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ROUND SARDINELLA (*Sardinella aurita*) AND ANCHOVY (*Engraulis encrasicolus*) ABUNDANCE AS RELATED TO TEMPERATURE IN THE SENEGALESE WATERS

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ABSTRACT

We report the use of generalized additive models to define possible thermal windows related to high abundance of *Sardinella aurita* and *Engraulis encrasicolus* in Senegalese waters. Landing data from 1999 to 2009, considered as an abundance index, remotely sensed thermal data (sea surface temperature, SST from AVHRR Pathfinder V5) and a temporal variable (month) were used to construct the models. The results from this work suggest that high abundance of round sardinella and anchovy was closely related to SST. High abundances of round sardinella and anchovy were associated with different temperature ranges, 21.0 to 25.0 °C and 22.0 to 23.0 °C, respectively. However, temperature corresponding to the highest abundance of round sardinella and anchovy were very close (22.7 °C and 22.3 °C respectively). Indeed, it might exist an optimal temperature window for these two species in Senegalese water might exist.

Key words: GAM, small pelagic fish, thermal window.

RESUMEN

Palabras clave:

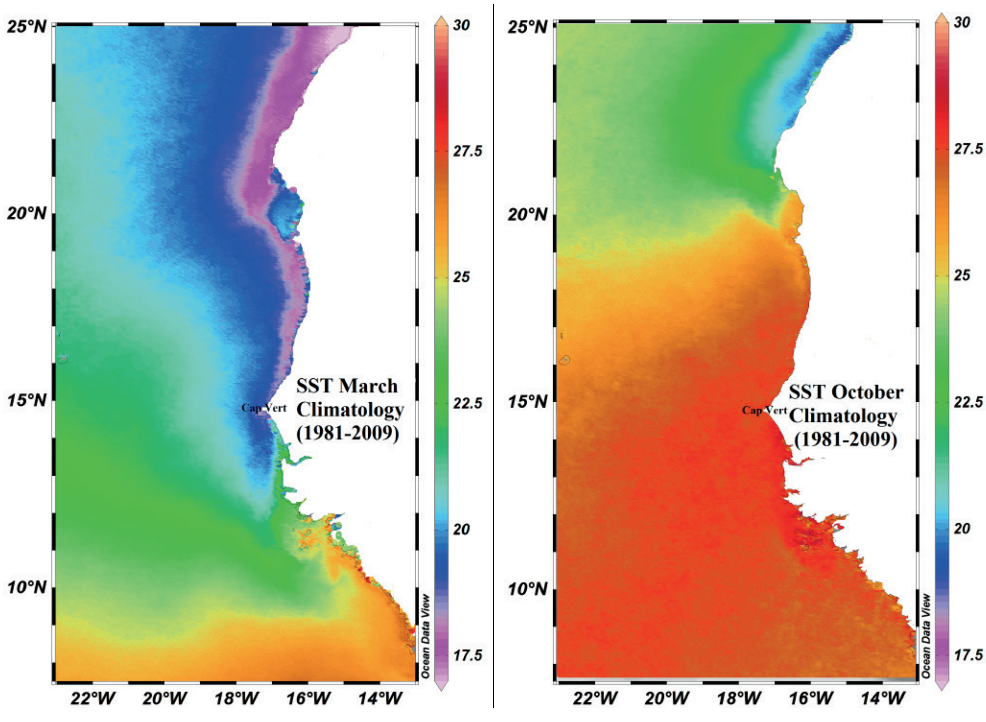

Figure 1: *SST structure in March and October.*

INTRODUCTION

The main species of small pelagic fish in West Africa are sardine (Sardina pilchardus), sardinella (Sardinella aurita and Sardinella maderensis), horse mackerel (*Trachurus trecae, Trachurus trachurus* and *Caranx rhonchus*), chub mackerel (*Scomber japonicus*), bonga (*Ethmalosa fimbriata*) and anchovy (Engraulis encrasicolus) (FAO, 2010). These small pelagic fish migrate from the north to the south and vice versa, thereby occurring the waters off Morocco, Mauritania and Senegal (Boely et Fréon, 1979).

