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3.2 NAO related small pelagic fisheries fluctuations off Morocco and Senegal

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Introduction

The small pelagics are one of the most important fish resources off the North West African coast. These resources are shared between different countries and are exploited by artisanal and industrial fleets.

Cupleids as *Sardina pilchardus* and *Sardinella* spp (*S. aurita* and *S. maderensis*) are important target species and make up over 80% of small pelagic catches in Morocco and Senegal. The fishing activity in this area and their statistics provide us ecological time series, which are suitable to compare with the dynamics of the climatic system.

Hydroclimatic regime

The large-scale small pelagic fisheries are supported by an important productive marine region in the NW African region: The Canary Current ecosystem, which is one of the largest wind-induced upwelling systems.

The seasonality of the upwelling and the displacement of a marine front along the coast of Mauritania and Senegal cause a "contrasting hydroclimatic situations" with cold waters in winter, warm waters in summer and two short transition periods between both seasons. This area is an important transition zone, both hydrologic and faunistic, between an "equatorial" warm region and a "Canary" cold region. (Wooster and McLain, 1976; Belvèze and Erzini, 1983).

This large abundance of small pelagics means that there is an important intermediate trophic level in this large ecosystem. Despite their importance, little is known about the climate effects in the region.

NAO Index (Why use NAO?)

The NAO is the most robust pattern of recurrent atmospheric behaviour in the North Atlantic region (Hurrell and Dickson, 2003). NAO fluctuations are widest during the colder months (December–March) when the atmosphere is most active dynamically (Hurrell *et al.*, 2003; Stenseth *et al.*, 2003).

The NAO index reduces complexity of time-space variability into simple measures, representing a "weather package", and might provide an assessment of the ecological effects of climate fluctuations.

Most research about the NAO and its effects has been made in the North Atlantic, where this climatic *proxy* explains a great part of the climate variability., The research on the relationship between climate processes and the Northwest African upwelling system began only a few years ago.

The NAO effects in NW Africa produces during the positive phases (NAO+) an intensification of the trade winds from the northeast and, as a consequence, an increase of the upwelling and cooling water. An inverse situation occurs during the negative phases (NAO-). The fluctuations in the upwelling extension are controlled by the predominant winds that are initiated in the Subtropical Atlantic, the trade winds, which are largely determined by the NAO (Van Camp *et al.*, 1991; Nykjaer and Van Camp, 1994). The NAO explains 50% of SST annual variability in the open sea in this Atlantic area (Helmke, 2003). The wind stress north-south component (τ_y) of the wind vector correlates significantly with the winter NAO index in most of the Atlantic basin (Visbeck *et al.*, 1998)

Background in Morocco and Senegal

Wind stress

In the NW Africa, NAO explained a high percentage of the variability of the winds in Morocco, off 21ºN (Meiners, 2007). The wind stress component (τ_y) was in synchrony and positively correlated with the NAO index. This *proxy* explained around 41% of wind stress variability in this wide area.

The same results were obtained in Mauritania and Senegal waters (from 21ºN to 15ºN) where the wind stress component (τ_y), showed changes in accordance with opposite NAO phases during the period 1960–2004 (Meiners *et al.*, 2010). The Figure 1 shows the high synchrony between NAO index and wind stress v-component (τ_y) time-series at time t, and were positively and significantly correlated (r=0.72; $F_{1,43}$=48.3265, p<<0.001). NAO explained around 53% of wind stress variability in this southern area.

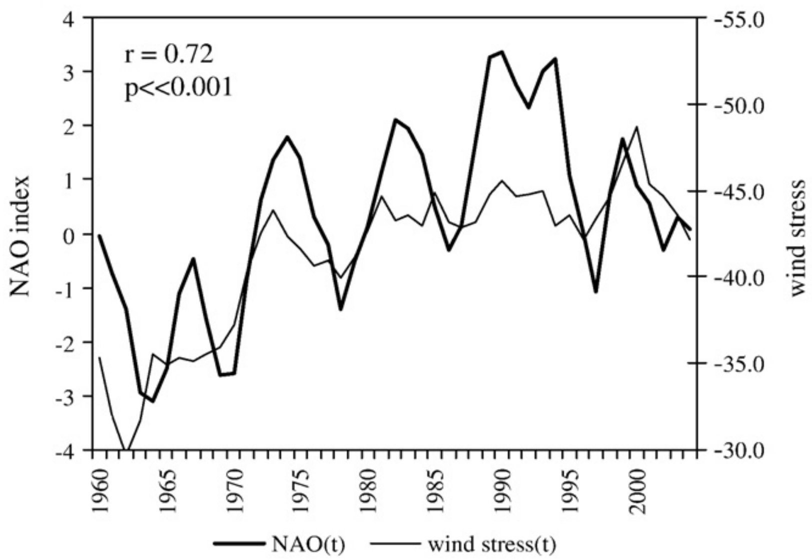

Figure 1. Synchrony between NAO index and wind stress v-component time-series at time t. Note that the negative sign indicates north–south vector (from Meiners *et al.*, 2010).

