

# Assessing the response of exploited marine populations in a context of rapid climate change: the case of blackspot seabream from the Strait of Gibraltar

J. C. Báez, D. Macías, M. de Castro,  
M. Gómez–Gesteira, L. Gimeno & R. Real

Báez, J. C., Macías, D., De Castro, M., Gómez–Gesteira, M., Gimeno, L. & Real, R., 2014. Assessing the response of exploited marine populations in a context of rapid climate change: the case of blackspot seabream from the Strait of Gibraltar. *Animal Biodiversity and Conservation*, 37.1: 35–47, Doi: <https://doi.org/10.32800/abc.2014.37.0035>.

## Abstract

*Assessing the response of exploited marine populations in a context of rapid climate change: the case of blackspot seabream from the Strait of Gibraltar.*— There is a growing concern over the decline of fisheries and the possibility of the decline becoming worse due to climate change. Studies on small-scale fisheries could help to improve our understanding of the effect of climate on the ecology of exploited stocks. The Strait of Gibraltar is an important fishery ground for artisanal fleets. In this area, blackspot seabream (*Pagellus bogaraveo*) is the main species targeted by artisanal fisheries in view of its relevance in landed weight. The aims of this study were to explore the possible effects of two atmospheric oscillations, the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO), on the capture of blackspot seabream in the Strait of Gibraltar, to determine their association with oceanographic conditions, and to improve our knowledge about the possible effects of climate change on fisheries ecology so that fishery management can be improved. We used two types of data from different sources: (i) landings per unit of effort reported from a second working group between Morocco and Spain on *Pagellus bogaraveo* in the Gibraltar Strait area, for the period 1983–2011, and (ii) the recorded blackspot seabream landings obtained from the annual fisheries statistics published by the *Junta de Andalucía* (Andalusian Regional Government). Our results indicate that the long-term landing of blackspot seabream in the Strait of Gibraltar is closely associated with atmospheric oscillations. Thus, prolonged periods of positive trends in the NAO and AO could favour high fishery yields. In contrast, negative trends in NAO and AO could drastically reduce yield.

Key words: Arctic Oscillation, Blackspot seabream, Climate, Fisheries collapse, North Atlantic Oscillation, Oceanography

## Resumen

*Evaluación de la respuesta de las poblaciones marinas explotadas en un contexto de cambio climático rápido: el caso del besugo de la pinta en el estrecho de Gibraltar.*— Existe una creciente preocupación por la disminución de la pesca y la posibilidad de que esta disminución se acelere debido al cambio climático. Los estudios sobre la pesca a pequeña escala podrían ayudar a mejorar nuestra comprensión de los efectos del clima en la ecología de las poblaciones explotadas. El estrecho de Gibraltar es una importante zona de pesca para la flota artesanal. En esta zona, el besugo de la pinta (*Pagellus bogaraveo*) es la especie más importante para la pesca artesanal en vista de su volumen de descarga. Los objetivos de este estudio consisten en estudiar los posibles efectos de dos oscilaciones atmosféricas: la oscilación del Atlántico Norte (NAO) y la oscilación del Ártico (AO), en la captura del besugo de la pinta en el estrecho de Gibraltar con objeto de determinar su relación con las condiciones oceanográficas, y mejorar nuestro conocimiento sobre los posibles efectos del cambio climático en la ecología de la pesca, para poder mejorar la gestión de la actividad pesquera. Utilizamos dos tipos de datos de diferentes fuentes: (i) los desembarques por unidad de esfuerzo registrados por un segundo grupo de trabajo entre Marruecos y España sobre el besugo de la pinta en la zona del estrecho de Gibraltar, para el período 1983–2011, y (ii) los desembarques registrados de besugo de la pinta obtenidos de las estadísticas anuales de pesca publicadas por la Junta de Andalucía. Nuestros resultados indican que el desembarque a largo plazo del besugo de la pinta en el estrecho de Gibraltar está íntimamente relacionado

con las oscilaciones atmosféricas. Por lo tanto, los períodos prolongados de tendencias positivas en la NAO y la AO podrían favorecer altos rendimientos pesqueros. En contraste, las tendencias negativas de la NAO y la AO reducen drásticamente el rendimiento pesquero

Palabras clave: Oscilación del Ártico, Besugo de la pinta, Clima, Colapso pesquero, Oscilación del Atlántico Norte, Oceanografía.

*Received: 14 I 14; Conditional acceptance: 11 III 14; Final acceptance: 1 IV 14*

*José Carlos Báez, Inst. Español de Oceanografía (IEO), Centro Oceanográfico de Málaga, Puerto pesquero de Fuengirola s/n., 29640 Fuengirola, Málaga, España (Spain); investigador asociado de la Fac. de Ciencias de la Salud, Univ. Autónoma de Chile, Chile.– David Macías, Inst. Español de Oceanografía (IEO), Centro Oceanográfico de Málaga, Puerto pesquero de Fuengirola s/n., 29640 Fuengirola, Málaga, España (Spain).– Maite de Castro, Moncho Gómez–Gesteira & Luis Gimeno, Ephylab, Fac. de Ciencias de Ourense, Univ. de Vigo, Ourense, España (Spain).– Raimundo Real, Depto. de Biología Animal, Fac. de Ciencias, Univ. de Málaga, 29071 Málaga, España (Spain).*