However, small pelagic populations are subject to considerable fluctuations caused by environmental variability (Bakun, 1996), essentially due to their relatively short life cycle (2–3 years). Along the coast of Senegal, Mauritania and Morocco, the fluctuation of pelagic species is caused by the changes in marine environment (Cury and Roy, 1991). Over the years the catch of pelagic fishes from major landing sites along the Canary Current Large Marine Ecosystem have shown fluctuations in abundance, which are thought to be linked to changes in environment (Bakun, 1996).

Sea surface temperature (SST) is the environmental factor, which is most often used in investigations of relationships between the environment and fish behavior and abundance (Kellogg and Gift, 1983; Ramos *et al.* 1996). Change in temperature as small as 0.1 °C can be perceived by many fish species (Well, 1914). Temperature can affect fish in many different ways. Temperature influences fish species at different stages of their life cycles, for instance, during spawning, at the development and survival of the eggs and larvae, as well as influencing distribution, aggregation, migration and schooling behavior of juveniles and adults (Laevastu and Hayes, 1981; Sund *et al*., 1981; Gordoa *et al*. 2000). Quaatey and Maravelias (1999) suggested that SST seems to be more determinant than zooplankton abundance to round sardinella maturation in Ghanaian waters. Recently, Raab *et al*. (2013) demonstrated that SST is the factor which better explains the distribution and abundance of anchovy in the North Sea than food availability.

Today there is an increasing need to understand how small pelagic fish abundance may be related to oceanographic conditions for the need of sustainable management plan of these resources. The aim of this work is to define possible temperature ranges associated with high abundance of round sardinella and anchovy off the Senegal coast using general additive models (GAMs). GAMs has been applied in several studies. Maravelias and Reid (1997), applied GAMs to study the effects of zooplankton and oceanography on prespawning herring distribution around the Shetland Islands. The interannual fluctuations of squid abundance in Scottish waters were investigated using GAMs (Bellido *et al.,* 2001). It has recently been used to explore the effects of temperature and food availability during the first growing season on the adult anchovy population across the North Sea (Raab *et al.,* 2013).

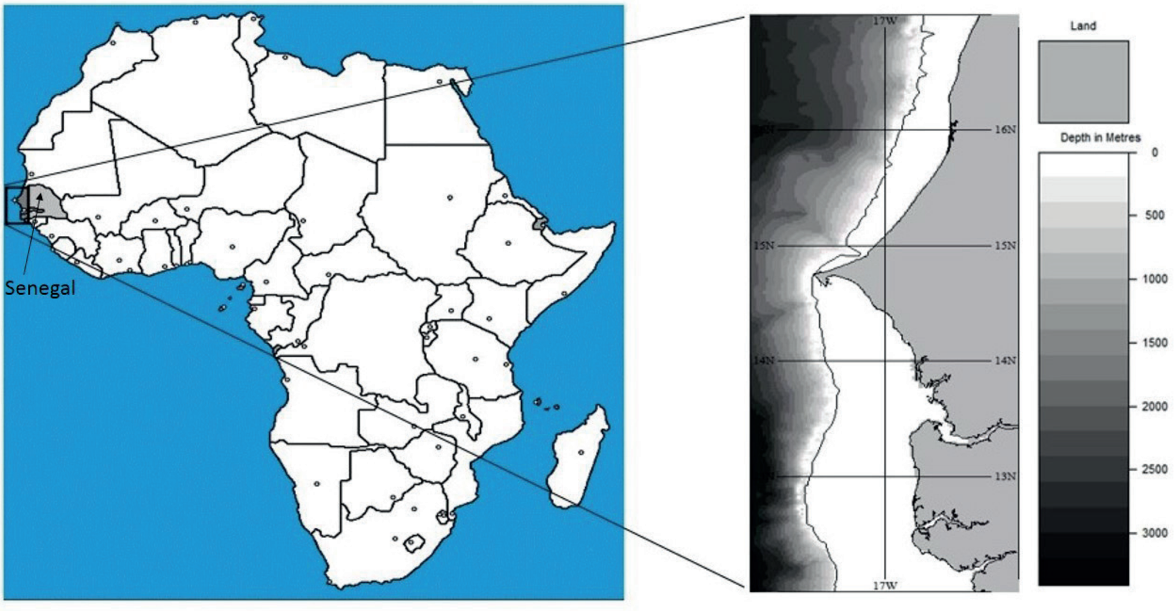

Figure 2: *Study area, (black line: 200 m isobaths). SST were averaged from the coast to 200 m isobaths and between* 12°5 N to 16°4 N.

