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Environment or catches? Assesment of the decline in blackspot seabream (*Pagellus bogaraveo*) abundance in the Strait of Gibraltar

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In this study we carried out an analysis of the relationship between the variation in environmental and oceanographic parameters and the changes in the abundance of blackspot sea bream (*Pagellus bogaraveo*) in the Strait of Gibraltar between 1983 and 2016. A discrete dynamic model was applied to simulate different scenarios of blackspot sea bream biomass on a monthly time scale. ARIMA models were applied to the simulated biomass time series in order to extract the effect of the fishing component and then correlate the residual series with each of the environmental and oceanic parameter sets. Regardless of the scenario analysed, the error terms provided by the ARIMA models indicated a strong auto-regression dependence on the series and that the fishing component accounted in the worst case scenario for 73% of the variation in sea bream biomass in the Strait of Gibraltar. Throughout the study period, part of the variation not explained by the fishing component was explained in certain years by environmental parameters. These correlations were particularly significant for the water temperature anomaly, salinity anomaly and the NAO index. Our analyses therefore suggest that the main factor responsible for the drastic decline in the abundance of sea bream in the Strait of Gibraltar is over-exploitation of the resource and that environmental conditions had a one-off effect which, depending on the year, favoured or harmed the recovery of the stock.

Keywords: Computational simulation, biomass time series, ARIMA models, oceanic parameters, environmental parameters.

Introduction

Severe problems in fisheries management and planning are evident from the current levels of overfishing (Mora et al., 2009), which greatly hinders the natural regeneration of fish species (Conover and Munch, 2002; Perry et al., 2005). Further, the situation can be expected to get worse with any changes in climatic conditions since, in the fisheries sector, little is known about the likely consequences for ecological systems and resources, in particular, the spatial distribution, abundance and yield of commercially important marine species (Gutiérrez-Estrada et al., 2009; Yánez et al., 2010; Báez et al., 2014; Torralba and Besada, 2015; FAO, 2016). Therefore, a prime objective should be to develop management systems that consider all elements of the ecosystem (biological and environmental dimensions) and human activity (socioeconomic and political dimensions) (Tupper, 2002; Safina et al., 2005).

The effect of fishing activity on the variation in available biomass of an exploited fish species may be characterized and quantified if measures for monitoring fishing effort are introduced and adhered to, this being essential for the management of fish resources (Hutchings and Myers, 1994; Pauly et al., 2002). In contrast, the specific direct effects of environmental factors on marine fish populations are difficult to predict and quantify (Lehodey et al., 2006; Alheit et al., 2012; Ullah et al., 2012; Pitois et al., 2015; Malta et al., 2016). Various studies have indicated that possible changes in spawning biomass and in the structure and abundance of phytoplankton may be due to events associated with climate shifts (Hidalgo et al., 2008; Gröger and Fogarty, 2011; Kane 2011; Santos et al., 2012; Perreti et al., 2017), but there is a lack of conclusive data that would enable us to analyse the direct impact of such environmental variability on the biomass available to a given fishery.

The blackspot seabream (*Pagellus bogaraveo*) fishery in the Strait of Gibraltar is not immune to the aforementioned changes resulting from exploitation and environmental changes. This demersal species, living at depths of 400 to 700 m, is the target of the artisanal blackspot seabream longline fishery known as the "*voracera*" fleet (Báez et al., 2009; Czerwinski et al., 2009). Due to its high commercial and gastronomic value, blackspot seabream has attracted great interest and become economically important for the area of the Strait of Gibraltar (Burgos et al., 2013). This fishery started in the early 1980s. Since then, the landings of this species in the main fishing ports have shown marked variability, characterized by two cycles with peaks around 1994-5 and 2009 (Gutiérrez-Estrada et al., 2017).

Very restrictive regulations for the management of blackspot seabream fishery have failed to prevent catches of this species falling to the current low levels. This might lead us to think that environmental factors have a relevant impact on catches of this species in the Strait of Gibraltar. In relation to this, Báez et al. (2014) assessed the response of the population of blackspot seabream to changes in North Atlantic oscillation (NAO) and Artic oscillation (AO) climate indices. Their results suggest that prolonged periods of positive trends in NAO and AO are associated with high yields, while yields fall with negative trends in these indices. On the other hand, Gutiérrez-Estrada et al. (2017), simulating the variation in available blackspot seabream biomass using known biological parameters for the species, only found significant correlations with the NAO and sea surface temperature (SST) in certain periods coinciding with moments in which fishing pressure may significantly compromise recruitment. These results indicate that the relative impact of fishing and environmental factors should be analysed in greater depth and independently.

To study the interaction between climate and fishing, numerous authors express fish abundance in terms of catch per unit effort (CPUE) or landing per unit effort (LPUE) (Lorance and Dupouy, 2001; Casini et al., 2005; Haggarty and King, 2006; Czerwinski et al., 2007; Gutiérrez-Estrada et al., 2007, 2009; Yánez et al., 2010). Notably, however, a correlation between these measures and the true abundance of the target species has yet to be demonstrated; that is, it is possible that not for all fisheries there is a significant correlation between CPUE or LPUE and abundance and therefore these indexes could not reflect the real number of fish in the sea (Paloheimo and Dickie, 1964; Bannerot and Austin, 1983; Harley et al., 2001; Branch et al., 2011; Campbell, 2015). This circumstance could be more probable in benthonic species. Given this, it is very difficult to properly assess the role of environmental factors in reductions in abundance in a given population by directly relating CPUE or LPUE with climate time series.

A potential solution, enabling us to explore environmental effects on the abundance of a given fish population, may be to combine simulated life cycles of the species exploited and the fishing component. For this purpose, Gutiérrez-Estrada et al. (2017) developed a general purpose program (SimFish version 1.0) that simulates, through a discrete abundance-biomass model, the life cycles, abundance and pristine biomass of a fish population, taking into account population growth dynamics, age class structure, the spawning-recruitment relationship, natural mortality and fishing mortality. Having estimated the biomass, it is possible to determine the effect of fishing activity on the given fish population, and then, variations not attributable to fishing activity can be assumed to be due to environmental factors.

In this study, we carried out the analysis of the blackspot seabream fishery in the Strait of Gibraltar between 1983 and 2016 with the objective of ponder the impact of fishing activity and environmental effects on the abundance of this specie. For that, we use the methodological approach propose by Gutiérrez-Estrada et al. (2017) compiled on the software SimFish (version 1.0). Using this approach, we generate simulations of changes in the abundance of blackspot seabream, considering various different scenarios concerning species life cycle that may contribute to decision making in the sustainable management of this fish resource.

Material and methods

Fishery data base

The present study was based on blackspot seabream catches off the south of the Iberian Peninsula from the Strait of Gibraltar to Cape St. Vincent, in the far southeast of the International Council for the Exploration of the Sea (ICES) Division IXa in the area bound by the following coordinates: 5º85’ W to 5º31’ W and 35º77’ N to 36º18’ N (Burgos et al., 2013). The historical time series of monthly landings of blackspot seabream correspond to landings from the Spanish ports of Tarifa, Algeciras, Conil, and Ceuta and the Moroccan port of Tangier between 1983 and 2016.

Data on quarterly size class distribution were obtained from the database of the Spanish Institute of Oceanography (IEO) for 1990 to 2014. To obtain monthly figures from this quarterly historical time series, we followed the proposal of Gutiérrez-Estrada et al. (2017) that assumes that the standard deviation and mean were the same for each month in a quarterly period as those for the entire period. The capture probability of each size class was calculated assuming they followed a normal distribution and using the monthly means and standard deviations. When monthly or quarterly distribution data were not available (between January 1983 and December 1989), we considered means and standard deviations of the data for the quarterly distributions from 1990 to 2014.