\*Corresponding author: J. C. Báez. E-mail: granbaez\_29@hotmail.com

## Introduction

Fisheries are an important source of food and income for many local communities, and their value as a source of animal protein was recently emphasized in a Food and Agriculture Organization report (FAO, 2010). Several studies (e.g. Thurstan et al., 2010) have suggested that over the last decade, 88% of monitored marine fish stocks in EU waters have been overfished, and some authors have predicted a global collapse of fisheries within the next few decades (Worm et al., 2006, 2009). The observed decline in fisheries is mainly due to overfishing at an industrial scale (Worm & Myers, 2004; Pitcher, 2005). However, this situation could be aggravated by the response of fish populations to climate change (e.g. see Brandt & Kronbak, 2010). Thus, with the aim of integrating fisheries within sustainable ecosystems, Pitcher (2005) proposed studying the effect of climate parameters and their temporal variability on global fisheries. Some fisheries have been shown to respond to multi-decadal oscillations, such as the oscillation of El Viejo (The Old Man), or La Vieja (The Old Woman), in the Pacific (Chavez et al., 2003), and decadal oscillations, such as the North Atlantic Oscillation (Báez et al., 2011; Báez & Real, 2011).

The North Atlantic Oscillation (NAO) is a dominant pattern of coupled ocean–climate variability in the North Atlantic and Mediterranean basin (Hurrell, 1995). Many authors have observed a relationship between the NAO and changes in fishery abundance (Graham & Harrod, 2009; Báez et al., 2011; Báez & Real, 2011) and recruitment (Fromentin, 2001; Borja & Santiago, 2002; Mejuto, 2003). The NAO reflects fluctuations in atmospheric pressure at sea-level between the Icelandic Low and the Azores High. The NAO is associated with many meteorological variations in the North Atlantic region, affecting wind speed and direction and differences in temperature and rainfall (Hurrell, 1995). Recent studies (e.g. Overland et al., 2010) have discussed the effect of large-scale climate variability on several marine ecosystems and suggest that marine ecosystems could respond to climate change. Straile & Stenseth (2007) have suggested that the NAO can be used to explain inter-annual variability in ecological series, citing the following reasons: (1) a strong relationship between the NAO and weather conditions during the winter season; (2) qualitative changes in environmental conditions in response to winter weather conditions, especially temperature; and (3) the great importance of these environmental conditions in the distribution and population dynamics of species in temperate and boreal regions.

Nevertheless, the dominant mode of variability in atmospheric circulation variability in the Northern Hemisphere is determined by the Arctic Oscillation (AO). The AO is characterized by a meridional dipole in atmospheric sea level pressure between the northern Polar Regions and mid-latitudes (Thompson & Wallace, 1998). The NAO and AO are closely correlated (Thompson et al., 2000). The AO has been attributed to stratosphere–troposphere coupling. According to Thompson et al. (2000), this includes the NAO, which may be considered a different view of the

same phenomenon. Thus, the AO and the NAO both tend to be in a positive phase during winters when the stratospheric vortex is strong (Douville, 2009). Few studies have analyzed the possible effect of the AO on fisheries ecology, for example Gancedo (2005) and Yatsu et al. (2005).

The possible effects of global climate change on the ecology of exploited stocks are difficult to study due to the multitude of other factors affecting these stocks, such as overfishing, coastal development, and pollution. Regional studies focused on small-scale fisheries could help to understand the effect of global climate change on the ecology of exploited stocks due to the reduction of the number of other variables (e.g. Meynecke et al., 2012; Pranovi et al., 2013).

The Strait of Gibraltar connects the western Mediterranean Sea with the Atlantic Ocean, providing an important fisheries ground for artisanal fleet (Silva et al., 2002). Because of the high frequency of maritime traffic in the Strait of Gibraltar, the largest Spanish fishing boats do not operate in this area; thus, the fishery is carried out by small numbers of artisanal boats working near the coast (Báez et al., 2009). According to Báez et al. (2013b), the physical condition of bluefin tuna (*Thunnus thynnus*) caught in this area, is correlate with both NAO and AO.

Blackspot seabream (*Pagellus bogaraveo*) is the most important species targeted by the artisanal fisheries, according to their importance in landed weight (Silva et al., 2002). In this context, the fishery landings and distribution by class of boat are easy to control at small-scale fisheries.

The blackspot seabream is a typical small demersal fish distributed from Eastern Atlantic Ocean to Western Mediterranean Sea, extensively fished from the early 80s by the artisanal fleet home-base in Gibraltar Strait. Fleets of Algeciras and Tarifa fished the blackspot seabream exclusively using a vertical deep water longline called 'voracera' baited with small sardines (*Sardina pilchardus*), while the artisanal fleet from Conil used a traditional bottom longline in the western part of the Strait of Gibraltar (for a detailed description of the fishery see Czerwinski et al., 2009; Gil-Herrera, 2010, 2012).

The aim of this study was to assess the responses of exploited marine populations in a context of rapid climate and oceanographic change using the landing of blackspot seabream in the Strait of Gibraltar as study case.

## Material and methods

### Fisheries data

The study area coincides with the fishing ground, an area within Spanish waters of the Strait of Gibraltar between the Rock of Gibraltar and Cape Trafalgar, and it included the landing harbours of Algeciras, Tarifa and Conil (fig. 1).