MATERIAL AND METHODS

Study area: Upwelling along Senegalese coasts

The Senegalese upwelling system is a part of the Canary Current Large Marine Ecosystem, which is strongly influenced by the Canary Current (CC) flowing along the African coast from north to south between 30°N-10°N and offshore to 20°W (Fedoseev 1970). The CC surface waters are cool because they are upwelled water from the coast (Mittelstaedt, 1991).

Upwelling at the Senegal coast begins at late autumn and ends in spring (Teisson, 1982). North of Cap Vert the continental shelf is narrow, so the upwelling occurs near the coast, while south of Cap Vert the upwelling is a trapped cold water tongue in the middle of the continental shelf surrounded by warmed waters (Fig.1). The lowest and highest of SST are observed in March and October, respectively. As with most of the coastal upwelling systems, the Senegalese upwelling shows a great seasonal and interannual variability thought to have effects on small pelagic fish (Cury and Roy, 1987; Fréon, 1991; Bakun, 1996; Fréon and Mendoza, 2003).

Fish landed catch data

To study the variability of abundance of round sardinella and anchovy in Senegalese waters, monthly landed catch data from 1999-2009 were used. The catches were considered as an index of abundance. These data were obtained from the statistical section of the Directorate for Sea Fisheries (Direction des Pêches Maritimes; DPM) and constitute total landings in Senegal. Two sets of data were provided, artisanal and industrial catch. Therefore, data from artisanal catch were used since fisheries of small pelagic fish in Senegal are mainly conducted by artisanal fishermen, operating from canoes. Indeed, according to this fishery service, artisanal fisheries provides more than 75% of landings of small pelagic fish in Senegal.

Sea surface temperature data

Monthly SST (°C) data (1981-2009) from the daily images from satellite AVHRR pathfinder version 5.0 was used as the environmental predictor variable. These images with a spatial resolution of 4.4 km were improved qualitatively using specific algorithms to obtain thermal images with geometric distortion and especially atmospheric effects eliminated. These data are available on the NOAA (National Oceanic and Atmospheric Administration) web site.

SST was averaged from 12°5 N to 16°4 N and from the coast to the 200-m isobaths, since artisanal fishermen use to operate within this area (Fig.2).

Data analysis

The generalized additive models (GAMs) were used to investigate the associations between the environmental

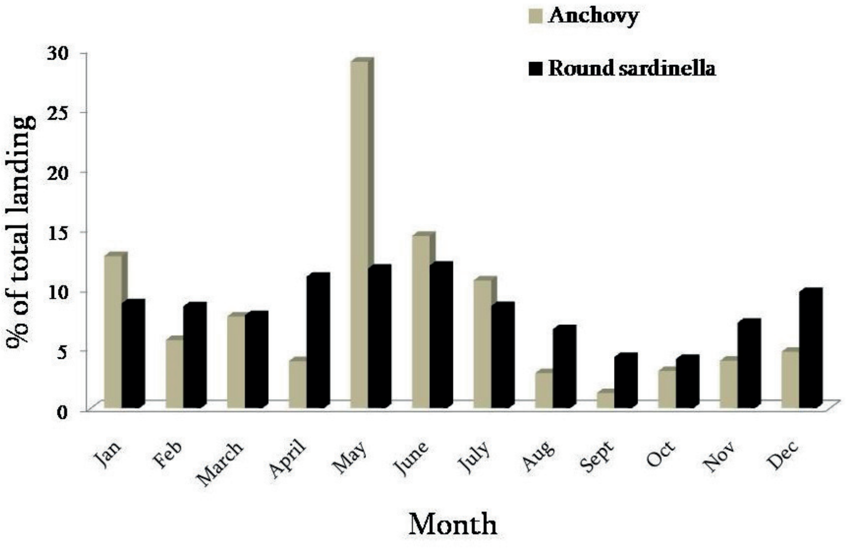

Figure 3: *Seasonal distribution of round sardinella and anchovy landing by artisanal fleet in Senegal. Average for 1999–2009.*

variable, SST, the temporal variable, month and abundance of round sardinella and anchovy. They allow depictions of complex relationships between species and their habitats (Zwolinski *et al*., 2011).

GAMs are described as a generalization of ordinary linear models (Wood, 2006). In these models the linear predictors are related to the response variables via a link function that extends the use of the regression models beyond non-Gaussian response variables. GAMs use data-driven functions, such as splines and local regression, which have superior performance relative to the polynomial functions used in linear models. The tensor-product smooth functions were used to fit the interactions between the predictors (SST, and month) and the dependent variable.