All the biological parameters used in the life cycle simulations were obtained from studies on the population biology of blackspot seabream in the Strait of Gibraltar (Gil and Sobrino, 2001; Gil, 2006; Czerwinski et al., 2008, 2010).

Environmental data base

The environmental database was composed of historical series of oceanographic and environmental data and climate indices available for the study area. In particular, the data on temperature (ºC), salinity (PSU), salt flux (kg m^{-2} s^{-1}), heat flux (W m^{-2}), wind speed (m/s) and current speed (m/s) were obtained for the period between 1983 and 2016 from the Simple Ocean Data Assimilation (SODA) v 3.3.1 reanalysis data set (http://www.atmos.umd.edu/~ocean). This data set contains monthly ocean data remapped in 3D to a horizontal 1/2° x 1/2° Mercator coordinate grid with 50 vertical levels (Carton et al., 2018). As blackspot seabream is a demersal species, the SODA data were filtered to obtain the first 24 layers, enabling us to analyse depths ranging from 5 to 525 m.

Data on chlorophyll-a concentration (mg m^{-3}) between 2003 and 2016 were obtained from monthly images from NASA's MODIS satellite. Images were downloaded using griddap from the Environmental Research Division's Data Access Program server (providing easier access to scientific data) version 1.76 of the US National Oceanic and Atmospheric Administration (http://coastwatch.pfeg.noaa.gov/erddap/griddap) (Esaias et al., 1998).

The historical time series of the NAO index spanning 1983 to 2016 were obtained from the US National Center for Atmospheric Research (https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based). For this study, we used the monthly and winter NAO indexes (Hurrell and National Center for Atmospheric Research Staff, 2017). Further, the monthly AO index from 1983 to 2016 was downloaded from the US National Oceanic and Atmospheric Administration's National Weather Service (http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/monthly.ao.index.b50.current.ascii) (Thompson and Wallace, 2000).

Description of the main SimFish algorithm

SimFish 1.0 is a computer program written in Microsoft Visual Basic 6.0 with the main aim of simulating fish biomass over time with and without exploitation. For this, the program uses a discrete abundance-biomass model that assumes that catches occur discretely on a monthly basis (Gutiérrez-Estrada et al., 2017).

The program contains on three subroutines. The first calculates the distribution of the theoretical frequencies for each age class, assuming that they follow a normal distribution. The biomass distribution function for each length class is calculated from the length-weight relationships experimentally established for the study area. Then, the algorithm calculates the contribution of each age class and size to the total biomass. At this point, the program subtract the real total monthly landings and the corresponding biomass to the natural mortality associated with each age class. The second subroutine recalculates natural mortality associated with the new distribution of frequencies, while the third assesses at what point in time there is a reproductive event and the level of recruitment to the next generation.

Given the general purpose and modular nature of this program, it can be modified, and for this study, modifications have been made to include compensatory effects of recruitment. This enables us to obtain a stable simulation in the absence of catches. We have also made it possible to evaluate the effect of spawning events taking place at different times.

Simulation process

Sensitivity analysis was performed, using different simulations that considered the effect of varying the number of age classes, instantaneous natural mortality, biomass of age class 0+ at t=0, spawning-recruitment population model parameters and the proportion of spawning occurring in the first quarter.

The number of age classes was varied from 15 to 20 and the initial biomass from 20 t to 45 t, in steps of 5 t, meaning that for each age class we considered six different amounts of biomass. In each age class, instantaneous natural mortality ranged between 0.20 and 0.35, in steps of 0.01. For survival rate, we considered values of 0.015 and 0.02 for the compensatory mortality a and values of 0.002 and 0.0025 for the coefficient of compensatory mortality b. Finally, the proportion of the spawning in the first quarter was distributed in three ways: 100% in January; 60% in January and 40% in February; and 60% in January, 30% in February and 10% in March. Taking into account the aforementioned factors, we designed seven different scenarios under which to obtain the simulations (Table 1).

For the different simulations, we obtained time series of the total biomass. Viable models were selected based the following criterion: the ratio of the initial biomass simulated at t=0 to the maximum biomass simulated across all the time series could not be higher than 70%. Viable models were grouped by age class and the 95% confidence levels were calculated.

Subsequently, each biomass time series was fitted to an autoregressive integrated moving average (ARIMA) model (p, d, q) (P, D, Q)^S that allows data to be adjusted for seasonality, where p and P are the number of autoregressive terms, d and D are the number of differences needed for stationarity, q and Q are the moving average terms and S is the number of periods in the season (in this case S=12), P, D and Q being the parameters for the seasonal component of the model. In this study, we assumed the time series of simulated biomass to be autoregressive, this hypothesis implying removal of the effect of moving average components of the ARIMA model (q=0 and Q=0). Residual variability not explained by the ARIMA model should be due to sources of variation other than the effect of past values of biomass itself, and hence, the series of residuals is related to the environmental parameters under study. The ARIMA models were constructed using RStudio v3.3.2 (Hyndman and Khandakar, 2008; Hothorn et al., 2017; Hyndman et al., 2017; Trapletti et al., 2017).

Results

Blackspot seabream landings

Since 1983, when the fishery first opened, blackspot seabream landings have varied significantly, and the pattern is characterised by two cycles, with peaks in June 1997 (144.6 t) and June 1999 (138.9 t) and troughs in March 1999 (8.2 t) and February 2004 (15.1 t). In general, trends in the fishery have been negative and show a strong and marked seasonal component, characterized by an increase in landings between January and June and a steady decrease to October (Figure 1a).

Analysing the contribution of the different fishing ports to the total landings, we see that in the first 4 years all the catches were landed in the port of Tarifa. Since 1987, we can observe three clearly distinct periods as a function of the ports involved in this fishery: (i) from 1987 to 1994, the catches were mostly landed in Tarifa (97.9%), though some were landed in Ceuta (2.1%); (ii) from 1995 to 2001, a high percentage of catches were landed in the port of Algeciras; and (iii) from 2002 to 2016, no landings were recorded in Ceuta, but this species started to be landed in Conil and Tangier. In the most recent period, we can observe that from 2009 onwards landings markedly decrease in Tarifa (-32.1%) and markedly increase in Tangier (+45.7%). On average, across the entire time series, the port with the highest landing activity was Tarifa (70.8%), followed by Tangier (12.7%), Algeciras (12.3%), Conil (2.6%) and Ceuta (1.5%) (Figure 1b).

Simulations of the blackspot seabream biomass

The simulations were carried out under the conditions of the scenarios described in Table 1. Of the 4032 simulations obtained, we selected 751 (18.6%). Viable simulations for each age class distribution were averaged to obtain the final total biomass time series (Figure 2a to 2g).

In all the scenarios, total biomass changed following a well-defined pattern. Since 1983, the total biomass has ranged from 4000 to 8000 t, with a progressive decrease until December 1991, when biomass ranged from 890 to 2700 t. This observed decrease in blackspot seabream populations was significant for scenarios 1, 2, 3, 4 and 7 (Tukey's HSD test: $p_{1983\text{-}1991}<0.05$). From this time point, the population grew slightly, and further changes to up to the present day depend on the scenario analysed.

For scenarios 5 and 6, we found similar behaviour in the initial part of the time series; biomass has been recovering since 1999, reaching 1700 t in December 2016; and unlike with other scenarios, we did not observe any biomass cycle, no significant differences being found between 1983, 1991, 2006, 2008, 2009 and 2016 (Tukey's HSD test: $p_{1983\text{-}1991,\ 1991\text{-}2006,\ 1991\text{-}2008,\ 1991\text{-}2009,\ 2006\text{-}2016,\ 2008\text{-}2016,\ 2009\text{-}2016}>0.05$). In all the scenarios, the total biomass by the end of 2016 was between 20% and 35% of the initial biomass.

