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INFLUENCE OF THE ARCTIC OSCILLATIONS ON THE SARDINE OFF NORTHWEST AFRICA DURING THE PERIOD 1976-1996

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AO
CECAF
FISHERIES
SMALL PELAGIC

ABSTRACT. – Studies on the impact of climate change on exploited marine fishes are numerous. However, the response of fish stocks to these effects is hard to predict, due to the inherent uncertainty in these models, and the lack of knowledge of the biological response of species in short time periods. Thus, some authors have modelled the response of marine species to large-scale climate phenomena. The main aim of the current study is to analyze the possible effect of the main large-scale climate indices: Atlantic Multidecadal Oscillation (AMO), the North Atlantic Oscillation (NAO), and Arctic Oscillation (AO) and Southern Oscillation Index (SOI) (as measured to El Niño/La Niña episodes) on the variability of the NW African sardine (*Sardina pilchardus*) stock. The sardine fishery data has its origin in the fishing activity of Spanish purse seine fleet in NW Africa from 1976 to 1996 developed within the Fishery Agreement between Spain-EU and Morocco. These fisheries data refer to one FAO statistical area along the African coast between the parallels 29°N and 26°N. The results indicate that there is an effect driven by AO affecting sardine relative abundance in the study area, at least for the period 1976-1996. Moreover, this relation between AO and sardine relative abundance could involve the Sea Surface Temperature.

INTRODUCTION

It is widely accepted that the planet is experiencing a period of rapid global warming (Oreskes 2004) and also that its impact on marine biodiversity and fisheries ecology is primarily driven by human activity (Keller 2007). In this context, there is increasing concern about the global warming impact over the ecosystems and services that they provide, i.e., food safety (Jaykus *et al.* 2007). For this reason, many studies attempt to forecast the effect of global warming on long-term exploited fish stocks (for example see Lehodey *et al.* 2010, 2013, Dueri *et al.* 2014).

Although there are numerous studies on the impact of climate change on exploited marine fishes (Lehodey *et al.* 2010, 2013, Dueri *et al.* 2014), these studies are affected by several sources of uncertainty associated with the different atmosphere-ocean general circulation models and emission scenarios of the Intergovernmental Panel on Climate Change (IPCC). Some results of these studies forecast fluctuations in biomass, and distribution changes of the studied species (e.g., Lehodey *et al.* 2010, 2013, Alheit *et al.* 2014, Dueri *et al.* 2014). However, the impact of these effects is hard to predict due to the inherent uncertainty in these models, and the lack of knowledge about the biological response of species in short time periods. Thus, some authors have modelled the response of marine species to large-scale climate phenomena, such as the North Atlantic Oscillation (NAO) or El Niño South Oscillation (ENSO) (e.g., Chávez *et al.* 2003, Báez *et al.* 2011, Alheit *et al.* 2014, Kumar *et al.* 2014, Báez 2016, Rubio *et al.* 2016, Muñoz-Exposito *et al.* 2017).

This type of studies allows us to analyze the regime shift of exploited species, their biological response to changes and the short-time response to climatic fluctuations, as well as cascade response.

Small pelagic fishes are the most important fishery resources worldwide. According to the FAO (2016a), seven of the top ten marine species with the highest catch production are small pelagic fish (three of them belong to the genera *Engraulis* and *Sardina*). Thus, food safety considerations must be primordial. Moreover, small pelagic fishes are key forage for marine predators, including the charismatic megafauna as dolphins (Checkley *et al.* 2017). Therefore, understanding the response of small pelagic fishes to climate variability is important to forecast the human-induced response to climate change.

The ecosystem of the Canary Current is one of the four major eastern boundary upwelling systems of the world oceans. The Moroccan Atlantic continental shelf forms part of that ecosystem, characterized by its high biological productivity and its intensive fisheries where the European pilchard *Sardina pilchardus* (Walbaum, 1792) represents the main landings (Kifani *et al.* 2008). Along the Western coast of Africa, sardines are an important resource for the countries in the region.