Data were collected from two different sources. First, in the period 1983–2011, we used landings per sale, reported in CopeMed II (2012) and Gil-Herrera

(2012) on *Pagellus bogaraveo* in the Gibraltar Strait area, as landings per unit of effort (LPUE), because each sale is equivalent to the trip per boat (which is typically the fisheries effort). The artisanal Moroccan fleet also fished blackspot seabream in the Strait of Gibraltar. However, we excluded these data because the data available from Moroccan fleet is a short-time series (CopeMed II, 2012).

Second, we used the recorded blackspot seabream landings obtained from the annual fisheries statistics published by the *Junta de Andalucía* (Andalusian Regional Government) (Galisteo et al., 2001a, 2001b, 2002, 2004, 2005; Alonso-Pozas et al., 2007; Galisteo et al., 2007, 2008, 2009a, 2009b, 2011, 2012, 2013) for the period 1985–2012 from Tarifa, the most important landing harbour in the study area (table 1).

#### Atmospheric data

Monthly values of the NAO index and AO index were taken from the website of the National Oceanic and Atmospheric Administration: [http://www.cpc.noaa.gov/products/precip/CWlink/pna/nao\\_index.html](http://www.cpc.noaa.gov/products/precip/CWlink/pna/nao_index.html) and <ftp://www.esrl.noaa.gov/psd/data/correlation/ao.data>, respectively.

The atmospheric oscillations present strong inter-annual and intra-annual variability (Hurrell, 1995). However, several studies have shown that changes in NAO/AO trends have a delayed effect on aquatic ecosystems due to ecosystem inertia (Maynou, 2008; Báez et al., 2011). For this reason, we used NAO and NAO in the previous year (NAOpy); and AO and AO in the previous year (AOpy).

#### Oceanographic data

Ocean temperature and salinity data were obtained using the Simple Ocean Data Assimilation (SODA) package (<http://www.atmos.umd.edu/~ocean>). SODA uses an ocean model based on Geophysical Fluid Dynamics Laboratory MOM2 physics. Assimilated data include temperature and salinity profiles from the World Ocean Atlas–94 (Levitus & Boyer, 1994), as well as additional hydrography, sea surface temperatures (Reynolds & Smith, 1994), and altimeter sea levels obtained from the Geosat, ERS–1, and TOPEX/Poseidon satellites. Re-analyses of world ocean climate variability are available from 1958 to 2007 at a monthly scale, with a horizontal spatial resolution of  $0.5^\circ \times 0.5^\circ$  and a vertical resolution of 40 levels (Carton et al., 2000a, 2000b; Carton & Giese, 2008).

According to previous research, the Mediterranean water mass is produced by the transformation of fresh and warm surface Atlantic water (AW) that enters in the Mediterranean Sea by the Strait of Gibraltar. The surface AW is gradually modified during its displacement eastward in the Mediterranean Sea due to air–sea interactions and mixing processes. A portion of these dense water masses flows back (after seven to 70 years) through the Strait of Gibraltar, mixing with Eastern North Atlantic Central Water (ENACW) to form the Mediterranean Outflow Water (MOW; Bozec et al., 2011). In the eastern Gulf of Cadiz, the MOW is very

dense and sinks under water with an Atlantic origin until it reaches an equilibrium level (around 1,100 m). In the western Gulf of Cadiz ( $8^\circ$  W), MOW reaches density values similar to those of mid-depth Atlantic layers and splits in two cores separating from the bottom. The upper core is characterized by a maxima temperature ( $\sim 13^\circ\text{C}$ ) and a potential density anomaly between 27.40 and 27.65  $\text{kg/m}^3$ , and the lower core is characterized by a maxima salinity ( $\sim 37.5$ ) and a potential density anomaly between 27.70 and 27.85  $\text{kg/m}^3$ . MOW spreads in the North Atlantic westward to the central Atlantic and northward along the coasts of Portugal and the Iberian peninsula. For this reason, the oceanographic analysis was carried out in a region large enough to contain the number of measurement points needed for a suitable oceanographic study of the MW taking into account ocean currents, coastal areas, and water properties. In the present study, the selected area ranged from  $8^\circ$  to  $13.75^\circ$  W and from  $35.25^\circ$  to  $40.25^\circ$  N (the southern coast of the Iberian peninsula). We used the first 24 vertical levels (which correspond to a water depth of 1,378 m) since the study focuses on the detection of upper Mediterranean water (MW<sup>u</sup> hereafter), whose core is located at 800 m. The thickness of the vertical layers increases from 10 m near the surface to 100 m below 300 m. The period under study ranges from 1980 to 2007.

We identified MW<sup>u</sup> using temperature, salinity and density values, which should lie within the intervals 10.5–13.5°C, 35.8–36.8, and 27.4–27.65  $\text{kg/m}^3$ , respectively. First, the grid points where MW<sup>u</sup> was not detected in at least 50% of the samples were discarded from the analysis. Salinity and temperature data for each grid point were averaged to transform them into annual values. All salinity and temperature data corresponding to the intervals mentioned above for a specific year were averaged, regardless of layer, to obtain the mean MW<sup>u</sup> salinity and temperature values for that year.

Long-term processes, such as warming–cooling or salinification–freshening, and their effect on the water column stratification were analyzed using annual trends, which were assumed to be linear. All trends were calculated using raw data, without using any filter or running mean. The Spearman rank correlation coefficient was used to analyze the significance of trends due to its robustness to deviations from linearity and its resistance to the influence of outliers (Saunders & Lea, 2008).

#### Data analysis

In a first step, we analysed the time series for each variable. We searched for common time trends and cyclicity in the time series using spectral analysis, to identify periodicity. 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).

