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ORIGINAL PAPER

Climate oscillations effects on market prices of commercially important fish in the northern Alboran Sea

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Abstract

Climate oscillations affect fish population dynamics, ecological processes and fisheries activities in marine ecosystems. In the western Mediterranean, several atmospheric indices associated with pressure oscillations have been identified as the main drivers of the abundance or availability of certain resources exploited by fisheries. The main aim of this study was to explore the association between the potential effects of the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO) on the first sale price of fresh fish at the fish market of the most representative commercial species of the fisheries in the Alboran Sea (Mediterranean Sea). We used the Pearson correlation test to investigate correlations between the atmospheric oscillation indices and the fish market price of the selected species. The results suggest that inter- and intra-annual atmospheric oscillations may have an effect on bonito (*Sarda sarda*), European anchovy (*Engraulis encrasicolus*) and catsharks (*Scyliorhinus spp.*) abundance and catchability in the Alboran Sea and, therefore, an impact on their fish market presence and price variability according to the law of supply and demand.

Keywords Atmospheric oscillation · Alboran Sea · Fisheries bioeconomy · Law of supply and demand

Introduction

Atmospheric oscillations operate on different time scales, seasonal, inter- and intra-annual (Hurrell 1995), with effects on biological and ecological *processes* and patterns (Stenseth and Mysterud 2002). This climate variability has an influence on the marine ecosystems functioning over a wide range of temporal and spatial scales (Bakun 1996; Walther et al. 2002; Rouyer et al. 2008; Badjeck et al. 2009). There are multiple oceanic climate variables that can affect availability, distribution patterns (Miller et al. 2010) and biological responses (Chaloupka et al. 2008; Laneri et al. 2010; Báez et al. 2011; Auber et al. 2015) of marine species. Several authors agree that marine species could respond to climate oscillations by modifying their phenology (Chaloupka et al. 2008), abundance, distribution and recruitment (Fromentin 2002; Borja and Santiago 2002; Mejuto 2003; Kell et al. 2005a; Gancedo et al. 2009; Graham and Harrold 2009; Báez et al. 2011). Likewise, numerous studies have analyzed the influence of climatic oscillations on the availability and catches of species targeted by fisheries (Drinkwater 2005; Kell et al. 2005b; Lehodey et al. 2006; Brander 2008; Ménard et al. 2007; Robinson et al. 2010; Báez and Real 2011).

Most studies on the influence of atmospheric oscillations on fishery resources analyze the effects on ocean productivity and its impact on fish production and distribution (Klyastorin 2001; Perry et al. 2005; Brander 2008; Cheung et al. 2008) while briefly examining the socioeconomic consequences. The general approaches typically used to analyze the economic impact of climate oscillations on fisheries and aquaculture are bioeconomic models and the law of supply and demand (Briones et al. 2006). Bioeconomic models for fisheries examine how the revenues and costs the profit potential of the

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fishery changes under different variables (Whitmarsh et al. 2000). The bioeconomic model can incorporate climate change scenarios by modifying a set of ecosystem or population parameters. The market law of supply and demand approach analyzes climate variability in terms of supply stocks and predicts the economic consequences by using the microeconomic tools of supply and demand (Dey et al. 2016).

Bioeconomic theory in fisheries combines the biological and economic aspects of a fishery to explain stock, catch, and effort dynamics under different regimes (Larkin et al. 2011). The main objective of the fisheries bioeconomy is to show how a fishery behaves given the endogenous but interdependent changes in the fleet and the stock size (Franquesa et al. 2001; Anderson and Seijo 2010) to improve the analysis of the management measures and strategies implemented in the region (Lleonart et al. 1996; FAO 2007). According to the law of supply and demand, the price of a good tends to the level at which demand equals supply (Mochon and Beker 1997). In this sense, the fish market prices should be adjusted to the Walrasian general balance theory model asserting that supply is the one that establishes the level of demand (Jeannot Rossi 2006; Gintis and Mandel 2012; Donier and Bouchaud 2015). The first sale value of fishery products is established in Spain and other countries through public auction at the fish market, not only depending on the law of supply and demand but also being conditioned by multiple factors. These may be biological, social, economic, institutional or commercial factors, which have an influence on the price of the fish markets and the price paid by the final consumer.

In the western Mediterranean, several atmospheric indices associated with pressure oscillations have been identified as the main drivers of the abundance or availability of certain resources exploited by fisheries, with the North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) being the most important ones in the region (Ambaum et al. 2001; Báez et al. 2013). The NAO is based on the difference between the Azores high-pressure atmospheric centre and the Icelandic low pressure centre (Hurrell 1995; Visbeck et al. 2001). This index is responsible for most of the inter-annual climate variability in the Northern Hemisphere (Vicente-Serrano and Trigo 2011) and may, therefore, be applied to the Alboran Sea. This inter- and intra-annual variability influences the temperature, precipitation and winds in the North Atlantic (Hurrell 1995) and could have an effect on the catches of certain marine species (Báez 2016). The AO (Arctic Oscillation) is an atmospheric oscillation associated with a meridional dipole at sea level of atmospheric pressure between polar regions and mid-latitudes (Thompson and Wallace 1998). In the Alboran Sea, the NAO and the AO, due to the oceanographic and topographic characteristics of the basin, could exert a combined influence (Ambaum et al. 2001; Overland et al. 2010; Báez et al. 2013).