Fitting ARIMA models to the simulated biomass time series

Table 2 shows the values of the error metrics considered in the validation phase of the ARIMA models (p,d,q) $(P,D,Q)^s$ (with S=12 and N=408). In all cases, the SEP was between 50% and 113% (Model 6, scenario 2: %SEP=50%; Model 6, scenario 6: SEP=113%). The PI was always over 0.448, with a mean of 0.795±0.08, indicating a high level of agreement between the observed and fitted values as well as a small temporal lag.

Oceanic parameters and climate indices in the Strait of Gibraltar

The time series of sea temperature anomalies in the Strait of Gibraltar between 1983 and 2016 showed that the years with the coldest water column were 1986 and 1994, with annual mean anomalies of -0.18ºC and -0.20ºC, respectively. On the other hand, the years with positive anomalies, that is, the years with the warmest water column were mainly 1995, 1997, 2000 and 2004, but also 2010, considering the upper layer of water column. In 1995 and 1996, we observed annual mean anomalies of 0.31ºC and 0.29ºC, respectively, while in 2010, the upper layer of water column (down to 95 m) the mean was as high as 0.49ºC (Figure 3).

Salinity anomalies showed a two-layer behaviour. In the upper layers, we observed negative, less saline anomalies and in the lower layers, positive, more saline anomalies, this being the normal pattern in the Strait of Gibraltar. The most negative anomalies were seen in 1991, with -0.09 PUS at the sea surface. In 1992, 1993 and 1994, there were positive anomalies of 0.17 PSU (525 m), 0.29 PSU (5 m) and 0.03 PSU (5 m), respectively, which corresponded to an increase in the salinity at the sea surface. In contrast, in 2001 and 2009, negative anomalies dominated with increasing depth, indicating that in these cases the salinity of the water column was decreasing on average by -0.05 PSU and -0.11 PSU, respectively (Figure 4).

In the Strait of Gibraltar between 1983 and 2016, we observed a downwards trend in current speed from the sea surface to a depth of 525 m. The highest current speeds near the surface (5-65 m) were found in 1994, 1995, 2001 and 2014 with mean recorded values of $5.60\ 10^{-2}\ m\ s^{-1}$, $5.20\ 10^{-2}\ m\ s^{-1}$, $5.52\ 10^{-2}\ m\ s^{-1}$ and $5.05\ 10^{-2}\ m\ s^{-1}$, respectively, the highest values being reached in 1994 and 2001. On the other hand, current speed tended to decrease from a depth of 65 m, with the most marked decreases in 1983, 1985, 2000 and 2002. A different pattern of change in current speed with depth was observed in 1993 and 2005, the speed remaining reasonably high in lower layers, reaching $4.15\ 10^{-2}\ m\ s^{-1}$ and $4.22\ 10^{-2}\ m\ s^{-1}$ at a depth of 385 m in 1993 and 2005 respectively.

The distribution of heat flux anomalies indicated the existence of two distinct periods. In the first period, from 1983 to 1997, there were mostly negative anomalies, with the strongest negative anomaly in October 1987 (-63.14 W m^{-2}). In the second period, from 1998 to 2016, positive anomalies predominated, the strongest being observed in January 2004 (46.15 W m^{-2}) and April 2014 (46.47 W m^{-2}).

During the study period, the salinity flux in the Strait of Gibraltar remained in the range [-1.50, 1.50] 10^{-7} kg m^{-2} s^{-1}. From 1983 to 1991, anomalies were mostly positive, with a peak of 2.60 10^{-7} kg m^{-2} s^{-1} in April 1990. Between 1990 and 1993, salinity flux tended to decrease, reaching a minimum in April 1993 (-2.83 10^{-7} kg m^{-2} s^{-1}). From 1994, the salinity flux progressively increased up to 1.52 10^{-7} kg m^{-2} s^{-1} in October, when it stabilized between approximately -0.5 and 0.5 10^{-7} kg m^{-2} s^{-1}.

Through the entire time series analysed, the wind speed ranged between 0.75 and 2.75 10^{-2} N m^{-2}. We detected three periods characterized by pronounced decreases in wind speed: the first between March 1990 and May 1992 (from 7.90 10^{-2} N m^{-2} to 0.45 10^{-2} N m^{-2}); the second between March 1997 and February 2000 (from 6.69 10^{-2} N m^{-2} to 0.30 10^{-2} N m^{-2}); and the third between December 2001 and April 2003 (from 6.22 10^{-2} N m^{-2} and 0.17 10^{-2} N m^{-2}, respectively).

Chlorophyll levels varied from 0.25 to 1 mg m^{-3} between 2003 and 2016. Higher levels were found in February 2010, March 2004, 2006 and 2012, April 2009, September 2014 and December 2010. The highest value was found in March 2006 (1.75 mg m^{-3}) and the lowest in March 2012 (1.37 mg m^{-3}).

Correlations between the residuals and environmental time series for the model 1 scenario 2 and model 2 scenario 5

From all the simulations performed, model 1 of scenario 2 was selected for having the smallest errors when fitting the ARIMA model and model 2 of scenario 5 for having a clearly non-cyclical pattern.

Oceanic parameters

There was a strong vertical gradient in temperature and temperature anomalies, with a high variability over time. In both models, the correlations between the series of residuals and the temperature anomaly had a similar pattern, except that the residuals significantly correlated with the anomaly over 14 years in model 1 of scenario 2 but only for 12 years in model 5 of scenario 2. The general pattern in both models was of significant positive correlations between 1987 and 1996 and in 2014. These correlations were generally found in the upper and middle water column (15-125 m). In contrast, there were clearly negative correlations in 1983, 2011, 2012 and 2015 in the deep water column (85-385 m) (Figure 5).

As for temperature, there was a strong vertical gradient in salinity and the salinity anomaly with a high variability over time. The significant anomalies found in both scenarios were negative in the deep water column (125-525 m) from the beginning of the series until 1990, when positive anomalies emerged in the middle water column (75-125 m). Between 1990 and 1995, there were mostly negative anomalies in the upper and middle water column, though positive anomalies were found at depth in 1995 in scenario 5 (Figure 6).

Similarly, the heat flux was found to have a high variability in the correlations in both models, and notably successive negative correlations dominated between 1986 and 1989 and between 1992 and 1995. At the end of the 1990s, there was a 3-year period with positive correlations. In the other years of the time series, there were alternating positive and negative correlations. The opposite was found for the salinity flux correlations, these being characterized by mostly positive correlations between 1984 and 1994 and between 2001 and 2009, while negative correlations were mainly found between 1995 and 2000 and 2011 and 2015.

With regards to the current speed, we found a similar pattern of significant correlations for both scenarios between 1983 and 1989. During this period, all the correlations were negative and were distributed throughout the entire water column. In 1990, the pattern reversed in both scenarios 2 and 5, with positive correlations in the upper water column layer (15-25 m) and at depth (165-335 m). After 1991, in both scenarios, the correlations became negative again at depth (385-525 m), remaining negative until 1998 in the case of scenario 2 and until 1999 in the case of scenario 5, and becoming positive again until 2013 in scenario 5 and 2015 in scenario 2.

Regarding wind speed, significant positive rather than negative correlations dominated in the two scenarios analysed. In scenario 5, correlations were mostly positive from the beginning of the series until 2000-2002. In contrast, from 2010-2013, the correlations were negative in both scenarios.