We tested the relationship between LPUE of blackspot seabream versus NAOpy and AOpy using linear multiple regressions. We selected the best fit among several significant regressions when different degrees of freedom were involved in accordance with the high-

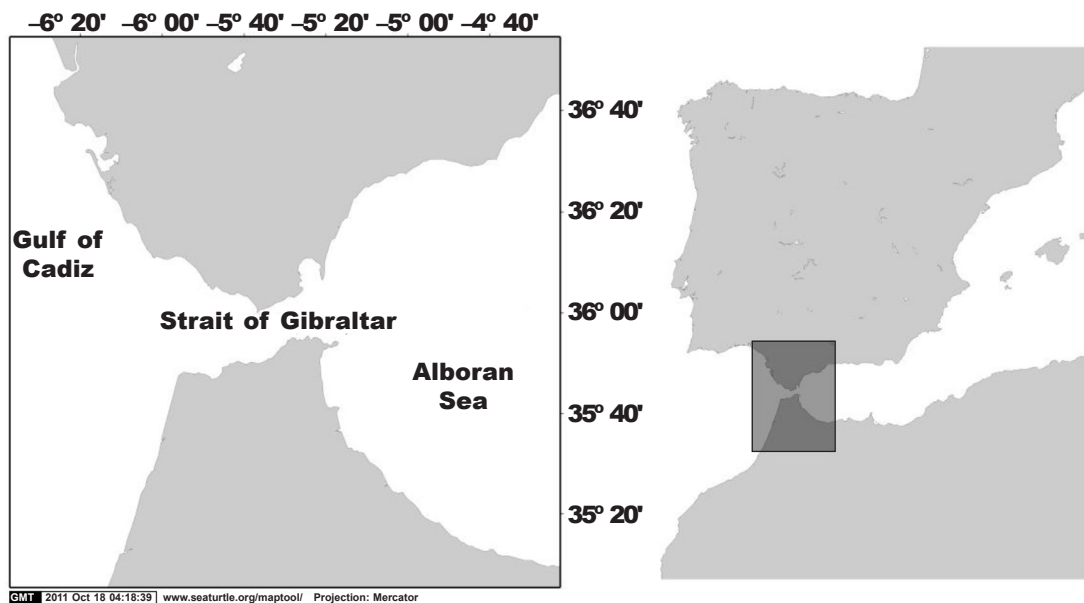


Fig. 1. The study area was centred on the Strait of Gibraltar. The Strait of Gibraltar separates two regions: the Gulf of Cadiz (in the Atlantic Ocean) and the Alboran Sea (within the Mediterranean Sea).

*Fig. 1. La zona del estudio tiene en su centro el estrecho de Gibraltar. El estrecho de Gibraltar separa dos regiones: el golfo de Cádiz (en el océano Atlántico) y el mar de Alborán (en el mar Mediterráneo).*

est  $R^2$  value. Normality of the data was tested using the Kolmogorov–Smirnov test (Sokal & Rohlf, 1995).

A probabilistic analysis was performed by taking a year at random and calculating the probability that this particular annual landing from Tarifa was higher or lower than the average landing for all the years available pooled together. Báez et al. (2011) used binary logistic regression to model the response of albacore fisheries to changes in the accumulated NAO index. Similarly, using binary logistic regression, we modelled the probability of the value for blackspot seabream landings being higher than the average landings for this species for each specific year. Thus, we assigned a value of 1 or 0, respectively, when the landing in a specific year was higher or lower than the average landing for the 26 years taken together; these were considered to be good and poor landings, respectively. We performed a forward stepwise logistic regression where the independent variables were NAO, NAOpy, AO and AOpy. The goodness-of-fit of the model was assessed using an omnibus test (for model coefficients) and a Hosmer and Lemeshow test, which also follows a Chi-square distribution (Zuur et al., 2007), with the low p-values indicating a lack of fit of the model. We evaluated the discrimination capacity of our model using the area under the receiving operating characteristic (ROC) curve (AUC) (Lobo et al., 2008).

Despite a good fit of the logistic regression model, it is sensitive to the presence/absence ratio (Real et al., 2006). The presence/absence ratio was 0.625 for blackspot seabream. To resolve this difference,

we applied the favourability function (Ff) (Real et al., 2006) based on a logistic regression model, which adjusts the model regardless of the presence/absence ratio. Favourability was easily calculated from the probability obtained from the logistic regression according to the expression:

$$Ff = [P / (1 - P)] / [(n_1 / n_0) + (P / [1 - P])]$$

where P is the probability of the value for blackspot seabream landings per a specific year was higher than the average landings for this species for all years, and  $n_1$  and  $n_0$  are number of years with good or poor blackspot seabream landings, respectively.

The correlation between the different climatic indices and landings can be also analyzed in terms of the accumulated values. Annual values were transformed into anomalies by subtracting the mean value calculated over the whole period 1985–2010. 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 2000 were calculated as the sum of the anomalies for the period 1985–2000).

## Results

The landing of blackspot seabream from Tarifa for 1985–2011 was the only variable with significant periodicity trend (table 2).

Table 1. Blackspot seabream (*Pagellus bogaraveo*) landing per year and corresponding average for the North Atlantic Oscillation (NAOpy) and Arctic Oscillation (AOpy) index in the year before the landing.