The fisheries sector is an important source of food supply, animal protein for human and animal nutrition and provider of employment for many local communities (FAO 2018). The oceanographic and biogeographical singularities of the Alboran Sea provide it with high biodiversity, thus resulting in an important fisheries activity in the region (Sobrino et al. 1994; Camiñas et al. 2004; García et al. 2012). The fishing fleet of Andalusia is mainly artisanal being well represented in all the fishing harbours. It consists of small boats that use passive and smaller fishing gears, but with a great heterogeneity both in the type of boat and in the fishing gear (Camiñas and Baro 2004; García et al. 2012). The vessels operate in near-shore areas, using more than 200 different types of fishing gears, being longlines and trammels the most commonly used. Trawl and purse-seine fishing is widely distributed, playing an important socioeconomic role and characterized by being multispecific (García et al. 2012). It is an intensive fleet in terms of labour, with low operational cost and environmental impact. Fishing activity in the Alboran Sea is subject to temporary closures (of certain areas and species) in winter and summer (Sistema de Información Andaluz de Comercialización y Producción Pesquera of the Junta de Andalucía. 2018). The fisheries production in the Andalusian fishing markets has been significantly reduced, from 70,182 t, with a first sale value at public auction of 95.19 million euros in 1985, to 17,317 t, with a value of 55.86 million euros in 2017 (Junta de Andalucía 2018). The small-scale fisheries sector is the most vulnerable to climate change due to their high dependence on fisheries and their limited ability to adapt (Allison et al. 2009; FAO 2015). For this reason, it is essential to analyze the effects of climate oscillations on the landings of the most representative commercially interest species and fluctuations of the first sale value, according to their catches and socioeconomic importance, to ensure sustainable fishery resource management (Seijo et al. 1998; Branch et al. 2006; Badjeck et al. 2009).

Therefore, it is important to consider if climate oscillations effects in the Alboran Sea induce fluctuations of abundance and catchability of commercial interest species, thus modulating the fish market prices due to the available supply of fishing products. Despite multiple studies, the effects of climate variability on the life cycle of migratory marine species remain unknown, and likewise the possible alterations that may be caused by the current forecasts of rising global temperatures (Báez et al. 2011). The objective of the present study is the analysis of the relationship between the inter- and intra-annual atmospheric oscillations and values at first sale at the fish market of commercially interest species of the Alboran Sea.

Material and methods

Study area

The Alboran Sea borders southern Spain (Andalusia), northern Morocco and north-western Algeria and runs from the Strait of Gibraltar to a line joining Cabo de Gata (Almería, Spain) with Cape Fégalo (Oran, Algeria). The study area includes 14 landing harbours in Andalusia (Fig. 1): Tarifa, Algeciras, La Línea, Estepona, Marbella, Fuengirola, Malaga, Caleta de Vélez, Motril, Adra, Roquetas de Mar, Almería, Carboneras and Garrucha, from west to east. Strictly speaking, neither Tarifa nor the last two harbours are within the area of the Alboran Sea.

The Alboran Sea can be considered as an independent biogeographic unit with a high biodiversity (Robles 2010; García et al. 2012). From the hydrographical point of view, the Alboran Sea basin is characterized by high currents flow (Parrilla and Kinder 1987). In its westernmost part, the exchange of water masses of different salinity and temperature is produced, with an incoming Atlantic surface current flowing eastward into the sea while underneath the Mediterranean waters (more saline and colder) run out into the Atlantic Ocean (Rodríguez 1982). It also represents an area rich in phytoplankton and zooplankton with values above the Mediterranean average, which favours the nursery phase of many species and, therefore, a great fishing activity (Camiñas et al. 2004; Mercado et al. 2007; Yebra et al. 2018).