Climate indices

The correlations between the monthly NAO index and the residual series were generally positive, being particularly strong in 1987-1988 and 2007. The most notable negative correlations were found in 1998 and 1999. On the other hand, stronger correlations were found for the winter NAO than the monthly NAO. In this case, we found greater variability, with alterations between positive and negative correlations. Despite these alterations, we found some periods of mostly positive (1987-1991 and 1996-2000) or mostly negative (2004-2007 and 2014-2015) correlations.

Similar behaviour was observed for the monthly and winter AO index. The significant correlations for the monthly AO under scenario 2 were all positive as they were under scenario 5, except in 1994 when the correlation was negative. The correlations were the same for the two scenarios for 1985, 1993 and 1996. On the other hand, the winter AO index showed a different behaviour under the two scenarios. under scenario 2, the correlations alternated between positive and negative each year, while under scenario 5 the correlations remained positive for 2 years before changing to negative for 2 years and then becoming positive again. The correlations agreed between the two scenarios in 1985 and 1990 with positive correlations and in 2008 with negative correlations.

Discussion

The collapse of the most economically important fishery in the Strait of Gibraltar highlights the need to clarify when and to what extent anthropic and environmental factors are responsible for this situation. To this end, this study investigate the impact of six environmental and oceanographic variables and two climate indices on blackspot seabream biomass by taking into account the simulated life cycle of this species and real landings reported.

To achieve this, we have followed the methodology proposed by Gutiérrez-Estrada et al. (2017). These authors established that in a simulation of the life cycle of a species under constant environmental conditions, the abundance or biomass can be described using autoregressive models, assuming a linear dependence between past and current abundance. In this way, significant differences between the fitted model and the simulated data can be interpreted as extra-compensatory effects contained in the series of real catches. As a consequence, the potential environmental effects on the abundance of the population should be contained in the residuals not explained by the ARIMA model.

This procedure makes it possible to mitigate the problems of working with CPUE series. For example, it is very common that CPUE is positively correlated with the catches (Chu-fa et al., 1996; Alós et al., 2008; Powers and Abeare, 2009) or negatively correlated with fishing effort (Gillis et al., 1993; Swain and Wade, 2003; Okemwa et al., 2016). Such proportionality implies that changes in the catches and/or in the fishing effort may lead to misleading correlations emerging between CPUE and species abundance (Kennedy and Jónsson, 2017). In particular, this proportionality leads to a hyperstability in which CPUE remains stable while the real abundance of the species decreases, leading to an overestimation of the biomass and underestimation of fishing mortality (Crecco and Overholtz, 1990). Hence, the relationship between abundance indices such as CPUE and time series of environmental variables may lead to misinterpretation of serial correlations.

Simulations

Independently of the scenario, all the viable simulations considered provided initial values of biomass between 4000 and 8000 t. In general, they all showed a reduction in biomass from 1983 until approximately 1991-1993, reaching values between 890 and 2700 t. This marked decrease in the simulated biomass coincided with the period in which the blackspot seabream fishery expanded geographically and fishing pressure increased due to very permissive legislation that allowed catches with a minimum size of only 25 cm [Council Regulation (EEC) No 3094/869]. This lead to unsustainably high levels of exploitation of the stock and very low landings in a period of 8-10 years (Jiménez-Toribio and García del Hoyo, 2006).

After 1993-1994, all the simulations indicate very low levels of biomass, as reflected in low landings. This is a direct consequence of the biology of this species. Blackspot seabream is a protandrous species in which individuals progressively transition from males into sexually mature females at 30-32 cm (Gil and Sobrino, 2001). Therefore, a minimum catch size of 25 cm puts excessive fishing pressure on females, which undoubtedly has direct effects on the sex ratio and recruitment.

After this apparent collapse of the fishery, all the simulations indicated a recovery in biomass that coincided with the period of low landings (1999-2007). During this period, the total allowable catches were reduced from 1000 t in 2003 [Council Regulation (EEC) No 2340/2002] to 850 t in 2007 [Council Regulation (EEC) No 2015/2006] and Spain increased the minimum catch size to 33 cm (Order APA/3323/2002, Order APA/274/2007). Additionally, the fishing effort was reduced, by shortening the season to 140 days. These measures helped to strengthen the population. Nevertheless, even with more restrictive legislation, landings started to increase between 2008 and 2011, these higher landings again coinciding with a decrease in biomass in all the simulations. This effect was also observed in all the models.

Between 2011 and 2016, there was a clear downward trend in landings which could be explained by the decrease in total biomass described in all the simulations run, except for those of scenario 1. In this period, despite the fact that there was stricter Spanish legislation, a smaller quota and less fishing effort, on average catches were not above 40 t per month. That is, landings were at the similar levels to those of 1999 which could be related with an increment of catches of specimens with total lengths lower than 33 cm by Morocco fleet. On the other hand, this lack of recovery observed in the simulations may be explained by a change in the status of the population in response to the intense disturbance caused by the fishing component in the previous years (Scheffer et al., 2001).

Environmental parameters

The oceanographic region of the Strait of Gibraltar is of great importance, not only at the local scale but also globally, for its essential role in the circulation and biogeochemical balance of the Atlantic Ocean (Ramírez-Romero et al., 2014a,b). An exchange of organic and inorganic carbon between the Atlantic Ocean and the Mediterranean Sea occurs through the Strait of Gibraltar (Huertas et al., 2009), which together with the area's climate system determine the population dynamics of the marine species in these waters.

Over the study period, the environmental parameters in the Strait of Gibraltar showed some variability, with changes in regime in certain years. For example, we found a change in temperature anomaly trend, from clearly negative anomalies (between 1983 and 1994) to mostly positive anomalies (1996-2006). Such changes in regime have also been detected at the global scale. In the Pacific ocean, Hare and Francis (1995) reported regime changes due to the interdecadal climate variability in the mid-1990s (Mantua et al., 1997) that according to some authors had an impact on the North Pacific red salmon and halibut fisheries (Pyper and Peterman, 1999; Clark and Hare, 2002; Ruggerone et al., 2003). In the Strait of Gibraltar, for the change between 1994 and 1996, we found positive correlations between the residuals of the ARIMA models and the temperature anomalies, particularly significant between 1994 and 1996, while for the second change of regime (2006-2007), we detected significantly negative correlations in 2011 and 2012. Hence, it seems that changes in temperature regimes have short-term effects on biomass recovery, these being negative if the anomalies are positive and vice versa.

Similar conclusions can be drawn from analysis of correlations of residuals with salinity, and heat and salinity flow. The combination of unusually low temperatures, lower heat flow, and lower salinity with higher salinity flow seems to favour recruitment, which in turn allows an increase in catches. Such a recovery in catches after a change in environmental regime has been observed in other species, including anchovies (*Engraulis encrasicolus*) in the Gulf of Cadiz (Ruiz et al., 2006) and European hake (*Merluccius merluccius*) off the northwestern coast of Africa (Meiners Mandujano, 2007).

With regards to the NAO and AO, we detected significantly negative correlations in 1994, 1995, 1996, 2009 and 2010. In the Iberian Peninsula, these indices are negatively correlated with precipitation, that is, negative values are associated with more precipitation (Esteban-Parra et al., 1998). In 1996, rainfall was relatively high, resulting in an increase in the fresh water discharge from rivers in the area of the Strait of Gibraltar, and this may have led to fertilization with nutrients from the shelf, in turn increasing primary production. These climatic patterns may have an effect on the population dynamics of the seabream juveniles and may explain the correlation between the residuals of the ARIMA models and the NAO and AO indices. Negative phases of these indices tend to be associated with weak recruitment events in pelagic species, and in turn, we could expect lower catches in these periods given the smaller number of individuals in the population (Santos et al., 2001, Santos et al., 2012). On the other hand, in positive phases, coinciding with periods of drought, there is stronger recruitment, which might increase catches in the following years. According to Gutiérrez-Estrada et al. (2017), this may mitigate decreases in biomass due to high mortality rates resulting from excessive fishing.