*Tabla 1. Desembarque por año del besugo de la pinta (Pagellus bogaraveo) y promedio correspondiente para los índices de oscilación del Atlántico Norte (NAO) y de oscilación del Ártico (AO) en el año anterior al desembarque.*

Year	Landing	NAOpy	AOpy
1985	209866	0.25	-0.19
1986	249000	-0.18	-0.52
1987	292732	0.5	0.08
1988	318578	-0.12	-0.54
1989	413375	-0.01	0.04
1990	426400	0.7	0.95
1991	421070	0.59	1.02
1992	629668	0.27	0.2
1993	764522	0.58	0.44
1994	854436	0.18	0.08
1995	501569	0.58	0.53
1996	659485	-0.08	-0.27
1997	527186	-0.21	-0.46
1998	282522	-0.16	-0.04
1999	198794	-0.48	-0.27
2000	193408	0.39	0.11
2001	154832	0.21	-0.05
2002	147793.6	-0.18	-0.16
2003	179146.5	0.04	0.07
2004	131692.6	0.1	0.15
2005	165616.8	0.24	-0.19
2006	161772.5	-0.27	-0.38
2007	273035	-0.21	0.14
2008	285481	0.17	0.27
2009	424849.4	-0.38	0.18
2010	227391	-0.24	-0.33

A significant association was found between the LPUE of blackspot seabream from the Gulf of Cadiz and the NAOpy index, according to the following function (fig. 2):

$$\text{LPUE} = 66.687 + 15.01 \text{ NAOpy}$$

(adjusted  $R^2 = 0.106$ ;  $F = 4.306$ ;  $P = 0.048$ )

Table 2. Results of spectral analysis. We show the peaks in observed periodicity (in years), and significance for the time series variables: Pbg-LPUE. Blackspot seabream (*Pagellus bogaraveo*) landing per unit effort (LPUE) from harbours Algeciras, Tarifa and Conil for the period 1983–2011; Pbg. Blackspot seabream (*Pagellus bogaraveo*) landing from Tarifa for the period 1985–2011; NAOpy. Corresponding average for the North Atlantic Oscillation index in the year before at landing; AOpy. Corresponding average for the Arctic Oscillation index in the year before at landing.

*Tabla 2. Resultados del análisis espectral. Mostramos los máximos en la periodicidad observada (en años) y la significación de las variables de series temporales: Pbg-LPUE. Desembarque de besugo de la pinta (Pagellus bogaraveo) por unidad de esfuerzo (LPUE) en los puertos de Algeciras, Tarifa y Conil para el período 1983–2011; Pbg. Desembarque de besugo de la pinta (Pagellus bogaraveo) de Tarifa para el período 1985–2011; NAOpy. Promedio de la oscilación del Atlántico Norte en el año anterior al desembarque; AOpy. Promedio de la oscilación del Ártico en el año anterior al desembarque..*

Variables	Periodicity	$p$ (random)
Pbg-LPUE	13.997 years	0.683
Pbg	18.18 years	0.003645
NAOpy	2.59 years	0.7846
AOpy	14.28 years	0.7866

In addition, we obtained a significant model for the probability of obtaining good blackspot seabream landings, according to logit ( $y$ ) function (fig. 3):

$$y = -0.645 + 3.344 * \text{AOpy}$$

The statistical tests for the goodness-of-fit of the model indicated a good fit. An omnibus test for model coefficients obtained  $\chi^2 = 6.774$ ,  $p = 0.009$ , and the Hosmer AND Lemeshow test obtained  $\chi^2 = 8.740$ ,  $p = 0.272$ . The AUC of the model was 0.756, which can be considered acceptable discrimination (Hosmer & Lemeshow, 2000). The Nagalkerke test obtained  $R^2 = 0.312$ .

The favourability function showed that the conditions that favour good blackspot seabream landings for a specific year coincided almost completely with the positive phase of the AOpy (fig. 3).

Accumulated values for the NAO and AO were highly correlated ( $R^2 = 0.91$ ,  $p < 0.01$ ) (fig. 4).

The temperature and salinity trends corresponding to MW<sup>u</sup> over the period 1982–2007 are shown in figures 5A and 5B. Black dots represent the grid points where

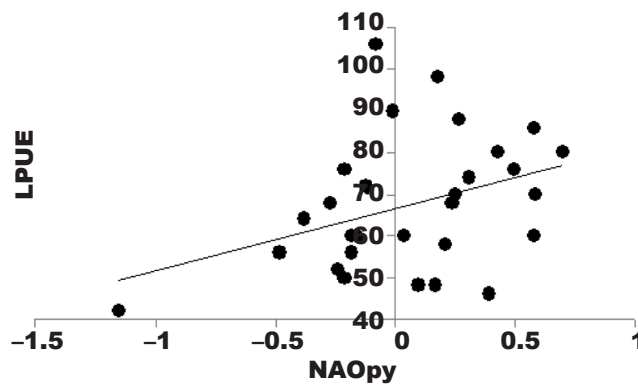


Fig. 2. Linear relationship between the landing per unit effort (LPUE) of blackspot seabream from the Algeciras, Tarifa and Conil harbours (Gulf of Cadiz) and the North Atlantic Oscillation previous year (NAOpy) to the landing, for the period 1983–2011.