Fisheries data

The most representative pelagic and demersal species targeted by the fishing fleet of the study area were selected, according to their volume of landings and commercial importance in the Alboran Sea. The species analyzed were wedge sole, *Dicologlossa cuneata* (CET); Atlantic bonito, *Sarda sarda* (BON); tope shark, *Galeorhinus galeus* (GAG), soles, *Solea spp.* (SOX); dusky grouper, *Epinephelus marginatus* (GPD); catsharks, *Scyliorhinus spp.* (SCL); monkfishes, *Lophius spp.* (MNZ); scorpionfishes, *Scorpaena spp.* (SCS); raja rays, *Raja spp.* (SKA); lefteye flounders, *Bothidae* (LEF); surmullets, *Mullus spp*. (MUX); common octopus, *Octopus vulgaris*

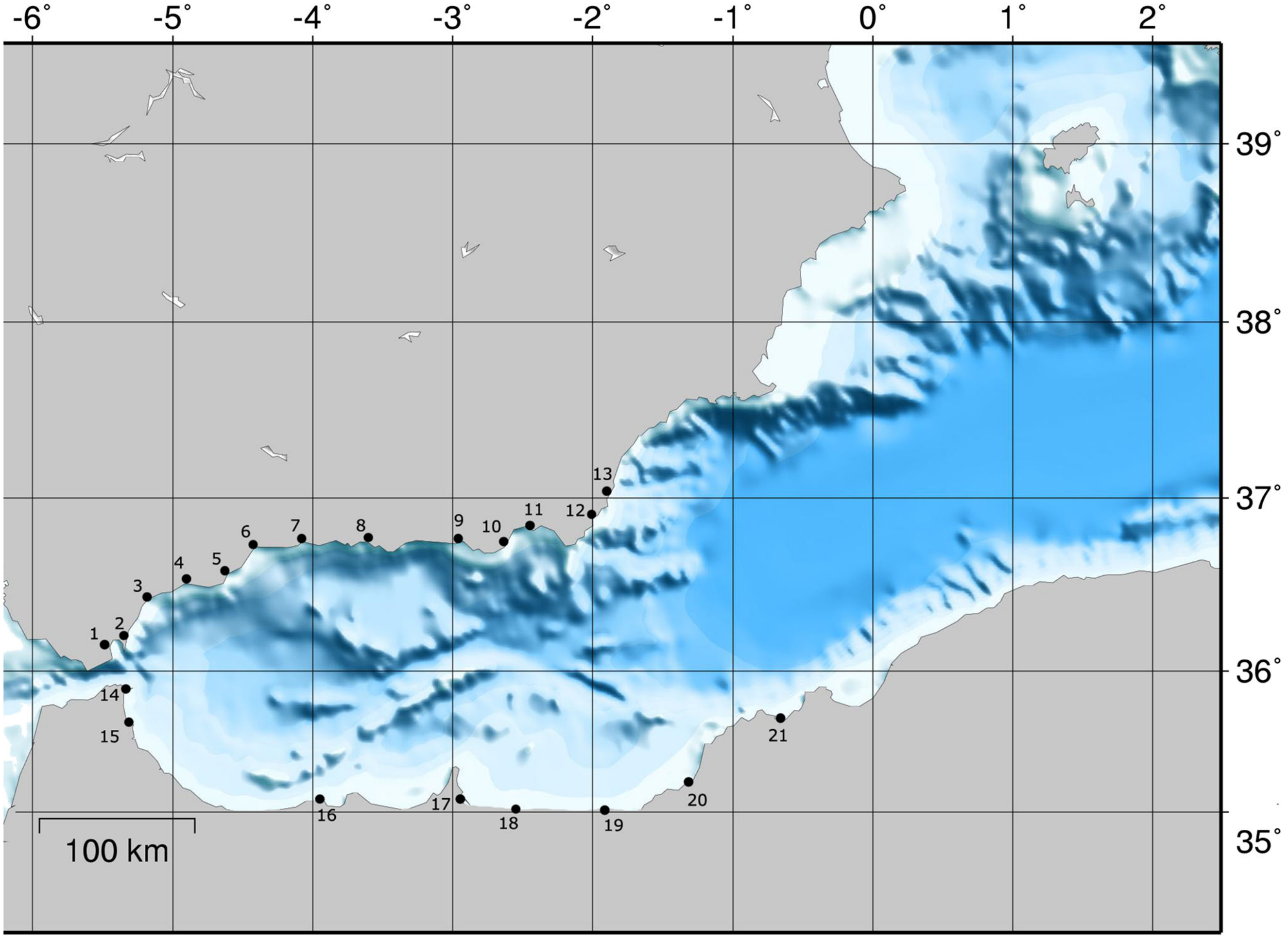


Fig. 1 Study area: the Alboran Sea within the Mediterranean Sea and the landing harbours: (1) Tarifa, (2) Algeciras, (3) La Linea, (4) Estepona, (5) Marbella, (6) Fuengirola, (7) Málaga, (8) Caleta de Vélez, (9) Motril, (10) Adra, (11) Roquetas de Mar, (12) Almería, (13) Carboneras and (14) Garrucha

(OCC), European sardine, *Sardina pilchardus* (PIL); jack and horse mackerels nei, *Trachurus spp.* (JAX) *and* European anchovy, *Engraulis encrasicolus* (ANE).