The mgcv package in the software R (version 2.14.1) was used. The dependent variable, landings of round sardinella and anchovy, is modelled as the additive sum of unspecified non-parametric functions of hypothesized covariates and their interaction. Three types of models were carried out:

- model_1=gam(Species abundance ~s(SST), family=Gaussian);
- model_2=gam(Species abundance~s(Month), family=Gaussian);
- model_3=gam(Species abundance ~s(Month, SST), family=Gaussian).

Approximate F-tests, the percentage of the explained deviance and the Akaike Information Criteria (AIC) were used to compare these models. The model with minimum AIC value is chosen as the best model to fit the data.

RESULTS

Figure 3 describes the seasonal variations of round sardinella and anchovy landings. Round sardinella landing shows two minor peaks in January and December and two major peaks in May and June. However, landing of anchovy exhibits two minor peaks in January and June, and one major peak in May. It appears a one-month lag as well as for maximum periods and minimum periods of landings for both species.

Round sardinella and anchovy landings are showing a strong variability from one year to another (Fig. 4). An overall gradual increase in round sardinella landing was observed in the period 1999-2009. However, in the same period, landing of anchovy demonstrates consistent decline. Withal, significant increase is observed in 2004.

Landings of round sardinella and anchovy show a non-linear relationship with regard to SST (Fig.5). Table 1 shows that all models were significant at $p = 0.05$ significance level. The temporal variable, month, was the most significant explanatory variable for both round sardinella and anchovy abundance. For sardinella, model_3 has the lowest AIC, while it is model_2 for anchovy (table 1). With regards to the percentage of the explained deviance, for both species, model_3 support the highest values (41.5% for the abundance of sardinella and 21.2%for the abundance of anchovy).

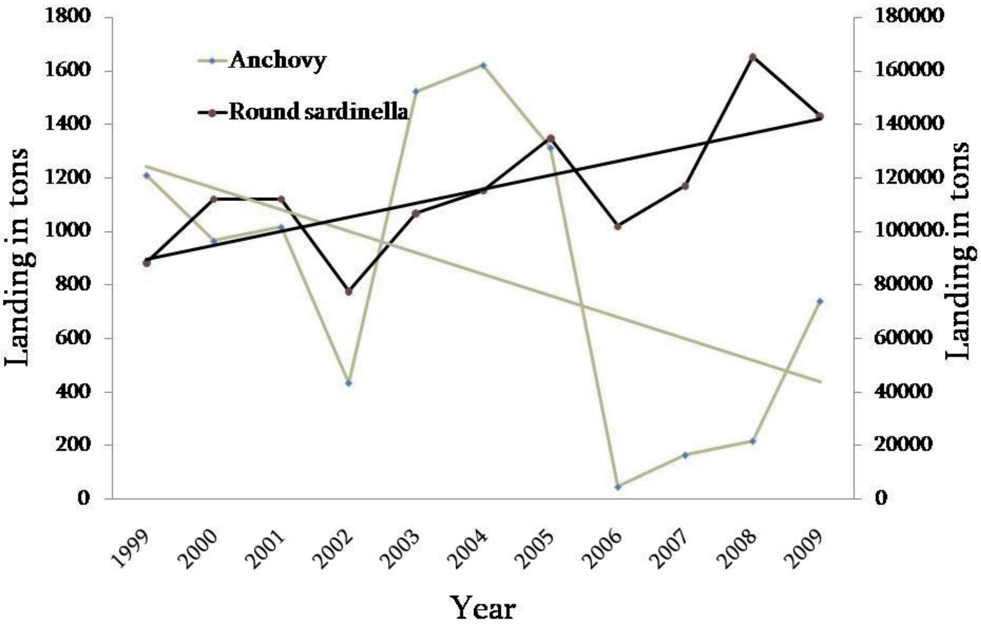

Figure 4: *Interannual variability of round sardinella and anchovy landing by artisanal fleet in Senegal.*

The effects that the explanatory variables have on round sardinella and anchovy abundance are shown (Fig.6 and 7). The environmental and temporal variable (SST and month) have approximately similar effects on round sardinella and anchovy abundance. The effects of month on round sardinella and anchovy abundance were high between May and June with a peak in May. The effects of temperature on round sardinella and anchovy abundance were high between 22.0 and 24.0^{o}C. The highest effect of SST on round sardinella abundance was at 22.7^{o}C, whereas that on anchovy abundance was at 22.32^{o}C.