Fig. 2. Relación lineal entre el desembarque por unidad de esfuerzo (LPUE) del besugo de la pinta en los puertos de Algeciras, Tarifa y Conil (golfo de Cádiz) y la oscilación del Atlántico Norte del año anterior (NAOpy) al desembarque para el período 1983–2011.

trends with a significance level greater than 90% were obtained. The blanks areas correspond to points with few measurements of MW<sup>u</sup> for the period under study following the protocol described above. The tempera-

ture trend (fig. 5A) was positive for the significant area with maximum values close to 0.2°C per decade near to the Portuguese coast. A similar pattern was observed for salinity trends (fig. 5B) with maximum values close

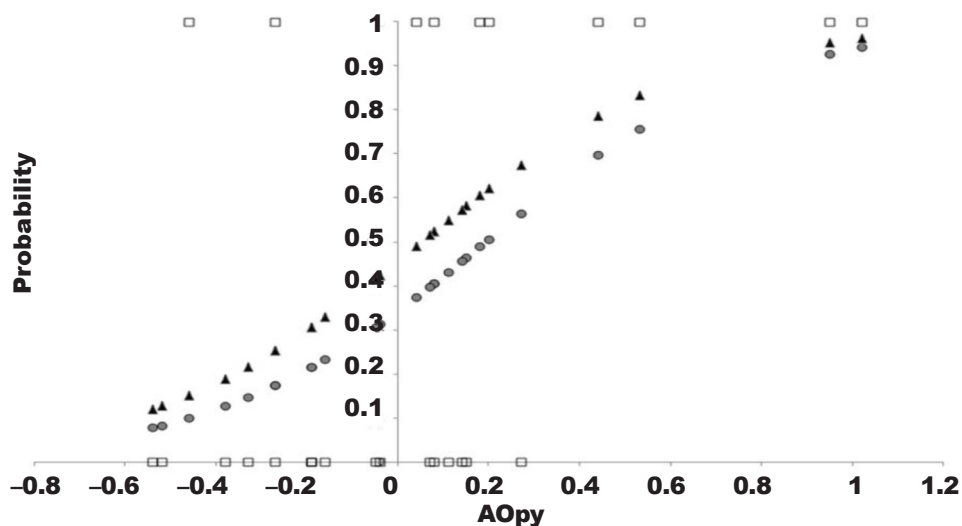


Fig. 3. Probability of obtaining good blackspot seabream landings from Tarifa harbour compared to the average Arctic Oscillation (AO) index for the year prior to landing (AOpy, gray circles), and the adjusted favorability for good blackspot seabream landings (black triangles). We plotted the years with good blackspot seabream landings (top squares) and years with poor blackspot seabream landings (bottom squares).

Fig. 3. Probabilidad de obtener buenos desembarques de besugo de la pinta en el puerto de Tarifa en comparación con el índice medio de oscilación del Ártico (OA) para el año anterior al desembarque (AOpy, círculos grises) y favorabilidad ajustada de los buenos desembarques de besugo de la pinta (triángulos negros). Elaboramos un gráfico con los años de desembarques buenos de besugo de la pinta (cuadrados superiores) y los malos (cuadrados inferiores).

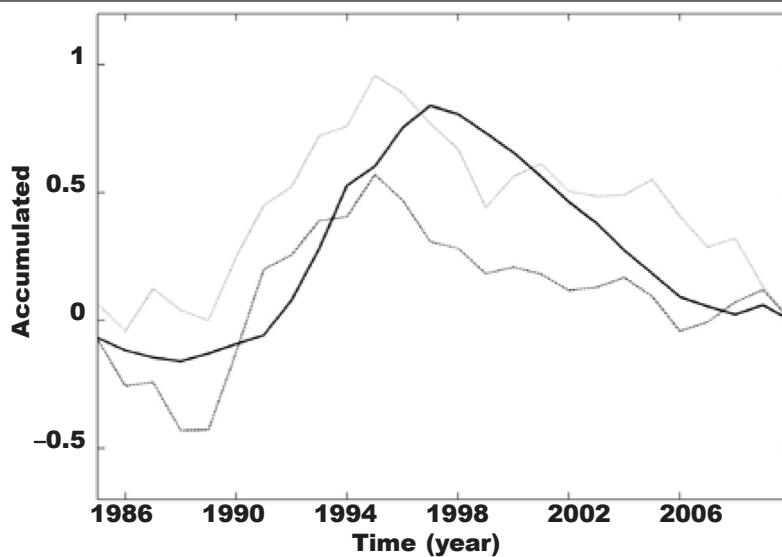


Fig. 4. Evolution of accumulated values for the North Atlantic Oscillation (gray line), Arctic Oscillation (dashed gray line), and *Pagellus bogaraveo* landings (black line). Signs were normalized so they could be represented in combination.

Fig. 4. Evolución de los valores acumulados para la oscilación del Atlántico Norte (línea gris), la oscilación del Ártico (línea discontinua gris) y los desembarques de *Pagellus bogaraveo* (línea negra). Se normalizaron los signos para que pudieran representarse en combinación.

to 0.05 per decade near the Portuguese coast. Warming and salinification were almost negligible at locations far from the coast. Salinity and temperature time series were calculated by averaging the grid points in the area under study where trends with a significance level greater than 90% were obtained. Figure 6 shows the time evolution of *Pagellus bogaraveo* landings and backward averaged MW<sup>4</sup> salinity and temperature, where the mean values (S and T) corresponding to a certain year were calculated by averaging the previous five years (e.g. backward averaged values for 1985 were calculated using values for the period 1980–1984). Both water properties were negatively correlated with landings (salinity:  $R = -0.71$ ,  $p < 0.01$ ; temperature:  $R = -0.68$ ,  $p < 0.01$ ).