Annual landings data and first sale value of fresh fish at the fish market by targeted commercial species were extracted from the Fisheries Information System database of the Junta de Andalucía (Andalusia Regional Government) (Sistema de Información Andaluz de Comercialización y Producción Pesquera of the Junta de Andalucía. 2018). We provided the average annual data in Table SS1 for the studied period (1985–2017). In a second step, for the same period, the first sale price of fresh fish at fish market standardized with the annual Consumer Price Index (CPI) (€/kg) (Table SS2).

Atmospheric oscillation data

The NAO and AO present strong inter- and intra-annual variability (Hurrell 1995) and they were considered as independent variables (Báez et al. 2013). The monthly values of the atmospheric oscillation indices (NAO and AO) for the period 1985–2017 (Appendix) were provided by the National Oceanic and Atmospheric Administration (NOAA, US) website, available at: https://www.noaa.gov/ (Table SS2).

Data analysis

The total annual volume of landings and first sale price for each species was determined to obtain the annual price/kilogram ratio. The ratio was standardized with the annual Consumer Price Index (CPI), provided by the Spanish National Institute of Statistics (Instituto Nacional de Estadística (Spain), 2018).

The average annual values from the monthly data of the atmospheric oscillation indices (NAO and AO) were obtained. The winter NAO value (NAOw) was calculated with the average of the NAO values of the winter months (November–February) in which the oscillation reaches its highest effects.

Firstly, the Kolmogorov-Smirnov test was used to test the normality of the NAO, AO and first sale price values. Given the normality of the distributions, a parametric statistical test was used. A logarithmic transformation of the *Scyliorhinus spp.* data was carried out as data was non-normally distributed, to be analyzed by a parametric test.

Subsequently, the statistical analysis of the data was conducted by using the Pearson correlation test in order to establish the possible correlations between the standardized commercial value with the average annual value of the CPI, for all selected species, and the average annual values of the atmospheric oscillation indices (NAO and AO). A 99% confidence interval was chosen to minimize type I errors due to the number of records in the data set.

All analyses were performed using the IBM SPSS Statistics (version 19) and the PAleontological Statistics v. 3.20 (PAST) software packages.

Results

The Andalusian fisheries production in the Alboran Sea was 17,317 t in 2017, with a first sale value of fresh fish at the fish market of 55.9 million euros. The fishery production in the 14 fish markets studied shows a gradual decrease in landings, with a 43.1% reduction in the last decade (2007–2017), together with a comparatively reduced loss in terms of economic value (20.3%) compared with the 70.1 million euros generated by the sector in 2007 (Sistema de Información Andaluz de Comercialización y Producción Pesquera of the Junta de Andalucía 2018).

The analysis of the species data under study concluded that there is a correlation between the first sale price at the fish market with the NAO and NAOw for Atlantic bonito (*S. sarda*) and NAOw ($r = 0.373$; $P = 0.032$), and catsharks (*Scyliorhinus spp.*) and NAO ($r = 0.350$; $P = 0.046$) (Table 1). Moreover, the AOpy was correlated with European anchovy (*E. encrasicolus*) ($r = 0.344$; $P = 0.05$) and catsharks ($r = 0.468$; $P = 0.006$) (Table 1) (complete correlation results including all species in Table SS4).

The correlation between landings and first sale price at the fish market standardized for all species was tested. We found a

Table 1 Results of the Pearson correlation between the first sale price at the fish market standardized with the annual Consumer Price Index (CPI) (€/kg) and atmospheric oscillations. Key: North Atlantic Oscillation (NAO), North Atlantic Oscillation of the previous year (NAOpy), North Atlantic Oscillation of the previous winter (NAOw), Arctic Oscillation (AO), Arctic Oscillation of the previous year (AOpy). Significant correlations with $P < 0.05$ are indicated by two asterisks, while $P < 0.01$ are indicated by three asterisks. An asterisk indicates a quasi-significant correlation (i.e. P value next to 0.05)

	Atlantic bonito	European anchovy	Catsharks
NAO	$r = 0.000$ $P = 1.000$ $N = 33$	$r = 0.057$ $P = 0.754$ $N = 33$	$r = 0.350$** $P = 0.046$ $N = 33$
NAOpy	$r = 0.144$ $P = 0.423$ $N = 33$	$r = 0.280$ $P = 0.114$ $N = 33$	$r = 0.343$ $P = 0.051$* $N = 33$
NAOw	$r = 0.373$** $P = 0.032$ $N = 33$	$r = 0.009$ $P = 0.961$ $N = 33$	$r = 0.333$ $P = 0.058$ $N = 33$
AO	$r = 0.101$ $P = 0.578$ $N = 33$	$r = 0.307$ $P = 0.082$ $N = 33$	$r = 0.334$ $P = 0.057$ $N = 33$
AOpy	$r = 0.235$ $P = 0.188$ $N = 33$	$r = 0.344$** $P = 0.050$ $N = 33$	$r = 0.468$*** $P = 0.006$ $N = 33$

significant negative correlation for 10 of the 15 species (complete correlation results including all species in Table SS3). In the case of groupers and monkfishes, the r was superior to − 0.8. For the three species (i.e. catsharks, European anchovy and Atlantic bonito) for which there is a correlation between climate oscillations and first sale price standardized, we obtained the results shown in Table 2. Catsharks did not show correlation between landings and first sale price standardized.