Upwelling

The NAO explains a high percentage of the upwelling variability periods to around 21ºN, and its changes were in phase and positively related with NAO fluctuations (Meiners, 2007).

A relation between the upwelling extension and intensity with the wind stress was observed in Mauritanian and Senegalese waters with high local variability. In the NAO-negative phases (1960–1973) the conditions for intense upwelling were less extended than during NAO-positive phases (1990–2000); (Meiners *et al.*, 2010).

Primary production

In this area, the high concentrations of photosynthetic pigments imply a significant productivity (Freudenthal *et al.*, 2001), due to the sustained supply of nutrients, the upwelling, and its retention or recirculation in the surface waters by the meso-scale processes.

Meiners (2007) find a strong and proportional relation at the same time t between wind stress, NAO and primary production with the chlorophyll concentrations from satellite imagery in Moroccan waters.

Objective

Recent studies in NW Africa waters have shown that wind-induced upwelling (τy) and primary production are related with the NAO. A significant relationship between hake abundance and the NAO index was observed (Meiners, 2007; Meiners *et al.*, 2010). Moreover, the hake is an important predator of clupeids and its abundances might be related.

Considering this, the goal of this approach was to perform an explorative analysis to test the possible relationship between the climate variability described by the NAO index and the abundance of small pelagics in Morocco and Senegal.

Methods

Fishery data

Annual CPUE data as abundance proxies from three commercial small pelagic species:

- *Sardinella aurita*: between 1981–2005 (25 years), from the artisanal fleet in Senegal. The catch is in tonnes and the effort in fishing trips.
- *Sardinella maderensis*: between 1990–2005 (16 years), from the artisanal fleet in Senegal. The catch is in tonnes and the effort in fishing trip.
- *Sardina pilchardus*: between 1990–1999 (10 years) from the industrial Spanish purse seiners fleet, fishing south to 26°N, in Saharan waters. The catch is in tonnes and effort in fishing days.

NAO index

The winter NAO index, between December to March. Source: National Center for Atmospheric Research (NCAR) http://www.cgd.ucar.edu/cas/jhurrell/indices.html. (Hurrell, 1995). NAO data were smoothed by a running average of 3 years to reduce time-series noise.

Analysis

Correlation techniques were used to analyze and quantify the relationships between climate variability (NAO index) and the annual yields of the small pelagic species at the same time. The statistical significance of each relation was estimated by an ANOVA (F test).

Results

A quadratic dependence between abundance series of small pelagic species and the NAO index of the same year (t) was found in all cases.

Sardinella aurita

There was a synchrony between the residuals of the CPUE and the smoothed NAO. The highest CPUE values coincided with the largest positive anomalies of the NAO, and negative residuals corresponded to negative NAO values.

A negative quadratic dependence was obtained and the polynomial regression was statistically significant ($p<0.05$) between the residuals CPUE and the NAO index. The *proxy* explains around 32% of abundance variability of this species (Figure 2).

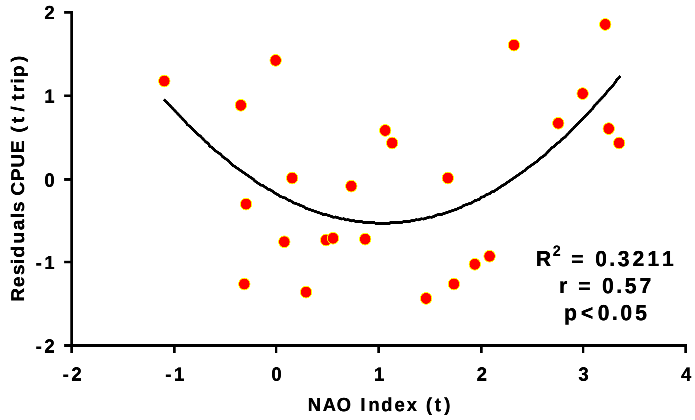

Figure 2. Negative polynomial relationship between residuals CPUE of *S. aurita* and NAO index at the same t.