The results of this study highlight the need to promote a strategic plan for the blackspot seabream fishery that is able to integrate environmental factors to dynamically adjust catch rates to the biomass available which corroborate the last recommendation of The General Fisheries Commission for the Mediterranean (GFCM/41/2017/2). We believe that it is essential to use methodologies like those described in this study, as a decision-making support tool for managers and technicians in charge of the management and planning of artisanal fishery resources, with the main goal of ensuring the sustainability of the fishing activity under continuous increases in demand and variable climatic conditions. If fishing management measures that reduce the economic, social and ecological disturbances are not put in place, however, we may see soon the total collapse of this fishery that takes place in this very specific climatic and oceanographic environment.

Author contributions

All authors conceived the research and contributed to development of concepts. Dr. Juan Carlos Gutiérrez Estrada and Dr. Inmaculada Pulido Calvo have developed the software SimFish 1.0 and Víctor Sanz Fernández programmed the R script that allows the adjustment of the ARIMA models. Dr. Juan Gil Herrera provided much of the biological data, landings and distribution of the blackspot seabrem catch in the Strait of Gibraltar. Dr. Said Benchoucha and Sana el Arraf kindly provided data on blackspot sea bream landings in Moroccan ports. All authors reviewed the literature and wrote the initial manuscript. All authors critically reviewed multiple drafts of the manuscript, as well as commented on and approved the final version.

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References

Alheit, J., Pohlmann, T., Casini, M., Greve, W., Hinrichs, R., Mathis, M., O'Driscoll, K., Vorberg, R., Wagner, C. 2012. Climate variability drives anchovies and sardines into the North and Baltic Seas. *Progress in Oceanography*, 96: 128-139.

Alós, J., Palmer, M., Grau, A. M., Deudero, S. 2008. Effects of hook size and barbless hooks on hooking injury, catch per unit effort, and fish size in a mixed-species recreational fishery in the western Mediterranean Sea. *ICES Journal of Marine Science*, 65: 899-905.

Baéz, 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 black spot seabream from the Strait of Gibraltar. *Animal Biodiversity and Conservation*, 37: 35-47.

Báez, J.C., Real, R., Camiñas, J.A., Torreblanca, D., García-Soto, C. 2009. Analysis of swordfish catches and by-catches in artisanal longline fisheries in the Alboran Sea (Western Mediterranean Sea) during de summer season. *Marine Biodiversity Records*, 2: 1-4.

Bannerot, S.P., Austin, C.B. 1983. Using frequency distributions of catch per unit effort to measure fish-stock abundance. *Transactions of the American Fisheries Society*, 112: 608-617.

Box, G.E.P., Jenkins, G.M. and Reinsel, G.C. 1994. Time series analysis: Forecasting and control, Prentice Hall, New Jersey.

Branch, T.A., Jensen, O.P., Ricard, D., Ye, Y., Hilborn, R. 2011. Contrasting global trends in marine fishery status obtained from catches and from stock assessment. *Conservation Biology*, 25: 777-786.

Burgos, C., Gil, J., del Olmo, A. 2013. The Spanish blackspot seabream (*Pagellus bogaraveo*) fishery in the Strait of Gibraltar: spatial distribution and fishing effort derived from a small-scale GPRS/GSM based fisheries vassel monitoring system. *Aquatic Living Resources*, 26: 399-407.

Campbell, R.A. 2015. Constructing stock abundance indices from catch and effort data: some nuts and bolts. *Fisheries Research*, 161: 109-130.

Carton, J.A., Chepurin, G.A., Chen, L. 2018. An updated reanalysis of ocean climate using the Simple Ocean Data Assimilation version 3 (SODA3), manuscript in preparation. (http://www.atmos.umd.edu/~ocean/index_files/soda3_readme.htm).

Casini, M., Cardinale, M., Hjelm, J., Vitale, F. 2005. Trends in cpue and related changes in spatial distribution of demersal fish species in the Kattegat and Skagerrak, eastern North Sea, between 1981 and 2003. *ICES Journal of Marine Science*, 62: 671-682.

Chu-fa, T., Chen, P. Y., Lee, M. A., Hsia, K.Y., Lee, K. T. 1996. Effects of fishing effort on stock larval anchovy in coastal waters Taiwan size and catch of southwestern Taiwan. *Fisheries Research*, 28: 71-83.

Clark, W.G., Hare, S.R. 2002. Effects of climate and stock size on recruitment and growth of Pacific Halibut. *North American Journal of Fisheries Management*, 22: 852-862.

Conover, D., Munch, S.B. 2002. Sustaining fisheries yields over evolutionary time scales. *Science*, 297: 94-96.

Crecco, V., Overholtz, W.J. 1990. Causes of density-dependent catchability for Georges Bank haddock *Melanogrammus aeglefinus*. *Canadian Journal of Fisheries and Aquatic Sciences*, 47: 385-394.

Czerwinski, I.A., Erzini, K., Gutiérrez-Estrada, J.C., Hernando, J.A. 2009. Deep water longline selectivity for black spot seabream (*Pagellus bogaraveo*) in the Strait of Gibraltar. *Fisheries Science*, 79: 285-294.

Czerwinski, I.A., Gutiérrez-Estrada, J.C., Casimiro-Soriguer- Escofet, M., Hernando, J.A. 2010. Hook selectivity models assessment for black spot seabream. Classic and heuristic approaches. *Fisheries Research*, 102: 41-49.

Czerwinski, I.A., Gutiérrez-Estrada, J.C., Hernando-Casal, J.A. 2007. Short-term forecasting of halibut CPUE: Linear and non-linear univariate approaches. *Fisheries Research*, 86: 120-128.

Czerwinski, I.A., Gutiérrez-Estrada, J.C., Soriguer, M.C., Hernando, J.A. 2008. Morphometric relations for body size and mouth dimensions for four fish species in the Strait of Gibraltar. *Acta Ichthyologica et Piscatoria*, 38: 81-90.

Esaias, W.E., Abbott, M.R., Barton, I., Brown, O.B., Campbell, J.W., Carder, K.L., Clark, D.K., Evans, R.H., Hoge, F.E., Gordon, H.R., Balch, W.M., Letelier, R., Minnett, P.J. 1998. An overview of MODIS capabilities for ocean science observations. *IEEE Transactions on Geoscience and Remote Sensing*, 36(4): 1250-1265.

Esteban-Parra M.J., Rodrigo, F.S., Castro-Díez, Y. 1998. Spatial and temporal patterns of precipitation in Spain for the period 1880–1992. *International Journal of Climatology*, 18: 1557-1574.

FAO. 2016. *The State of World Fisheries and Aquaculture (SOFIA)*. Rome, Italy.

Gil, J. 2006. *Biología y pesca del voraz (Pagellus bogaraveo) en el Estrecho de Gibraltar*. PhD Thesis, University of Cádiz, Spain.

Gil, J., Sobrino, I. 2001. Studies on reproductive biology of the red (blackspot) seabream *Pagellus bogaraveo* (Brünnich, 1768) from the Strait of Gibraltar (ICES IXa/SW Spain). *NAFO SCR Doc*. 01/86, Serial No. N4473.

Gillis, D.M., Peterman, R.M., Tyler, A.V. 1993. Movement dynamics in a fishery: application of the ideal free distribution to spatial allocation of effort. *Canadian Journal of Fisheries and Aquatic Sciences*, 50: 323-333.