When analyzing the landings data (1985–2017), we observed a gradual decline in catches over time in the landings for the major study species (Table SS1). The landings of the three species correlated with NAO and AO showed numerous inter-annual oscillations (Fig. 2). European anchovy catches in this period have been highly variable, with values ranging between 5418.0 (1985) and 216.4 t (2008). The fishery of *E. encrasicolus* is mainly focused on individuals from early age classes, corresponding to class 0 and 1. Years with higher catches are usually associated with a high recruitment period, while unsuccessful recruitment in a given year is correlated with a low level of catch (ICES 2017). Despite the lack of information on Atlantic bonito fishery in the Alboran Sea, changes in recruitment and migrations could explain *S. sarda* landings inter-annual fluctuations (Rey et al. 1984; Di Natale et al. 2005; Di Natale and Mangano 2019), with a maximum in 1987 (705.0 t), and a minimum in 2000 (30.1 t). *Scyliorhinus spp.* maximum landings were in 2009 (190.9 t) while in 2003 they were only 5.9 t.

The annual evolution of the first sale price (€/kg) of fresh fish at the fish market standardized with the annual Consumer Price Index (CPI) of *S. sarda*, *E. encrasicolus* and *Scyliorhinus spp.* is shown in Fig. 3. The fluctuations in the abundance and catchability of these species, due to the climate oscillations in the Alboran Sea, could modulate their first sale market price at the fish market due to the available supply. We observed a gradual decline in catches over time.

Table 2 Results of the Pearson correlation between landings (kg) and first sale price at the fish market standardized with the annual Consumer Price Index (CPI) (€/kg). Key: Atlantic bonito, *Sarda sarda* (BON); European anchovy, *Engraulis encrasicolus* (ANE); catsharks, *Scyliorhinus spp.* (SCLrev); Atlantic bonito landings (BONL); European anchovy landings (ANEL) and catsharks landings (SCLrevL). Significant correlations with $P < 0.05$ are indicated by two asterisks

		ANEL	BONL	SCLrevL
BON	Pearson correlation	− 0.405**	− 0.489**	0.120
	Sig. (2-tailed)	0.019	0.004	0.505
	N	33	33	33
ANE	Pearson correlation	− 0.501**	− 0.019	− 0.095
	Sig. (2-tailed)	0.003	0.916	0.600
	N	33	33	33
SCLrev	Pearson correlation	− 0.208	− 0.179	− 0.131
	Sig. (2-tailed)	0.246	0.320	0.469
	N	33	33	33

The results obtained showed a positive and significant correlation between the value of the first sale price of fresh fish at the fish market of *S. sarda*, *E. encrasicolus* and *Scyliorhinus spp.* and the NAO/AO as independent variables (Table 1).

A positive association between the *S. sarda* first sale price and the NAOw as an independent variable was found. In the case of *E. encrasicolus*, a significant positive correlation was found between the first sale price and the AOpy as an independent variable (Fig. 4), according to the function (Eq. (1)):

$$\text{European anchovy €/kg/CPI} = 2.9375 + 0.7134 \times \text{AOpy} \left(r^2 = 0.1153\right) \quad (1)$$

Likewise, a significant positive association was found between the *Scyliorhinus spp.* first sale price and the NAO and AOpy (Figs. 5 and 6), according to the functions (Eqs. (2) and (3)):

$$\textit{Scyliorhinus spp.}\text{€/kg/CPI} = 0.2699 + 0.3439 \times \textit{AOpy} \left(r^2 = 0.2158\right) \quad (2)$$