Figure 8 shows the temporal interactions of sardinella and anchovy abundance with SST variations. The model fitted the maxima effects of SST on round sardinella abundance at 21 to 25.0 °C, while those on anchovy abundance were fitted between 22.0 to23.0 °C. The result indicates that at lower temperatures less sardinella and anchovy were landed.

DISCUSSION

The preceding hypotheses are based on landing series. Although it is difficult to appreciate the respective roles of recruitment and availability in the figures cited, we shall consider them as reflections of real changes in abundance of round sardinella and anchovy.

The results of this work seem to suggest the existence of a preference in temperature for these two species. Temperature values associated with the highest abundance appear very close, 22.3 °C for anchovy and 22.7 °C for round sardinella. However, SST ranges which correspond to high abundance of round sardinella and anchovy differ.

Table 1: *Significance values (p-values), the AIC and the deviance explained [%] of the covariate tested on round sardinella and anchovy abundance. Level of significance was set to 0.05. (signif. codes: '***' 0.001, '**' 0.01, '*' 0.05, '(.)' 0.1, '' 1).*

Specification	**Sardinella aurita**			**Anchovy**		
Covariates	p-value	AIC	% of explained deviance	p-value	AIC	% of explained deviance
model_1	4.65e-08 ***	2548.1	28.4	0.02 *	1634.1	9.0
model_2	9.77e-10 ***	2536.4	36.2	0.001 **	1625.2	19.3
model_3	2.42e-08 ***	2533.6	41.5	0.008 **	1626.2	21.2

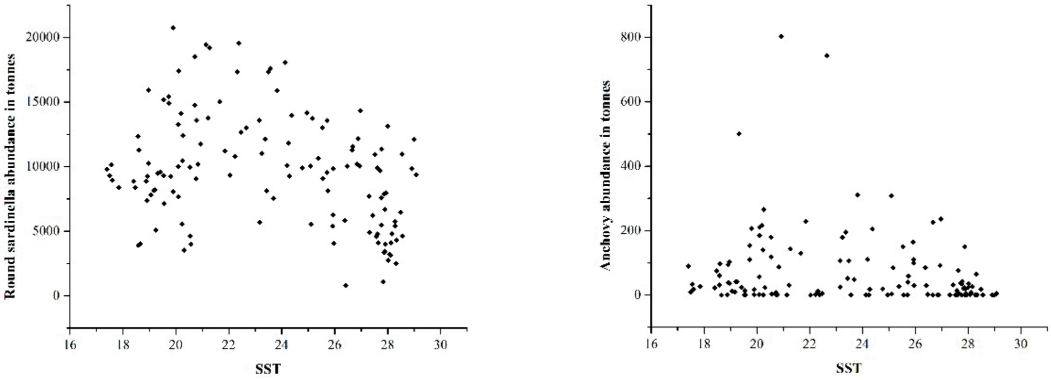

Figure 5: *Scatterplot showing the relationship between sardinella and anchovy abundance and SST (1999-2009).*

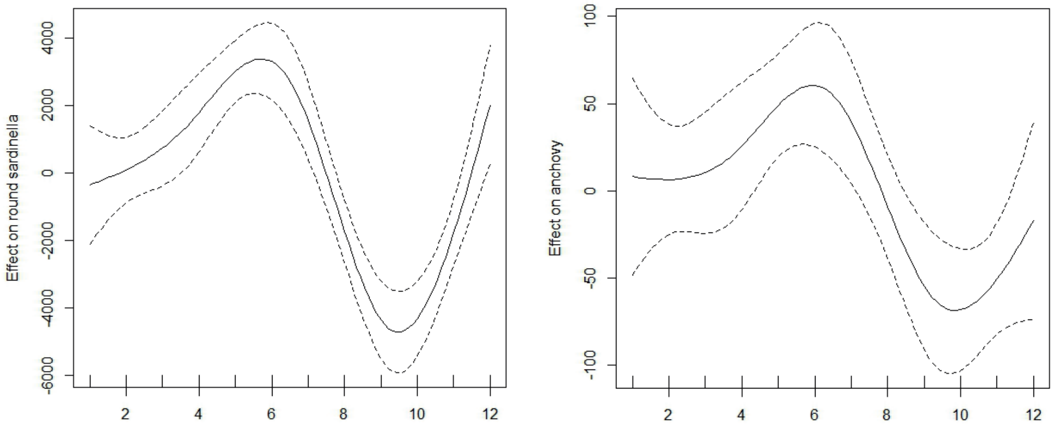

Figure 6:

Results of GAMs regression from 1999 to 2009. Sardinella and anchovy landing are represented as a function of month from January to December. Dashed lines represent two standard error boundaries around the covariate main effects.