The main aim of the current study is to contribute to the knowledge on the possible effect of climate variability described by the Atlantic Multidecadal Oscillation (AMO), the North Atlantic Oscillation (NAO), Arctic Oscillation (AO) and El Niño Southern Oscillation (ENOS) on the *Sardina pilchardus* fishery along NW African coast, both in regard to the variability of this resource, and in its possible biological implications.

MATERIAL AND METHODS

The sardine fishery data source is the fishing activity of Spanish purse seine fleet in NW Africa from 1976 to 1996, developed under different Fisheries Agreement between Spain-EU and Morocco. These fishery data refer to FAO Zone B (along the African coast between the parallels 29°N and 26°N). The agreement ended in 1999, but from 1996 to 1999 was mandatory fishing in Zone C (south of 26ºN). Sardine stocks are highly influenced by the eastern boundary upwelling system (EBUS) of the Canary Current, constituting the most abundant small pelagic resource in the study area. We consider that CPUE, in this particular scenario, reflects the local relative abundance or at least available biomass of sardine stocks. The annual CPUE of Spanish statistics available during this period was used. These data use fishing days as fishing effort unit (FAO 2016b).

Monthly values of the AMO, AO, NAO and SOI index were downloaded from the website of the National Oceanic and Atmospheric Administration: http://www.cpc.noaa.gov/. Firstly, we analyzed the time series for each variable. In order to identify periodicity or autocorrelation, we searched for common time trends and cyclicity in the time series using spectral analysis. Spectral analysis was performed with the software PAST (available from web site: http://folk.uio.no/ohammer/past/) (Hammer *et al*. 2001, Hammer & Harper 2006). Different curve regression models were applied using the CPUE of sardine *versus* the climatic oscillations used as independent variables. We selected the best fit among several significant regressions when different degrees of freedom were involved, in accordance with the highest F-value.

The relation between the different climatic indices and CPUE can be also analyzed in terms of the accumulated values (as in Báez *et al*. 2014). Annual values were transformed into anomalies by subtracting the mean value calculated over the whole period 1976-1996. The accumulated variables corresponding to a specific year were then calculated as the sum of the anomalies of the previous years (e.g., the accumulated values corresponding to 1990 were calculated as the sum of the anomalies for the period 1976-1990), according to the expression:

$$\sum_{i=m}^{n} = \text{Annual value}_i - \text{Mean period}$$

where n is the reference year, Annual value of the variable for a particular year, and Mean period is the mean value of the variable for the whole studied period (i.e., since initial year *m* to last year *z*).

Moreover, to test the effect of climatic oscillations in the environment, correlations were sought between SST and chlorophyll *a* (as a proxy for productivity). We used satellite environmental data to establish a possible causal link between climatic oscillations and fisheries, and the variability of environmental conditions (SST and ocean productivity in the region).

Monthly SST was obtained from the NOAA Extended Reconstructed Sea Surface Temperature Dataset (ERSST) version 4. This dataset is derived and statistically enhanced from the International Comprehensive Ocean-Atmosphere Dataset (ICOADS, http://icoads.noaa.gov/), it is available at 2×2 degrees spatial resolution (NCEI 2018).

RESULTS

No time trend autocorrelation or periodicity in the CPUE data was observed. A periodogram is shown in Fig. 1, and the autocorrelation plot are shown in Fig. 2.