Gröger, J.P., Fogarty, M.J. 2011. Broad-scale climate influences on cod (*Gadus morhua*) recruitment on Georges Bank. *ICES Journal of Marine Science*, 68: 592-602.

Gutiérrez-Estrada J.C., Silva, C., Yáñez, E., Rodríguez, N., Pulido-Calvo, I. 2007. Monthly catch forecasting of Anchovy *Engraulis ringens* in the north area of Chile: non-linear univariate approach. *Fisheries Research*, 86: 188-200.

Gutiérrez-Estrada, J.C., Gil-Herrera, J., Pulido-Calvo, I., Czerwinski, I.A. 2017. Is it possible to differentiate between environmental and fishery effects on abundance-biomass variation? A case study of blackspot seabream (*Pagellus bogaraveo*) in the Strait of Gibraltar. *Fisheries Oceanography*, 26: 455-475.

Gutiérrez-Estrada, J.C., Yáñez, E., Pulido-Calvo, I., Silva, C., Plaza, F., Bórquez, C. 2009. Pacific sardine (*Sardinops sagax*, Jenyns 1842) landings prediction. A neural network ecosystemic approach. *Fisheries Research*, 100: 116-125.

Haggarty, D.R., King, J.R. 2006. CPUE as an index of relative abundance for nearshore reef fishes. *Fisheries Research*, 81: 89-93.

Harley, S.J., Myers, R., Dunn, A. 2001. Is catch-per-unit-effort proportional to abundance? *Canadian Journal of Fisheries and Aquatic Sciences*, 58: 1760-1772.

Hare, S. R., Francis, R.C. 1995. Climate change and salmon production in the Northeast Pacific Ocean. p. 357–372. In *Climate Change and Northern Fish Populations*, ed. by R. J. Beamish, Canadian Special Publication on Fisheries and Aquatic Science 121.

Hidalgo, M., Massutí, E., Morante, J., Cartes, J., Lloret, J., Oliver, P., Morales-Nin, B. 2008. Seasonal and short spatial patterns in European hake (*Merluccius merluccius* L.) recruitment process at the Balearic Islands (western Mediterranean): The role of environment on distribution and condition. *Journal of Marine Systems*, 71: 367-384.

Hothorn, T., Zeileis, A., Farebrother, R.W., Cummins, C., Millo, G., Mitchell, D. 2017. *Lmtest: Testing Linear Regression Models. R Package* (https://CRAN.R-project.org/package=lmtest).

Hurrell, J., National Center for Atmospheric Research Staff (Eds). Last modified 17 Nov 2017. *The Climate Data Guide: Hurrell North Atlantic Oscillation (NAO) Index* *(station-based)*. Retrieved from https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based.

Hutchings, J.A., Myers, R.A. 1994. What can be learned from the collapse of a renewable resource? Atlantic cod, *Gadus morhua*, of Newfoundland and Labrador. *Canadian Journal of Fisheries and Aquatic Sciences*, 51: 2126-2146.

Huertas, I.E., Ríos, A.F., García-Lafuente, J., Makaoui, A., Rodríguez-Gálvez, S., Sánchez-Román, A., Orbi, A., Ruíz, J., Pérez, F. 2009. Anthropogenic and natural CO2 exchange through the Strait of Gibraltar. *Biogeosciences*, 6: 647-662.

Hyndman, R., O´Hara, M., Bergmeir, C., Razbash, S., Wang, E. 2017. *Forecast: Forecasting Functions for Time Series and Linear Models. R Package* (https://CRAN.R-project.org/package=forecast).

Hyndman, R.J., Khandakar, Y. 2008. Automatic time series forecasting: The forecast package for R. *Journal of Statistical Software*, 26(3):1-22.

Jiménez-Toribio, R., García-del-Hoyo, J.J. 2006. Evidence of market Price leadership in the Spainsh red seabream value chain. Implications for fisheries management. *Fisheries Research,* 81**:**51-59.

Kane, J. 2011. Inter-decadal variability of zooplankton abundance in the Middle Atlantic Bight. *Journal of the Northwest Atlantic Fishery Science*, 43: 81-92.

Kennedy, J., Jónsson, S.P. 2017. Do biomass indices from Icelandic groundfish surveys reflect changes in the population of female lumpfish (*Cyclopterus lumpus*)? *Fisheries Research*, 194: 22-30.

Kitanidis, P.K., Bras, R.L. 1980. Real time forecasting with a conceptual hydrological model. 2. Applications and results. *Water Resources Research*, 16: 1034-1044.

Lehodey, P., Alheit, J., Barange, M., Baumgartner, T., Beaugrand, G., Drinkwater, K., Fromentin, J.M., Hare, S.R., Ottersen, G., Perry, R.I., Roy, C., van der Lingen, C.D., Werneri, F. 2006. Climate variability, fish and fisheries. *Journal of Climate*, 19: 5009-5030.

Lorance, P., Dupouy, H. 2001. CPUE abundance indices of the main target species of the French depp-water fishery in ICES Sub-areas V-VII. *Fisheries Research*, 51: 137-149.

Malta, T., Santos, P.T., Santos, A.M.P., Rufino, M., Silva, A. 2016. Long-term variations in Ibero-Atlantic sardine (*Sardina pilchardus*) population dynamics: Relation to environmental conditions and exploitation history. *Fisheries Research*, 179: 47-56.

Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J. M., Francis, R. C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of American Meteorology Society, 78: 1069-1079.

Meiners-Mandujano, C.G. 2007. Importancia de la variabilidad climática en las pesquerías y biología de la merluza europea *Merluccius merluccius* (Linnaeus, 1758) de la costa Noroccidental Africana. PhD Thesis, Barcenona, Spain.

Mora, C., Myers, R.A., Coll, M., Libralato, S., Pitcher, T.J., Sumaila, R.U., Zeller, D., Watson, R., Gaston, K.J., Worm, B. 2009. Management effectiveness of the world's marine fisheries. *PLoS Biology*, 7 (6): e1000131.

Okemwa, G.M., Kaunda-Arara, B., Kimani, E.N., Ogutu, B. 2016. Catch composition and sustainability of the marine aquarium fishery in Kenya. *Fisheries Research*, 183: 19-31.

Paloheimo, J.E., Dickie, L. M. 1964. Abundance and fishing success. *Rapports et Procès-verbaux des Réunions du Conseil International pour Exploration de la Mer*, 155: 152-163.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., Zeller, D. 2002. Towards sustainability in world fisheries. *Nature*, 418: 689-695.

Perreti, C.T., Fogarty, M.J., Friedland, K.D., Hare, J.A., Lucey, S.M., McBride, R.S., Miller, T.J., Morse, R.E., O'Brien, L., Pereira, J.J., Smith, L.A., Wuenschel, M.J. 2017. Regime shifts in fish recruitment on the Northeast US Continental Shelf. *Marine Ecology Progress Series*, 574: 1-11.

Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D. 2005. Climate change and distribution shifts in marine fishes. *Science*, 308: 1912-1915.

Pitois, S.G., Jansen, T., Pinnegar, J. 2015. The impact of environmental variability on Atlantic mackerel *Scomber scombrus* larval abundance to the west of the British Isles. *Continental Shelf Research*, 99: 26-34.

Powers, J.E., Abeare, S. M. 2009. Fishing effort redistribution in response to area closures. *Fisheries Research*, 99: 216-225.

Pyper, B. J., Peterman, R. M. 1999. Relationship among adult body length, abundance, and ocean temperature for British Columbia and Alaska sockeye salmon (*Oncorhynchus nerka*), 1967-1997. *Canadian Journal of Fisheries and Aquatic Sciences*, 56: 1716-1720.