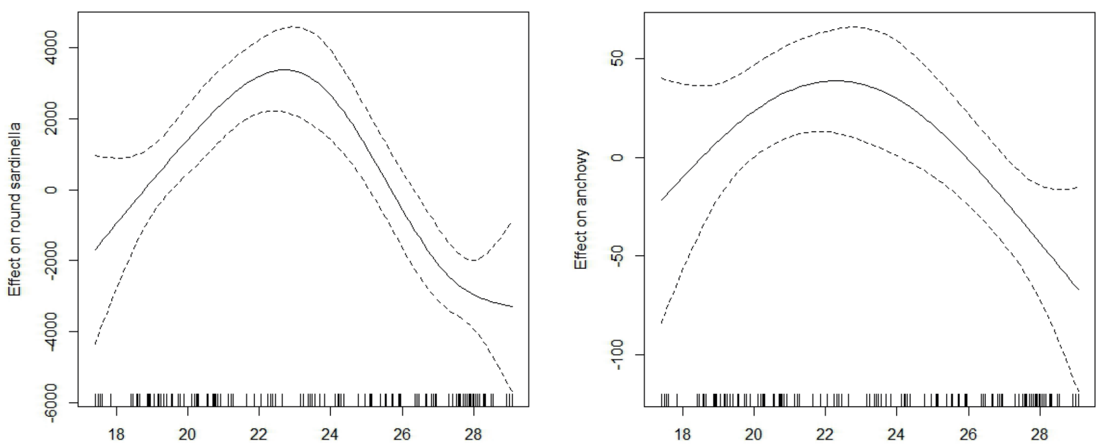

Figure 7:

Results of GAMs regression from 1999-2009. Sardinella and anchovy landing are represented as a function of SST. Dashed lines represent two standard error boundaries around the covariate main effects. lines represent two standard error boundaries around the covariate main effects.

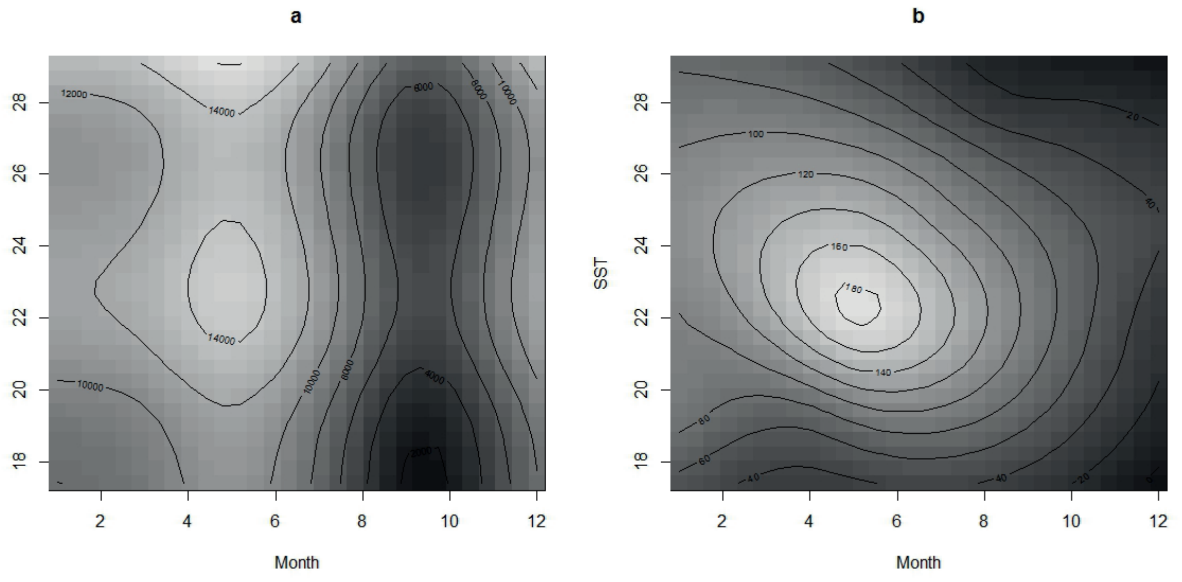

Figure 8:

Results of GAMs regression from 1999-2009. Sardinella landing is represented as a function of SST and month (a) and anchovy landing is represented as a function of SST and month (b).