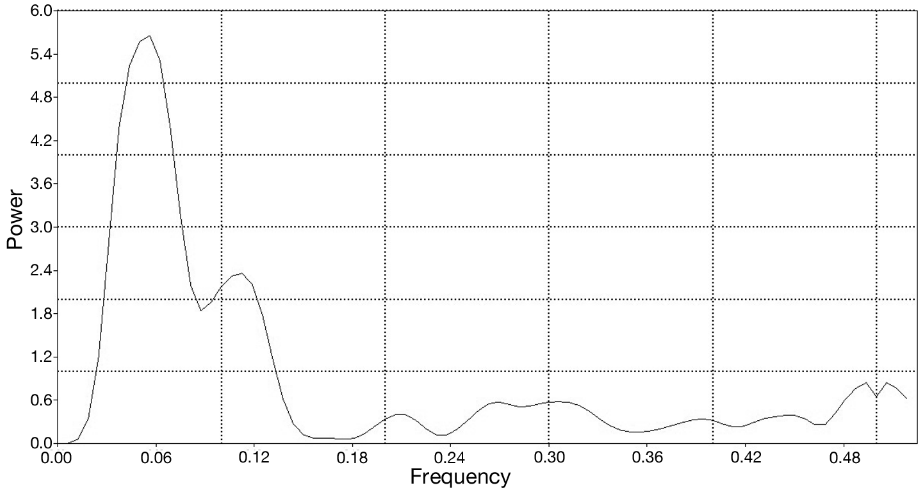

Fig. 1. – Periodogram of the sardine Catch Per Unit Effort (CPUE) time series. Cyclicity is not observed.

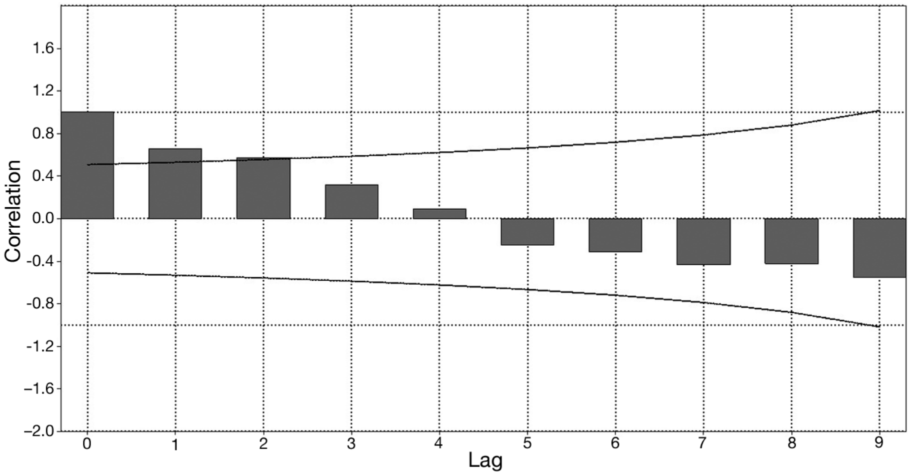

Fig. 2. – Autocorrelation graph bar of the sardine Catch Per Unit Effort (CPUE) time series. Time correlation is not observed.

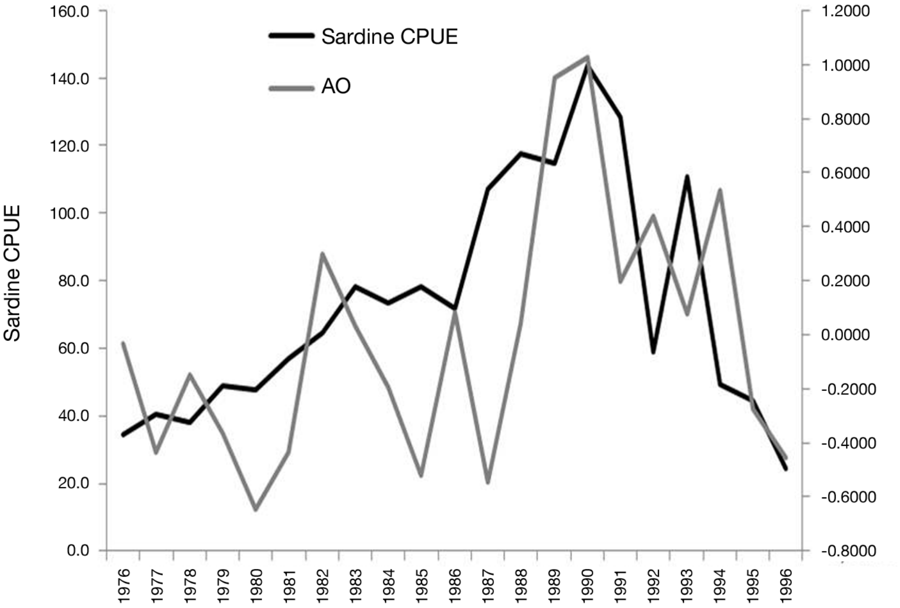

Fig. 3. – Plot between sardine CPUE and the AO.