Sardinella maderensis

A positive quadratic function was obtained, statistically significant ($p<0.05$), between the CPUE time series and the climatic *proxy*. In this case, the NAO explains around 42% of abundance variability of this species (Figure 3).

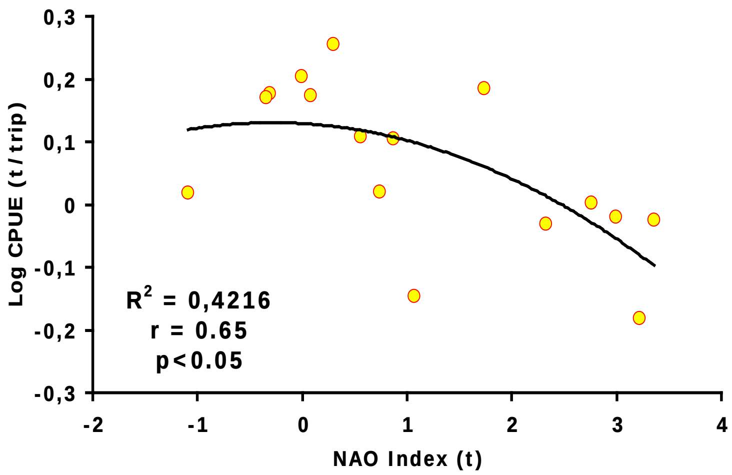

Figure 3. Positive polynomial relationship between residuals CPUE of *S. maderensis* and NAO index at the same t.

Sardina pilchardus

This species provided a weak fit, but one must take into account that is a very short time series (only 10 years).

The negative quadratic dependence obtained was not statistically significant ($p>0.05$). The NAO explains only 14% of abundance variability of this species. The results were not conclusive.

Discussion

The winter NAO index changes are supposed to have immediate effects on fast growing species such as small pelagics.

The quadratic responses may suggest an "environmental window" defined by the NAO for every species, showing a mid-high dependence of the abundance with respect to the NAO index for *Sardinella* species.

S. aurita presented a broad “environmental window", with optimal NAO values in the range from -1 to 0 and >2. *S. maderensis* showed an inverse relationship, with optimal NAO values between 0 and 1.7, given the fit to positive quadratic function.

S. pilchardus had the widest window (from -1.1 to 3.4) and a negative relationship with the NAO, as *S. aurita*, although the results are not conclusive, surely because the series is not long enough. However, this species has shown strong dependence with oceanographic conditions in the North Atlantic (Guisande *et al.*, 2001; Santos *et al.*, 2001), and one may assume that the response to the NAO index is close. Probably, a relationship would be indicated by a longer time series.

Contrasting reactions between *Sardinellas* species suggest important ecological differences in response to the same phenomena and a less competitive behavior of *S. maderensis*. In fact, this species is less abundant in the catches and its distribution is more restricted than that of *S. aurita*. In addition, the broad “environmental window” of this latter species could imply greater abundances and a wider latitudinal distribution when compared with *S. maderensis*, at it really occurs.

One may also deduce from these results that *S. maderensis* is a more “tropical” and *S. aurita* more “temperate” species.

The similar behaviour of *S. aurita* and *S. pilchardus*, another “temperate” species, could point to a comparable ecological role on both sides of the permanent upwelling, but the results are inconclusive with respect to the of sardine.

In general terms, it is necessary to use longer time series in order to establish conclusions about relationships with large-scale phenomena such as the NAO index and, in these cases, further analysis is required.

In any case, to describe and quantify these relationships it is helpful to consider climate factors as state variables in predictive and functional fishery models. Also, different kinds of relationships may explain diverse features in ecological terms, showing divergent effects over species under fishing pressure in the same region.

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3.3 Historical landings of small pelagics off North West Africa. "Signals" of the climatic effect on small pelagics in North West Africa and in the Canaries

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Introduction

The North West African marine area located between 36ºN and 12ºN belongs to the Canary Current Large Marine Ecosystem, which is one of the most productive areas in the world. The high productivity of this ecosystem supports very important fishery resources that have led to a great development of the fishing activity in the area. West African stocks are exploited by the coastal countries as well as by foreign fleets. This fact advises the establishment of a scientific cooperation framework, over-arching cooperative actions, such as the assessment of the exploited resources. This scientific framework is provided by the Committee for the Eastern Central Atlantic Fishery (CECAF) and NW African stocks are assessed in the CECAF Working Groups (Subgroup North).

Three main data sources have been analysed to study the temporal evolution of small pelagics in North West Africa: