intervals" of increased catches. Elevated CPUE values could be somehow located when the lunar disc is illuminated at a percentage of 60-70% of the whole disc (Fig. 3 low). Draganik *et al.*(1987) and Moreno *et al.* (1991) concluded to similar results in the past.

Given that our GAM analysis covers a few years and a small number of variables, it may be immature to draw strong inferences regarding environmental effects on swordfish distribution and abundance. Nevertheless, our preliminary results indicated that operational (*Fishing gear type*), spatial (*Longitude*, *Latitude*), and temporal (*Month, Year*) factors played a significant role in the model (explaining 61% of total CPUE deviance), while the environmental features (*SST, Bathymetry, Distance from coast, Lunar index*) were subsequent constituents (explaining 39% of total CPUE deviance).

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REFERENCES

1. Bigelow K.A., Boggs C.H., and He X., 1999. Environmental effects on swordfish and blue shark catch rates in the US North Pacific longline fishery. *Fish. Oceanogr.*, 8: 178-198.
2. Draganik, B., and Cholyst, J., 1987. Temperature and moonlight as simulators for feeding activity by swordfish. *Reports of Sea Fisheries Institute*, vol. 22:73-84.
3. Hastie, T.J., & R.J. Tibshirani, 1990. Generalized Additive Models. London: Chapman and Hall, 335 pp.
4. Moreno, S., Pol, J., and Munoz, L., 1991. Influencia de la luna en el abundancia del emperador. *Coll.Vol.Sci.Pap. ICCAT* vol. 35(2):508-510.
5. Nakamura, I., 1985. FAO species catalogue. Vo1.5. Billfishes of the World. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. FAO Fish.Synop., (125)Vo1.5:65 p.
6. Ortiz, M., and Arocha, F., 2004. Alternative error distribution models for standardization of catch rates of non-target species from a pelagic longline fishery: billfish species in the Venezuelan tuna longline fishery. Fish. Research 70:275-297.
7. Sedberry G R & J K Loefer, 2001. Satellite telemetry tracking of swordfish, Xiphias gladius, off the eastern United States. Marine Biology 139:355-360.
8. Ward, P., Porter, J.M. and Elscot. S. 2000. Broadbill swordfish: status of established fisheries and lessons for developing fisheries. Fish and Fisheries 2000 (1) :317-336.

Table 1. Stepwise Generalized Additive Model building for factors affecting swordfish catches in the Eastern Mediterranean Sea (1998-2004). *Assuming a Poisson error distribution.* (last column refers to the *p*-value from a *Chi*-squared test between the model for that row and the model for the previous row).

Model structure-terms added	**Residual *df***	**Residual Deviance**	**Deviance decrement**	**Cumulative deviance explained**	**% of total deviance explained**	**Pr(Chi)**
NULL		4033.9				
+*Fishing gear type*	999.0	3085.6	948.3	23.5	41.3	0.000
+*lo*(*SST, 0.2*)	991.8	2544.6	541.0	36.9	23.6	0.001
+ *Month*	963.8	2261.3	283.3	43.9	12.3	0.000
+*lo*(*Bathymetry, 0.2*)	957.2	2061.7	199.5	48.8	8.7	0.000
+*lo*(*Dist.from coast, 0.2*)	950.7	1942.1	119.6	51.8	5.2	0.000
+ *Year*	945.7	1866.1	76.0	53.7	3.3	0.000
+ *lo*(*Longitude, 0.2*)	939.1	1800.2	65.8	55.3	2.9	0.000
+*lo*(*Lunar index, 0.2*)	932.7	1766.5	33.6	56.2	1.5	0.002
+*lo*(*Latitude, 0.2*)	925.8	1739.6	26.9	56.8	1.2	0.000