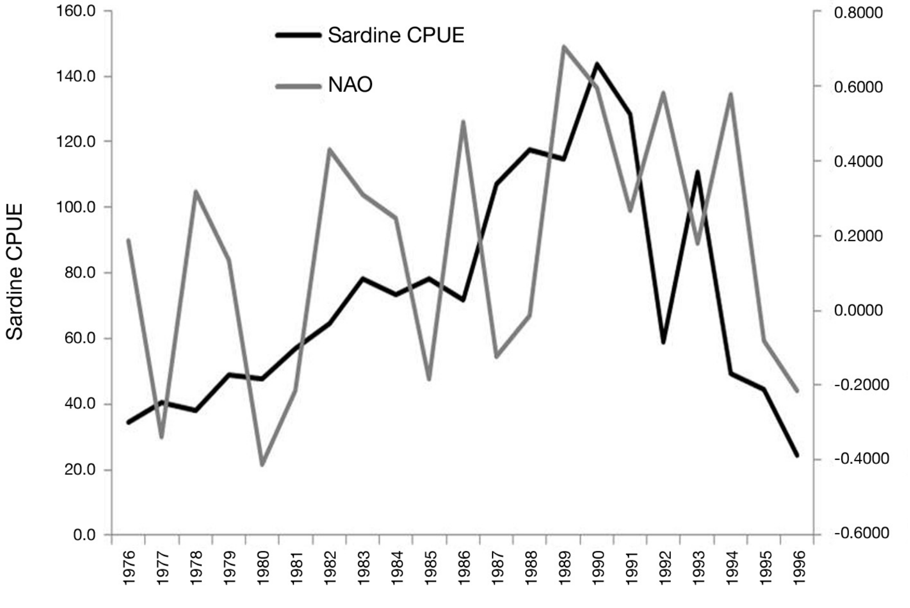

Fig. 4. – Plot between sardine CPUE and the NAO.

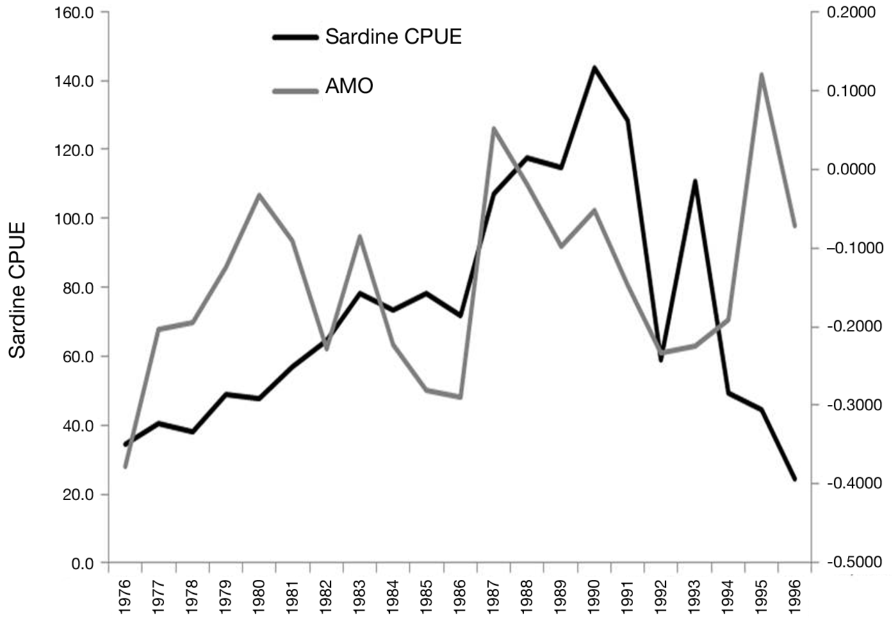

Fig. 5. – Plot between sardine CPUE and the AMO.