## Discussion

Few studies have shown that large-scale atmospheric phenomena could affect deep-sea population dynamics (e.g. Ruhl & Smith, 2004; Maynou, 2008; and references therein). Maynou (2008) found that the annual strength of red shrimp (*Aristeus antennatus*) landings is affected by variations in NAO (especially in winter) in the previous two or three years our results indicate that the long-term landing of blackspot seabream from the Strait of Gibraltar is associated with the atmospheric oscillations.

The positive NAO results in stronger-than-average westerly winds across northern mid-latitudes, affect-

ing both marine and terrestrial ecosystems, while a positive AO phase is characterized by a strong polar vortex (from the surface to the lower stratosphere). In this situation, storms increase in the North Atlantic and drought prevails in the Mediterranean basin. Strong winds agitate the water, favouring the mixing of deep water and surface water, and thus increasing the supply of nutrients at the surface. When the NAO and AO is in a negative phase, the continental cold air sinks into the Midwestern United States and Western Europe, while storms bring rain to the Mediterranean region (Ambaum et al., 2001).

According to Maynou (2008), 'decreased rainfall during positive NAO years may increase water-mass mixing in the NW Mediterranean, enhancing mesozooplankton production and food resources to *Aristeus antennatus*, especially in late winter when females are undergoing ovary maturation and require higher energy input. During years of enhanced food resources the reproductive potential of females would increase, and strengthen particular year classes that appear in the landings two to three year later'. Our results suggest the same explanation. We observed a significant negative correlation between blackspot seabream landings and the temperature and salinity values obtained by calculating MW<sup>4</sup>. According to Báez et al. (2013a) a positive NAO<sub>py</sub> and AO<sub>py</sub> increases the amount of snow in the mountains surrounding the Alboran Sea, thus increasing the amount of continental freshwater entering the sea the following year, which in turn reduces surface salinity, and blocks water upwelling.



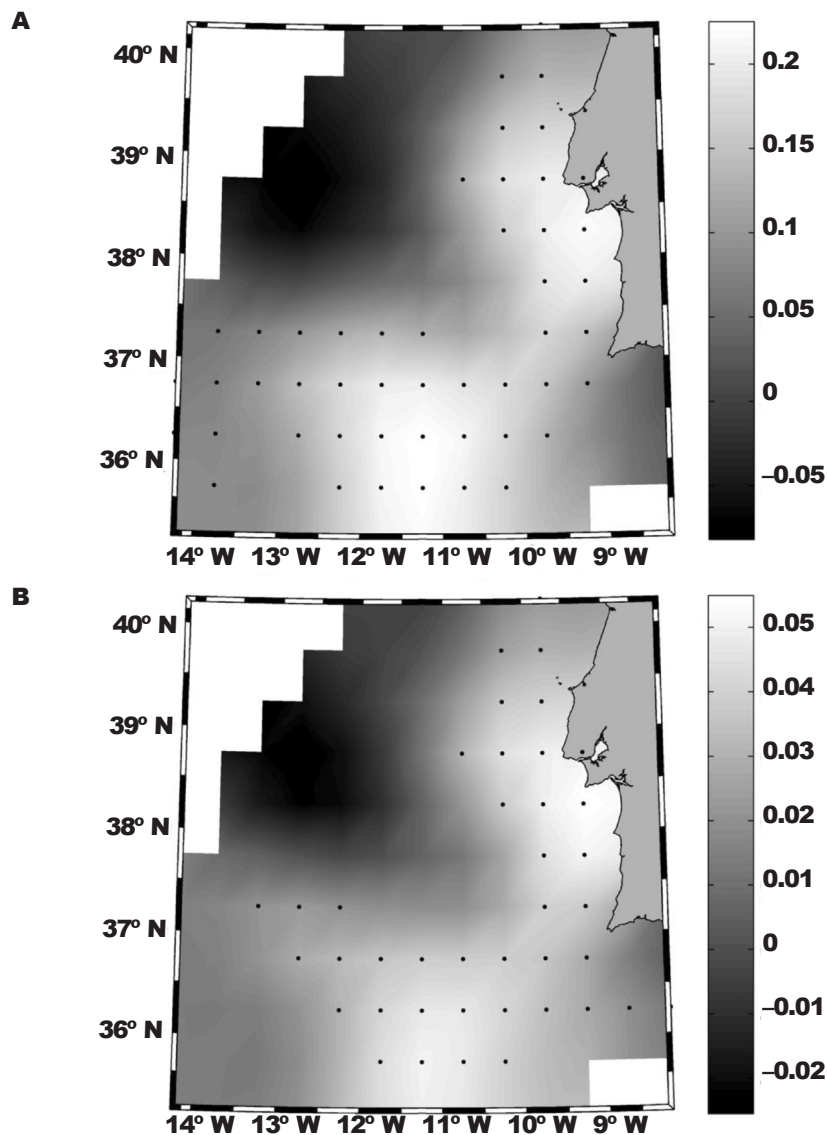


Fig. 5. Temperature (A, in °C/d) and salinity (B, in psu/d) trends corresponding to upper Mediterranean water (MW<sup>u</sup>). Dots mark locations where trends with a significance level greater than 90% were obtained. Blank areas correspond to points with few measurements of MW<sup>u</sup>.