Ramírez-Romero, E., Macías, D., García, C.M., Bruno, M. 2014a. Biogeochemical patterns inthe Atlantic inflow through the Strait of Gibraltar. *Deep Sea Research Part I: Oceanographic Research Papers*, 85: 88-100.

Ramírez-Romero, E., Vichi, M., Castro, M., Macías, J., Macías, D., García, C.M., Bruno, M. 2014b. Modeling the biogeochemical seasonal cycle in the Strait of Gibraltar. *Journal of Marine Systems*, 139: 348-361.

Ruggerone, G.T., Zimmermann, M., Myers, K.W., Nielsen, J.L., Rogers, D.E. 2003. Competition between Asian pink salmon (*Oncorhynchus gorbuscha*) and Alaskan sockeye salmon (*O. nerka*) in the North Pacific Ocean. *Fisheries Oceanography*. 123: 209-219.

Ruíz, J., García-Isarch, E., Huertas, E., Prieto, L., Juárez, A., Muñoz, J.L., Sánchez La-Madrid, A., Rodríguez, S., Naranjo, J.M., Baldó, F., 2006. Meteorological and oceanographic factors influencing *Engraulis encrasicolus* early life stages and catches in the Gulf of Cádiz. *Deep Sea Research II,* 53 (11–13): 1363-1376.

Safina, C., Rosenberg, A.A., Myers, R.A., Quin ll, T.J., Collie, J.S. 2005. U.S. ocean fish recovery: staying the course. *Science*, 309: 707-708.

Santos, A.M.P., Borges, M.F., Groom, S. 2001. Sardine and horse mackerel recruitment and upwelling off Portugal. *ICES Journal of Marine Science*, 58(3): 589-596.

Santos, M.B., González-Quirós, R., Riveiro, I., Cabanas, J.M., Porteiro, C., Pierce, G.J. 2012. Cycles, trends, and residual variation in the Iberian sardine (*Sardina pilchardus*) recruitment series and their relationship with the environment. *ICES Journal of Marine Science*, 69: 739-750.

Scheffer, M., Carpenter, S., Foley, J.A., Folke, C., Walker, B. 2001. Catastrophic shifts in ecosystems. *Nature*, 413: 591-596.

Swain, D.P., Wade, E.J. 2003. Spatial distribution of catch and effort in a fishery for snow crab (*Chionoecetes opilio*): tests of predictions of the ideal free distribution. *Canadian Journal of Fisheries and Aquatic Sciences*, 60: 897-909.

Thompson, D.W.J., Wallace, J.M. 2000. Annual modes in the extratropical circulation. Part II: Trends. *Journal of Climate*, 13: 1018-1036.

Torralba, J., Besada, M. 2015. A stochastic model for the Iberoatlantic sardine fishery. Global warming and economic effects. *Ocean and Coastal Management*, 114: 175-184.

Trapletti, A., Hornik, K., LeBaron, B. 2017. *Tseries: Time Series Analysis and Computational Finance. R Package* (https://cran.r-project.org/web/packages/tseries/).

Tupper, M.H. 2002. Marine reserves and fisheries management. *Science*, 295: 1233-1235.

Ullah, H., Leitão, F., Baptista, V., Chícharo, L. 2012. An analysis of the impacts of climatic variability and hydrology on the coastal fisheries, *Engraulis encrasicolus* and *Sepia officinalis*, of Portugal. *Ecohydrology & Hydrobiology*, 4: 337-352.

Yáñez, E., Plaza, F., Gutiérrez-Estrada, J.C., Rodríguez, N., Barbieri, M.A., Pulido-Calvo, I., Bórquez, C. 2010. Anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) abundance forecast off northern Chile: A multivariate ecosystemic neural network approach. *Progress in Oceanography*, 210: 242-250.

Table 1. Parameters used in the different scenarios (Sce). In all cases the number of age classes ranged from 15 to 20 [with 1 in 1 increments]. The biomass of the case of age 0+ at time t=0 ranged from 20 to 45 t [with increments of 5 in 5 t]. A stock-recruitment relationship with compensatory effects of mortality (Ricker type; parameters *a* and *b*) and a class to class ratio of natural mortality of linear type were assumed in all scenarios.

	Sce.1	**Sce.2**	**Sce.3**	**Sce.4**	**Sce.5**	**Sce.6**	**Sce.7**
a	0.02	0.02	0.02	0.015	0.015	0.015	0.02
b	0.002	0.002	0.002	0.002	0.002	0.002	0.0025
January spawn	100%	60%	60%	100%	60%	60%	100%
February spawn	0%	40%	30%	0%	40%	30%	0%
March spawn	0%	0%	10%	0%	0%	10%	0%

Table 2. Parameters and error measures of the best ARIMA $(p,d,q)(P,D,Q)^S$ models in each scenario. In all cases S=12. M is natural mortality. The best result in bolt

Scenario	**Model**	**Age Classes**	**Biomasa Inicial (t)**	***M***	***p***	***d***	***P***	***D***	**MAE (kg)**	**%SEP**	**PI**
1	2	16	37.500	0.226	2	1	1	1	13016.565	68	0.868
2	**1**	**15**	**44.166**	**0.216**	**2**	**2**	**1**	**1**	**15426.223**	**60**	**0.876**
3	1	15	43.666	0.255	2	1	1	1	13662.725	61	0.809
4	1	15	31.551	0.236	2	1	1	1	10256.194	82	0.826
5	2	16	29.375	0.222	2	1	2	1	11118.512	81	0.784
6	2	16	25.000	0.215	2	1	2	1	11843.690	87	0.725
7	1	15	37.083	0.252	2	1	1	1	10388.093	80	0.834

FIGURE CAPTIONS

Figure 1. a) Time series (1983-2016) of blackspot seabream landings considering the ports of Tarifa, Algeciras, Ceuta, Conil and Tangier; b) Percentage contribution by port and year to blackspot seabream landings.

Figure 2. Time series of blackspot seabream biomass in the Strait of Gibraltar in 7 different scenarios. Each curve is the average of the simulations selected according to the criteria established in this work. The grey continuous line represents the absolute variation as well as the annual moving average of landings.

Figure 3. Temperature anomaly as a function of depth. Each sector is the average temperature of an area between 35º-37.5º N and 6.5º-5º W. The time series of the average biomass ± 95% confidence limits of model 1 scenario 2 (blue) and model 2 scenario 5 (green) is shown.

Figure 4. Salinity anomaly as a function of depth. Each sector is the average salinity of an area between 35º-37.5º N and 6.5º-5º W. The time series of the average biomass ± 95% confidence limits of model 1 scenario 2 (blue) and model 2 scenario 5 (green) is shown.

Figure 5. Linear spatio-temporal correlation between the residuals (above black line) of the ARIMA(2,2,0)(1,1,0)^{12} model fit (model 1 scenario 2) and the temperature anomaly. Serial delay=0.

Figure 6. Linear spatio-temporal correlation between the residuals (above black line) of the ARIMA(2,1,0)(2,1,0)^{12} model fit (scenario 5 model 2) and the salinity anomaly. Serial delay=0.