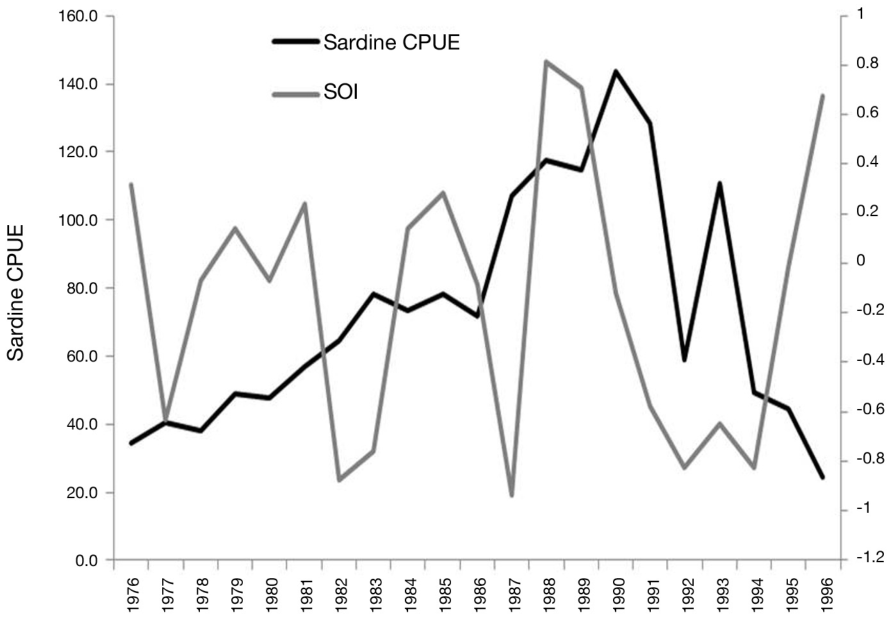

Fig. 6. – Plot between sardine CPUE and the SOI.

Figs 3 to 6 show the plots between sardine CPUE and the climatic indices AO, NAO, AMO and SOI, respectively.

In a first step, we only observed significant non-parametric correlation between the sardine CPUE *versus* AO (Table I) (Fig. 7).

We found a significant correlation between SST and AO, and CPUE for the period 1976-1996. AMO was the only variable not correlated with SST in this interval of time (Table II). However, for the time series available of SST from 1951-2016, the AMO shows a strong correlation (Table III).

When we adjusted a multiple model by step-forward with both climatic oscillations and SST, the only variable that entered the model was the AO according to the model (Fig. 8):

$$\mathrm{CPUE}_{\mathrm{sardine}} = 73.598 + 38.192 \times \mathrm{AO}$$
$$(R^2 = 0.271;\ F = 7.055;\ P = 0.016)$$

Table I. – Non-parametric correlation results between climatic oscillations and Sardine Capture Per Unit Effort (CPUE) for the studied period (1976-1996), from North Western African. Key: Arctic Oscillation (AO), Atlantic Multidecadal Oscillation (AMO), North Atlantic Oscillation (NAO), and Southern Oscillation Index (SOI).

		AO	AMO	NAO	SOI
CPUE	Rho	0.449**	0.127	0.382	–0.129
	P	0.041	0.582	0.088	0.576
	N	21	21	21	21

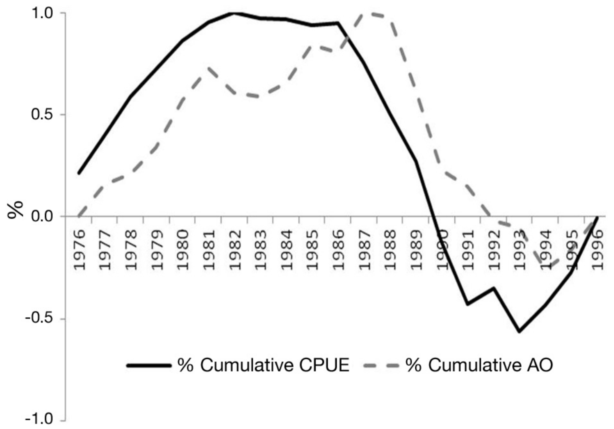

Fig. 7. – Accumulated values correlation between Artic Oscillation (AO) *versus* sardine CPUE for the studied period (1976-1996) from North Western Africa.