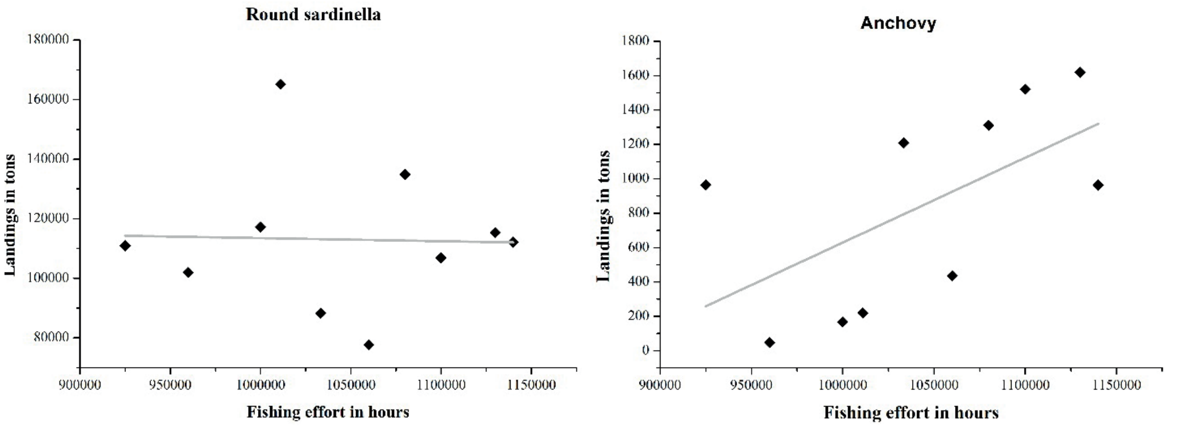

Figure 9: *Round sardinella and anchovy landing (tons) , and fishing effort (hours) (1999-2008).*

Temperature range for anchovy abundance (22.0-23.0 °C) is less wide than that found for round sardinella abundance (21.0 to 25.0 °C). Thus, it seems that round sardinella would tolerate a wider SST range than anchovy. Such results may lead to think that round sardinella seems to be more flexible in terms of choosing a suitable habitat than anchovy. In this case, it could be say that increasing temperatures might enhance the migratory demand of anchovy stronger than that of round sardinella.

Previous studies have attempted to link round sardinella abundance to SST. In Mauritanian waters, it has been demonstrated that temperature below 21 °C was associated with low catch of round sardinella while sardinella was abundant in Senegalese waters where the temperature remains above 21 °C (Zeeberg *et al*., 2008). Sabatés *et al*. (2006) showed that abundance of round sardinella in the western Mediterranean was positively related to SST warming.

Most studies on anchovy were focused on temperature ranges related to anchovy spawning. In the Bay of Biscay, Arbault and Lacroix (1977) have reported anchovy spawning within a thermal window of 14.0-20.0 °C. Sola *et al.* (1990) have found a thermal window of 16.5-19.0 °C whilst according to Motos *et al.* (1996) the thermal range is between 14.0-18.0 °C. In the Benguela region thermal range of 17.4-21.1 °C was associated with anchovy spawning period (van der Lingen *et al.* 2001).

In conclusion, this study shows that it might exist thermal window for round sardinella and anchovy abundance. It appears high degree of coupling between round sardinella and SST. Besides SST, abundance of both species could also have been the result of non-climatic influences such as fishing effort. This hypothesis can be disregarded because the fishing effort during the 1999-2008 period is not correlated (r= -0.001, n=10) against round sardinella landings (Fig.9). However, correlation between fishing effort and anchovy landings is relatively significant during the 1999-2008 period (r=0.58, n=10). Indeed, further investigation should be done using monthly fishing effort in order to better estimate the abundance index.

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