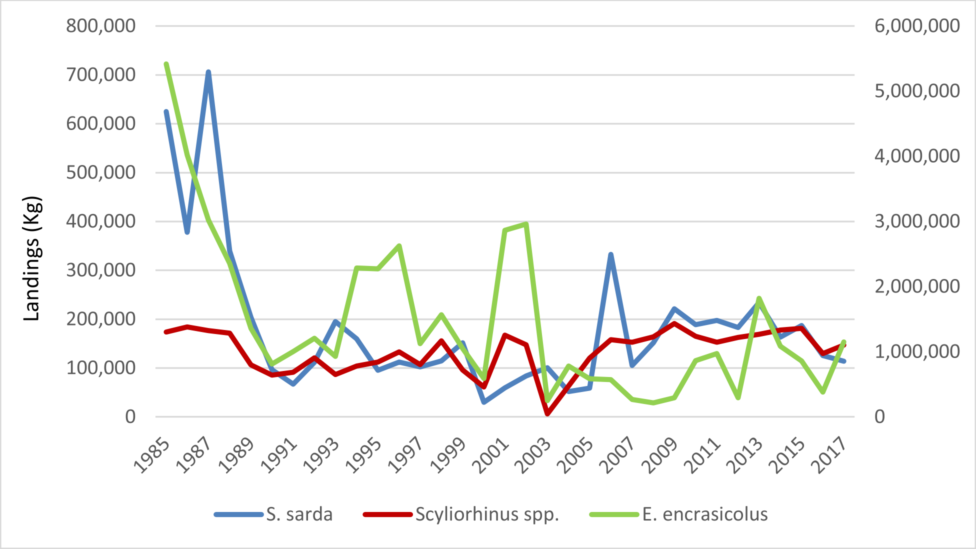
$$\textit{Scyliorhinus spp.}\text{€/kg/CPI} = 0.2614 + 0.2846 \times \text{NAO} \left(r^2 = 0.1216\right) \quad (3)$$

Discussion

The results of this study show the possible effects of climate oscillations on the availability of biomass of several marketable species targeted by fisheries in the northern Alboran Sea (Martín et al. 2012; Báez et al. 2014; Báez 2016) and, therefore, on the market price inter-annual variability (Trenkel et al. 2013). Despite the limitations of the catches with different fishing gears and in different landing ports (Najmudeen and Sathiadhas 2008; Tzanatos et al. 2013), the fluctuations in price does not depend on the landing port or fishing gear used, but on the relative abundance of each species (Seijo et al. 1998; Anderson and Seijo 2010). Hence, it is essential to understand the influence of climate oscillations on landings and the variation of price of the analyzed species for implementing effective socioeconomic policies and sustainable fisheries in the region (Branch et al. 2006).

At the ex-vessel stage, prices of fresh fish are linked with the level of landings (Jiménez-Toribio et al. 2010; Sun et al. 2017) but they also depend on so many more

Fig. 2 Landings annual evolution (kg) of Atlantic bonito, European anchovy and *Scyliorhinus spp.* in the northern Alboran Sea (1985–2017)

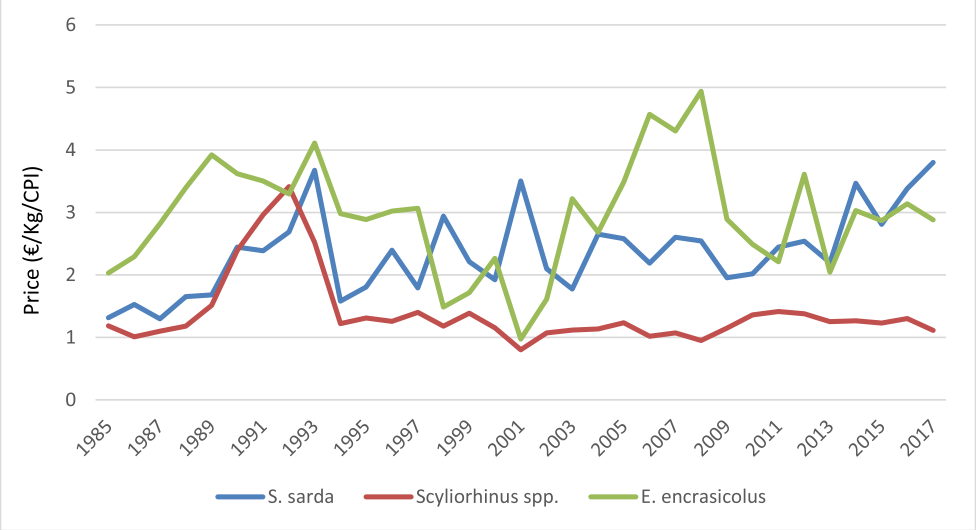


other variables (Whitmarsh et al. 2000). Market price analyses are performed starting with a delineation approach to define market boundaries through cointegration techniques, and finishing with a theory-grounded demand model or a price transmission model (Nielsen et al. 2009; Jiménez-Toribio et al. 2010; Pan et al. 2010; Fernández-Polanco and Llorente 2015; Sun et al. 2017).

In the North Atlantic, the NAO is associated with climate variability, thus affecting temperature, precipitation, and wind speed and direction (Hurrell 1995; Hurrell et al. 2003; Vicente-Serrano and Trigo 2011; Vicente-Serrano et al. 2011). The different phases of the NAO and AO (positive and negative) determine the climate of the region, affecting the marine and terrestrial ecosystems. The negative phase of the NAO and AO brings warm and wet air towards the Mediterranean Sea, which results in stronger and more frequent storms and precipitation in the region (Ambaum et al. 2001). The positive phase of the NAO and AO results in increasing the westerly winds that brings dry air leading to a warming of the Alboran Sea region (Muñoz-Díaz and Rodrigo 2003). These events favour the mixing of deep and shallow waters, thus increasing the contribution of nutrients on the surface. The dynamics of water masses, and phenomena such as upwelling, which is affected by both phases of the NAO and AO, has a great impact on the ecophysiology of marine species by increasing or decreasing their biomass (Báez et al. 2014).