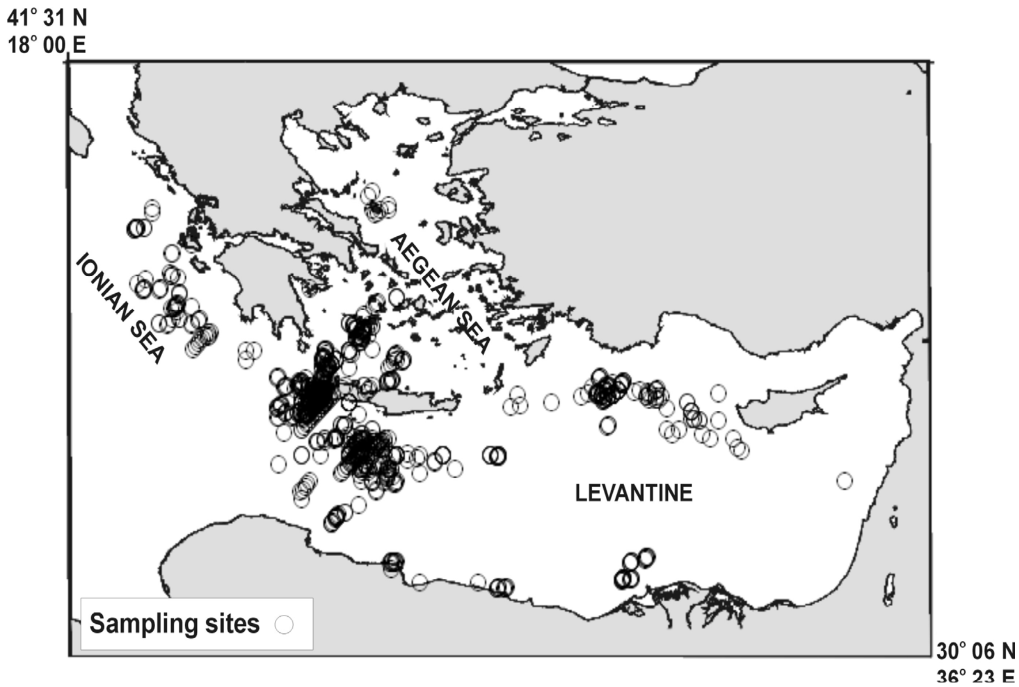

Figure 1. Map of the studied area during 1998-2004 in the eastern Mediterranean Sea