Therefore, although the SST is correlated with the CPUE, the AO was the only explanatory variable of those tested for the study period.

DISCUSSION

The results indicate that there is an effect driven by AO affecting the sardine's relative abundance in the study area, at least for the period 1976-1996. Moreover, this relation between AO and sardine relative abundance could relate to SST variability. The AO, together with the NAO, is the largest source of variability in the Northern Hemisphere of the Atlantic. When the AO is in its positive phase, the polar vortex, a belt of strong winds circulating around the polar region is most strong, confining colder air masses across polar regions. Contrarily, during the negative phase of the AO, the polar vortex is weaker, thereby allowing cold air to circulate southward (Budikova 2008). A positive AO phase increases the intensity of trade winds (Marshal *et al.* 2001, Hall *et al.* 2014) impacting across the Northwestern African region (Justino & Peltier 2008). These north-easterly trade winds drive surface water offshore, which are replaced by nutrient rich colder subsurface water masses giving rise to high levels of productivity (Pelegrí & Benazzouz 2015), subsequently intensifying hydrodynamic activity inducing mesoscale features as upwelling/downwelling processes, as well as, generating cross-shelf transport, the evolution of the

Table II. – Non-parametric correlations between sardine CPUE, climatic oscillations (i.e., AO, AMO, NAO, and SOI) and Sea Surface Temperature (SST) during the period 1976-1996. Key: Atlantic Multidecadal Oscillation (AMO), the North Atlantic Oscillation (NAO), Arctic Oscillation (AO) and Southern Oscillation Index (SOI).

		CPUE	AO	AMO	NAO	SOI
SST	Rho	0.521**	0.514**	–0.021	0.621**	–0.476**
	P	0.015	0.017	0.929	0.003	0.029
	N	21	21	21	21	21

Table III. – Correlation results between climatic oscillations and Sea Surface Temperature (SST) for the time series available of SST 1951-2016. Key: Atlantic Multidecadal Oscillation (AMO), the North Atlantic Oscillation (NAO), Arctic Oscillation (AO) and Southern Oscillation Index (SOI).

		AO	AMO	NAO	SOI
SST	Rho	0.269**	0.416**	0.145	–0.104
	P	0.029	0.001	0.244	0.405
	N	66	66	66	66

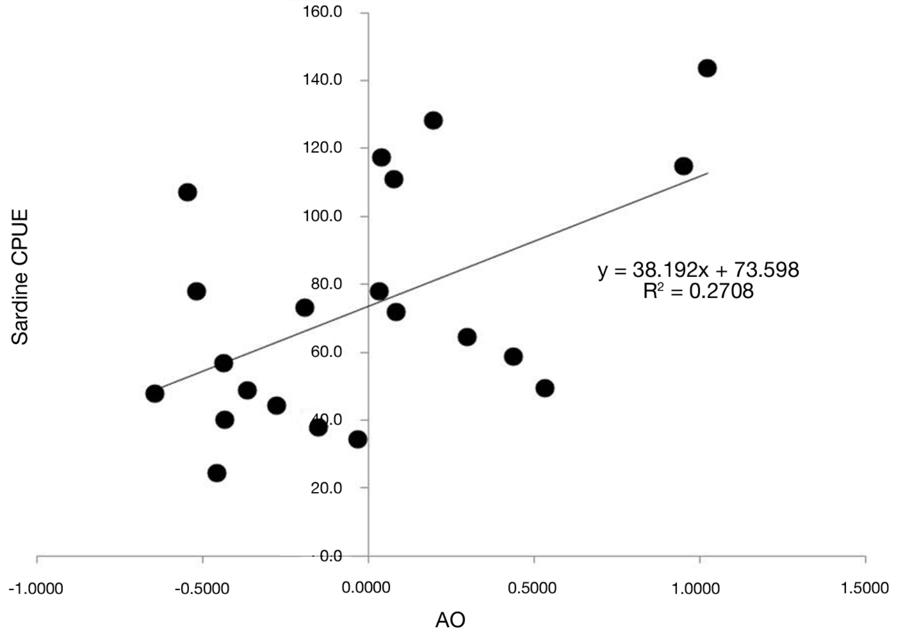

Fig. 8. – Linear relationship observed between Artic Oscillation (AO) *versus* Sardine CPUE for the studied period (1976-1996) from North Western Africa.

mixed layer and the formation of deep water (Bourassa *et al.* 2010, Pelegrí & Benazzouz 2015).