The positive phases of the NAO increase the intensity of the westerlies (Hurrell 1995) bringing the northern Alboran Sea under the influence of the system of prevailing winds (Arévalo and García Lafuente 1983; Cano and García Lafuente 1991). The market prices of Atlantic bonito, *S. sarda* and the NAOw could be associated given the creation of surface currents due to the winds during the positive phase

Fig. 3 First sale price of fresh fish at the fish market standardized with the annual Consumer Price Index (CPI) (€/kg/CPI) of Atlantic bonito, European anchovy and *Scyliorhinus spp.* in the northern Alboran Sea (1985–2017)



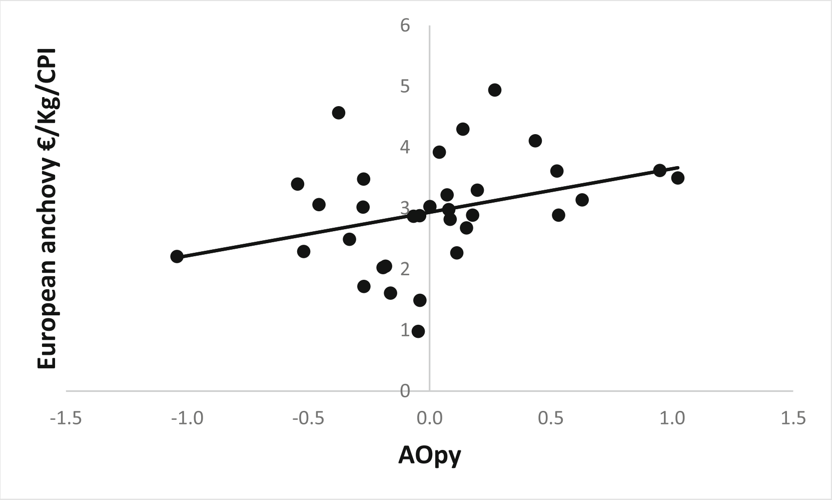


Fig. 4 Significant positive correlation between first sale price stardandized with the CPI of European anchovy, *E. encrasicolus* fresh fish at the fish market and the Arctic Oscillation of the previous year (AOpy)

of the NAO. These currents would help *S. sarda* to migrate through the Strait of Gibraltar towards its spawning areas in the Mediterranean modifying, therefore, first sale prices at the fish market according to the law of supply and demand. These results are in line with the Cattaneo-Vietti et al. (2015) and Muñoz-Expósito et al. (2017) research about the NAOw and bullet tuna (*Auxis rochei*) correlation. The existence of a strong association between the combined effects of the NAO and AO on the sea surface temperature of the Alboran Sea (Báez et al. 2013) has been confirmed. Likewise, the negative phases of the NAO favour precipitation and snowfalls, which could increase plankton productivity and nutrient-induced blooms along the coast (Báez 2016). These effects could also explain the correlation of the NAO and the AOpy with the variation of the first sale prices of *Scyliorhinus spp*. and *E. encrasicolus*.

According to the law of supply and demand, and indirectly, atmospheric oscillations (NAO and AO) could have an effect on the supply (Brander 2008; Dey et al. 2016; Barange et al. 2018), either with the reduction of the catch per unit effort, fishing effort due to adverse weather conditions, or leading to an increase of the seasonal abundance of certain species (Overland et al. 2010; FAO 2011), as well as the survival of the populations. This can be verified by analyzing the relation between the fluctuations in landings and market price of these representative species in the region and the atmospheric indices. The influence that both the NAO and AO may have at the regional level in the Alboran Sea (Ambaum et al. 2001; Báez et al. 2013) could explain the variations in the landings and market prices of Atlantic bonito *Sarda sarda*, European anchovy *Engraulis encrasicolus* and catsharks *Scyliorhinus spp.* Furthermore, catsharks did not show correlation between landings and first sale price standardized. In this context, the relation between first sale price standardized of catsharks and climate oscillations may have another explanation, including and not discarding a spuriousness correlation. However, the correlation for European anchovy and Atlantic bonito was highly significant; therefore, we found a direct relation between landings-first sale price standardized-climate oscillations.