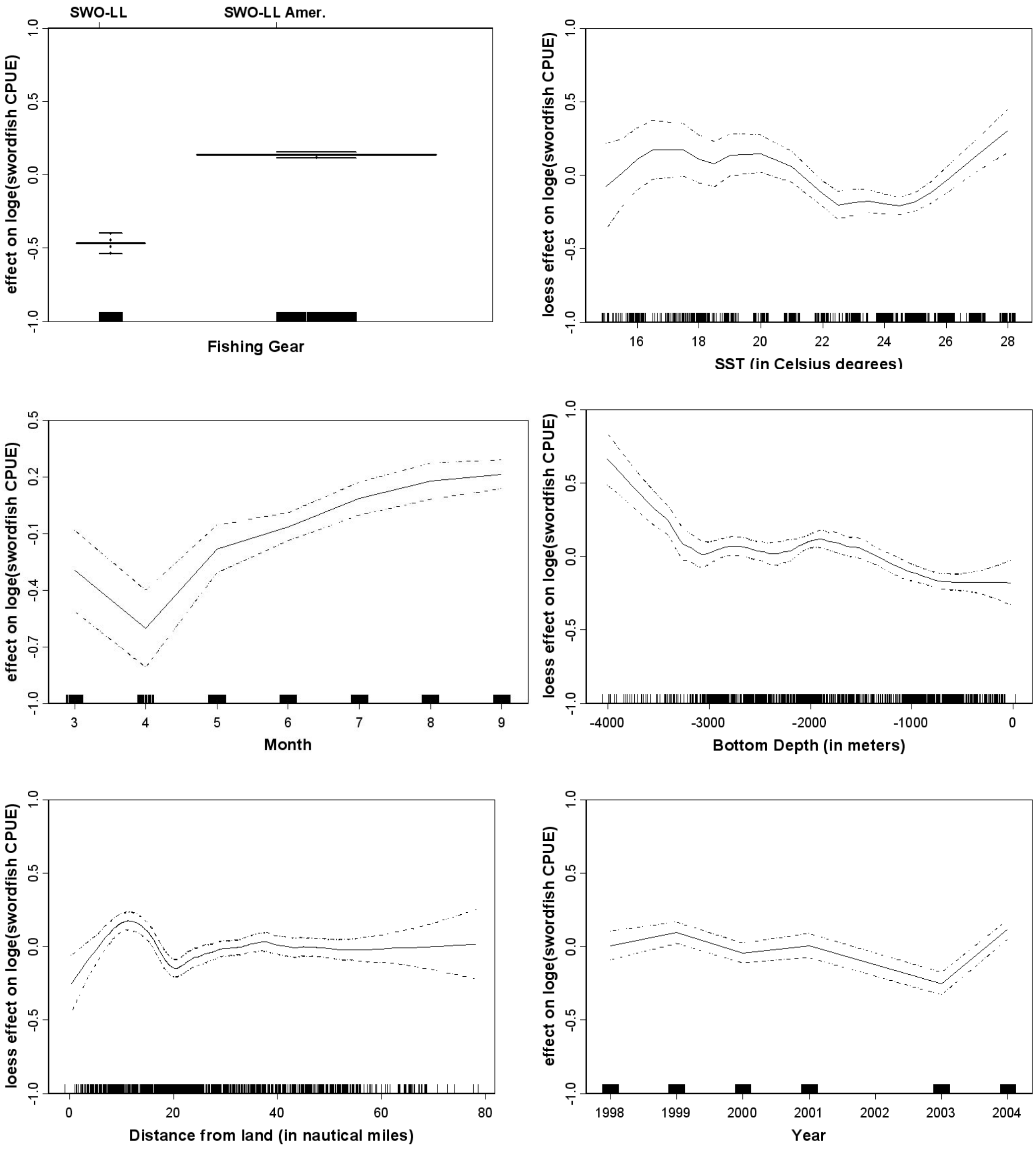

Figure 2. Generalized additive model (GAM) derived effects of *Fishing Gear type*, *SST*, *Month, Bathymetry*, *Distance from coast* and *Year* on the log transformed swordfish catch rates. Dashed lines (or upper and lower brackets) indicate 95% confidence bands. Relative density of data points is shown by the 'rug' on the x-axis.

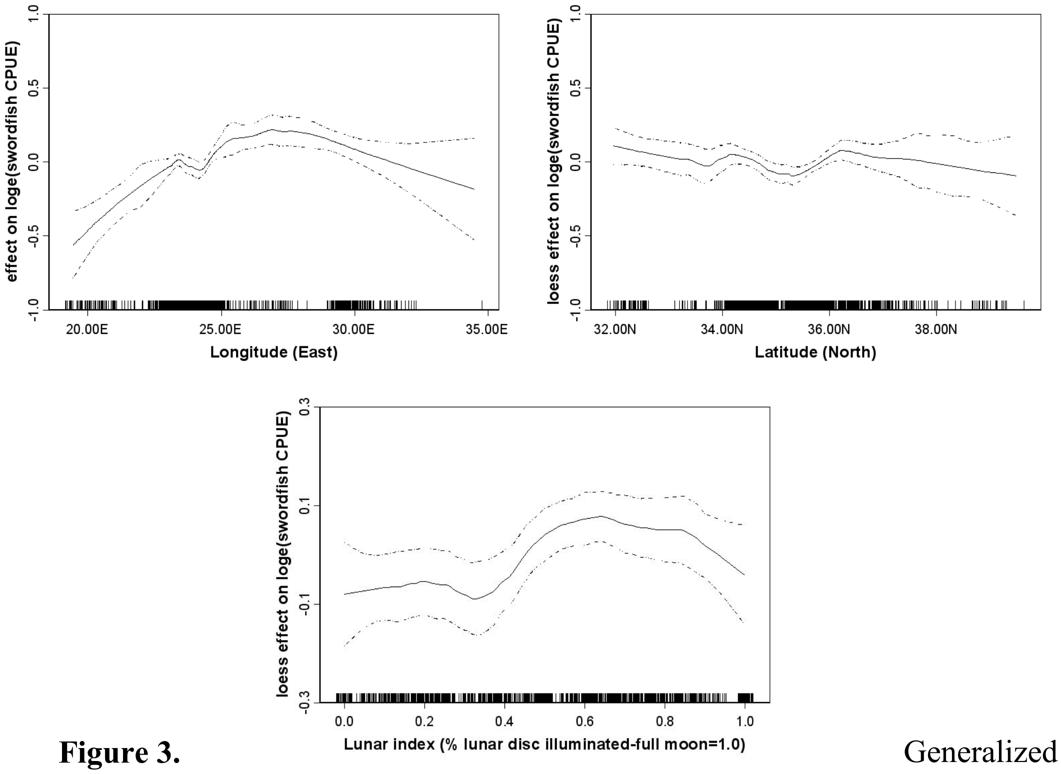

Figure 3. Generalized additive model (GAM) derived effects of *Longitude*, *Latitude*, and *Lunar index* on the log transformed swordfish catch rates. Dashed lines (or upper and lower brackets) indicate 95% confidence bands. Relative density of data points is shown by the 'rug' on the x-axis.