*Fig. 5. Tendencias de la temperatura (A, en °C/d) y la salinidad (B, en psu/d) correspondientes a la corriente superior de agua del Mediterráneo (MW<sup>u</sup>). Los puntos indican los lugares en los que se obtuvieron tendencias con un grado de significación superior al 90%. Las zonas en blanco corresponden a los puntos con pocas mediciones de la MW<sup>u</sup>.*

We hypothesize that deep cold waters in the Alboran Sea are prevented from upwelling in the years following positive NAO and AO phases, and appear in the Atlantic as colder MW<sup>u</sup>. This chain of events seems to benefit the eco-physiology of blackspot seabream by increasing their biomass. In this context, the dependence link could be due to an increase in survival of larvae related to higher amounts of

food. This hypothesis is reinforced by the strongest correlation found for the AO with a lag of two years ( $R^2 = 0.95$ ,  $p < 0.01$ ).

In recent years, a decreasing trend in blackspot seabream landings has been observed. However, this trend has coincided with the end of a long positive NAO and AO cycle between the 1980s and 1990s (Fyfe et al., 1999). Thus, prolonged periods of a

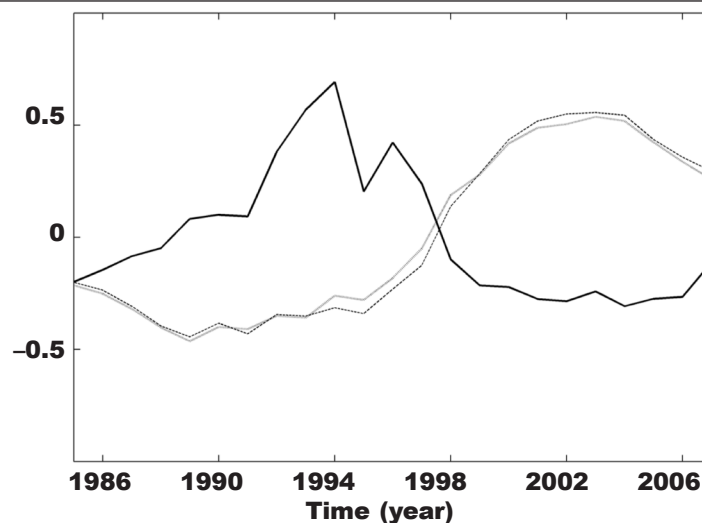


Fig. 6. Time evolution of *Pagellus bogaraveo* landings (black line) and backward averaged  $MW^u$  temperatures (gray line) and salinity (dashed gray line). Signs were normalized so they could be represented in combination.

*Fig. 6. Evolución de los desembarques de *Pagellus bogaraveo* (línea negra) y los promedios de la temperatura (línea gris) y la salinidad (línea gris discontinua) de la  $MW^u$  saliente. Se normalizaron los signos para que pudieran representarse en combinación.*

positive AO trend could favour high fishery yields. In contrast, a negative NAO and AO phase drastically reduces production. In the context of global change, this situation could have major implications for fisheries management. Thus, during positive NAO and AO phases, high exploitation levels could be allowed while maintaining the stocks within safety limits. During negative NAO and AO phases, more restrictive management measures should be adopted, such as lower exploitation levels, or temporary fishery closure, to preserve fishery sustainability and population safety.

Changes in the NAO and AO are correlated over long time periods (Feldstein & Franzke, 2006). Given the strong impact of the AO and NAO on the weather and climate of the wealthiest areas of the planet, and their large socioeconomic impact on energy, agriculture, fisheries, industry, traffic and human health throughout the whole of Europe and eastern North America, there has been great interest in quantifying the extent to which the phenomena are predictable and the ability of climate numerical models to simulate them. Bojariu & Gimeno (2003a) provide a good review of the topic. Predictive patterns have been identified in the Atlantic SSTs preceding specific phases of the AO and NAO by up to six months (Rodwell & Folland, 2003), in Eurasian snow cover by up to one year (Bojariu & Gimeno, 2003b), and in the extent of sea-ice over the Arctic (Deser et al., 2000). Thus, the Atlantic SST, Eurasian snow cover, and Arctic sea-ice are good candidates to explore fisheries in Strait of Gibraltar up to one year in advance.

It is widely accepted that the planet is experiencing a period of rapid global warming (Oreskes, 2004), primarily driven by human activity (Keller, 2007). Although there is increasing concern over the impact of global warming on marine biodiversity and fisheries ecology (Yatsu et al., 2005), it is difficult to predict how the climate could alter marine biodiversity. In this context, climate change simulations with greenhouse gas and aerosol forcing for the period 1900–2100 indicate a positive trend in the AO (Fyfe et al., 1999). On the other hand, the AO responds to natural changes, such as the increase in stratospheric aerosols due to volcanic eruptions (Christiansen, 2007). Thus, via the NAO and AO, global warming could affect the fisheries ecology of blackspot seabream from the Strait of Gibraltar. This possibility could be extrapolated to other northern hemisphere stocks.

#### Acknowledgements

This work was partially supported by projects from the IEO based in Malaga, GPM-4 programs (IEO) and PNDB (EU-IEO), project CGL 2009-11316/BOS from the Spanish Government and FEDER, and from the Xunta de Galicia under 'Programa de Consolidación e Estruturação de Unidades de Investigación' (Grupos de Referencia Competitiva) funded by FEDER. An anonymous reviewer provided helpful comments on earlier versions of the manuscript. We would also like to thank to Andrew Paterson for style corrections.

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