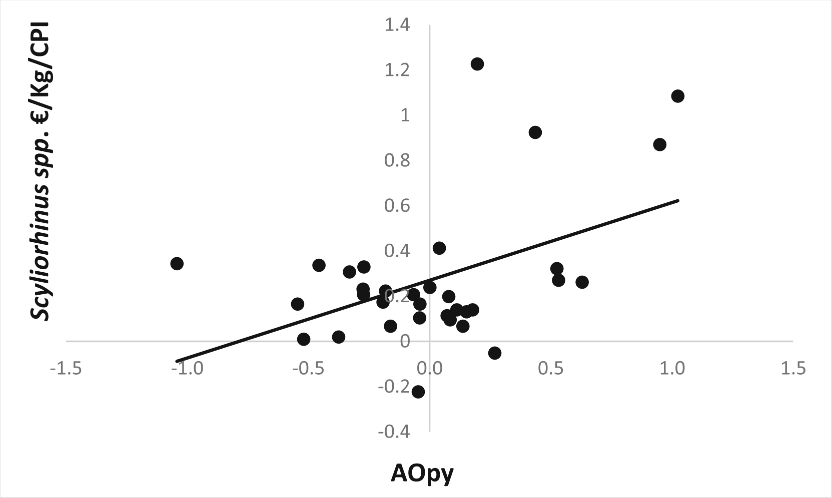


Fig. 5 Significant positive correlation between first sale price stardandized with the CPI of *Scyliorhinus spp*. fresh fish at the fish market and the Arctic Oscillation of the previous year (AOpy)

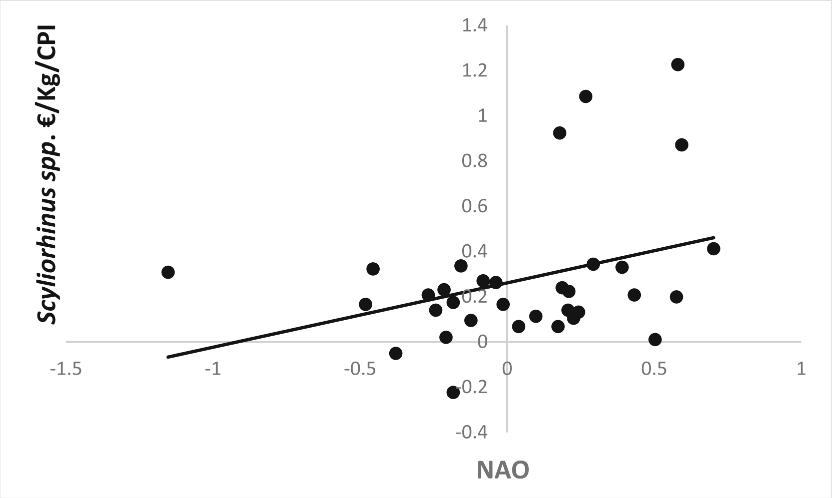


Fig. 6 Significant positive correlation between first sale price stardandized with the CPI of *Scyliorhinus spp*. fresh fish at the fish market and the North Atlantic Oscillation (NAO)

When using simple Pearson coefficients, the statistical properties of time series may lead to spurious regressions with this methodology (Granger 1988; Sanjuán López and Gil 2001) and correlation may appear as simple artefacts linked to time, without any demonstration of causality (Granger 1988; Johansen and Juselius 1992). The fisheries involved are very diverse and with complex dynamics, showing a great heterogeneity both in the type of boat and in the fishing gear. There are factors such as temporary closures (of certain areas and species), which occur in the Alboran Sea in winter and summer, thus leading to intra-annual fluctuations in the fisheries economy.

Moreover, the complete series is not available on a monthly basis (data series of the period 1985–1999 is available on an annually basis). In addition, we used also lags in the climate oscillation, which are difficult to translate on a monthly basis. For this reason, despite some information is lost, we preferred to soften these differences within the year by averaging on a yearly basis for prices and landings. Thus, price fluctuations in periods of the year with an increase in demand are averaged within the year. Nevertheless, the strength of the relationships for the Atlantic bonito and European anchovy is highly significant in the correlations between landings-first sale price standardized-climate oscillations. Obviously, when there are so many factors modulating prices (many of which are incommensurable), it is expected to find low correlations.

The NAO, therefore, has a significant influence on the fluctuation of the market values (Vicente-Serrano and Trigo 2011), making upwards or downwards adjustments of the first sale prices of these species. Particularly, the NAO seems to modulate the first sale price at the fish market based on the fluctuations in the abundance and catchability of these three species according our results.

Although some studies try to predict the impacts of climate change on fishery resources (Merino et al. 2012; Deyle et al. 2013; Arthun et al. 2018), marine ecological predictions and the effects on the stakeholders of the value chain of the fisheries sector are still in its infancy. Considering that the fisheries sector represents a pillar of the economy of the Alboran Sea region and according to our results, it is essential a greater emphasis on strengthening adaptive capacity and incorporating climate change to national and regional policy.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights and informed consent This article does not contain any studies with human participants or animals performed by any of the authors. Informed consent was obtained from all individual participants included in the study.

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