The eastern boundary upwelling system of the Canary Current supports the main small pelagic fish resources of the region, among which sardine (*Sardina pilchardus*) is the most important and mostly fished off Morocco (Braham & Corten 2015). The hydroclimatic variability can show its influence on the oscillations of sardine abundance by enhancing early life survival to recruitment. Direct evidence of coastal upwelling plumes was reported to affect the offshore transport of sardine eggs and larvae (Rodriguez *et al.* 1999).

Thereby, the intensification of trade winds mediated by AO can enhance productivity in the area, maintaining the condition status of the small pelagic resources by ameliorating the physical fitness of fish and their relative abundance and CPUE's, despite the increasing temperatures in the region attributed to climatic changes (Braham & Corten 2015). In this study, increased mean temperatures SST show a positive correlation with the AO (Table II).

According to Checkley *et al.* (2017), the population fluctuation of anchovies and sardines are nitrogen-input dependent in the pelagic domain, which in turn influences the magnitude of primary production and its temporal variability. These primary sources are projected to vary with climate change mainly due to wind regime changes, water column stratification, and river discharge. Thus, we forecast that the *Sardina pilchardus* stock from this zone of Western Africa will respond with fluctuations in its population abundance to short-term changes of the climate regime.

It is widely accepted that the small pelagic resources are prone to strongly suffer the effects of climate change, resulting in drastic fluctuation of biomass in large marine ecosystems (Reid & Valdés 2011, Alheit *et al.* 2012, 2014). In a similar way, despite uncertainties regarding the validity of trends observed in two decades, our results show that the relative abundance of sardine is related with AO variability. Braham *et al.* (2014) suggested that changes in species distribution and abundance in pelagic ecosystems are difficult to relate to environmental dynamics. For this reason, CPUE's relationships with AO are important to be clarified.

According to Cury & Roy (1989), the relations between annual recruitments and upwelling intensity are dome-shaped in Ekman-induced upwellings from West African sardines. In this upwelling scenario, annual recruitment increases with upwelling intensity until wind speed reaches a value of 5-6 $m.s^{-1}$ and decreases with higher speed winds. Recruitment of small pelagic stocks are driven by this dome-shaped which defines an environmental window which may modulate sardine recruitment hypothesized for sardine of the Iberian upwelling ecosystem (Roy *et al.* 1995). Thus, positive AO phases could be responsible for ideal wind speeds in which the ecosystem is sustainable. Inversely, the AO negative phase would show decreasing wind regimes. According to AO forecasts, it will reach extreme values in a context of climate change (Givati & Rosenfeld 2013). This could drop the abundance of sardine resources during prolonged periods.

We did not observe direct significant correlation between sardine CPUE *versus* NAO, SOI and AMO. Cropper *et al.* (2014) found that NAO plays a significant leading role in modifying interannual variability of spatial and temporal seasonal trends in coastal upwelling off Northwest Africa. In a previous study, Alheit *et al.* (2014) found that AMO modulates dynamics of abundance of small pelagic fishes in the eastern North and Central Atlantic. Thus, the contractions and expansions of the subpolar gyre (SPG) can play a key role in the abundance and distribution of small pelagic fishes from eastern North Atlantic. When the SPG abruptly contracted, it gave way to movements of warm subtropical water masses north- and eastwards. Small pelagic fish populations in the eastern North and Central Atlantic responded quickly by changing their abundance and migrated northwards (e.g., Alheit *et al.* 2014). However, for the NW Africa sardine, these authors did not find any relationship with population fluctuations consequent with the short time scale for an AMO approximation. However, in short temporal scales, the effect of the climatic indices of the AO in NW Africa can play a key role through its effect in upwelling variability that can influence the abundance of the sardine resources.

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