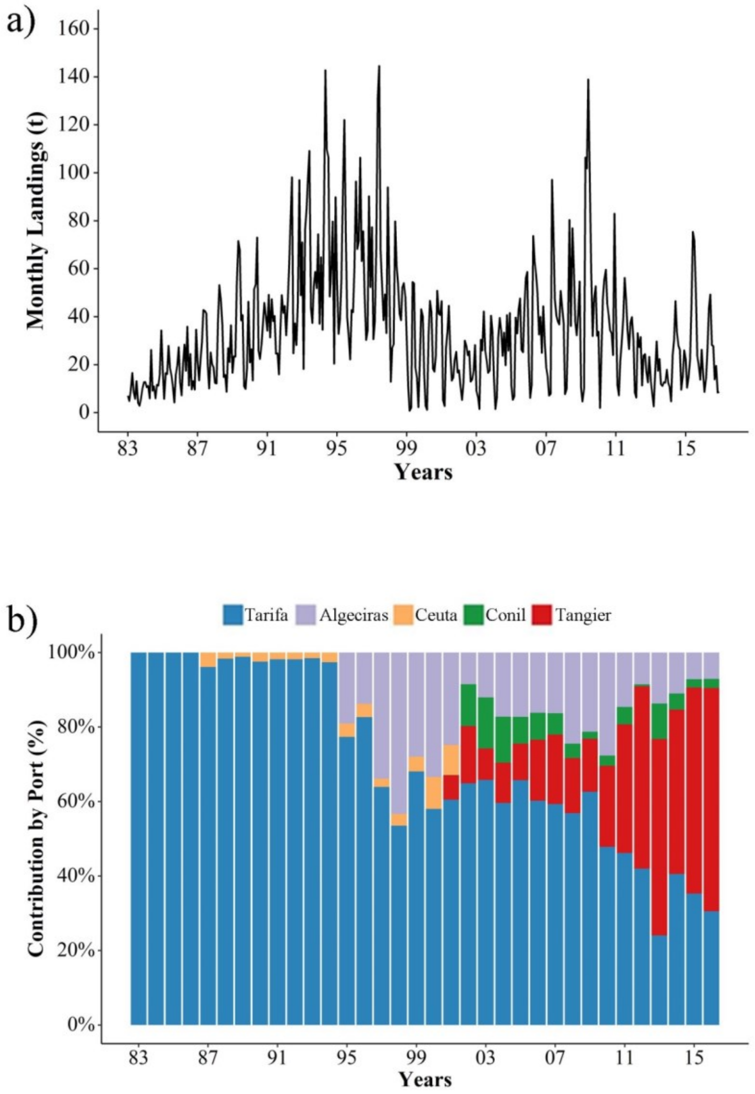
a)
Monthly Landings (t)
0
20
40
60
80
100
120
140
160
83
87
91
95
99
03
07
11
15
Years
b)
Tarifa
Algeciras
Ceuta
Conil
Tangier
Contribution by Port (%)
0%
20%
40%
60%
80%
100%
83
87
91
95
99
03
07
11
15
Years

Figure 1

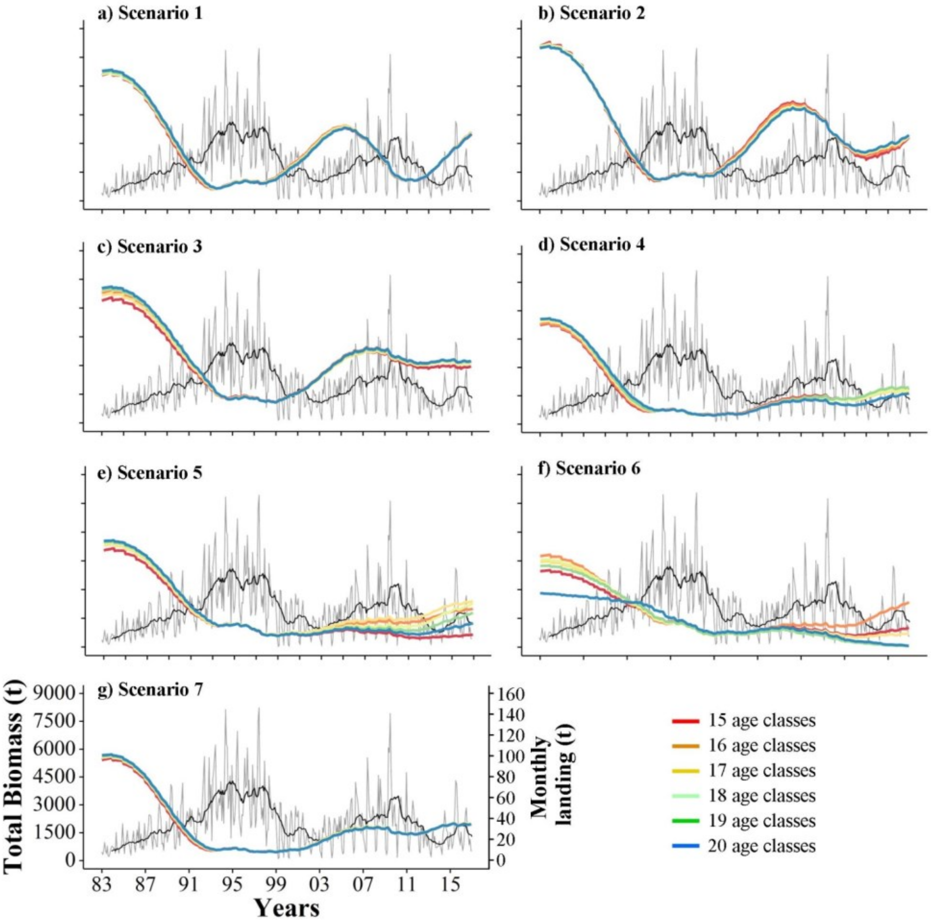
a) Scenario 1
b) Scenario 2
c) Scenario 3
d) Scenario 4
e) Scenario 5
f) Scenario 6
g) Scenario 7
Total Biomass (t)
9000
7500
6000
4500
3000
1500
0
Monthly landing (t)
160
140
120
100
80
60
40
20
0
83
87
91
95
99
03
07
11
15
Years
15 age classes
16 age classes
17 age classes
18 age classes
19 age classes
20 age classes

Figure 2

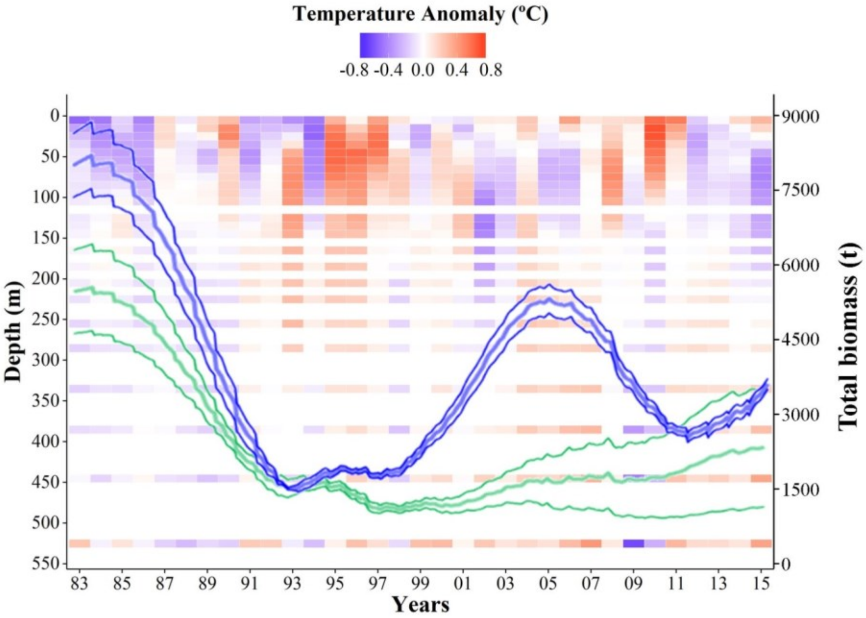
Temperature Anomaly (ºC)
-0.8 -0.4 0.0 0.4 0.8
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
550
Total biomass (t)
9000
7500
6000
4500
3000
1500
0
83
85
87
89
91
93
95
97
99
01
03
05
07
09
11
13
15
Years

Figure 3

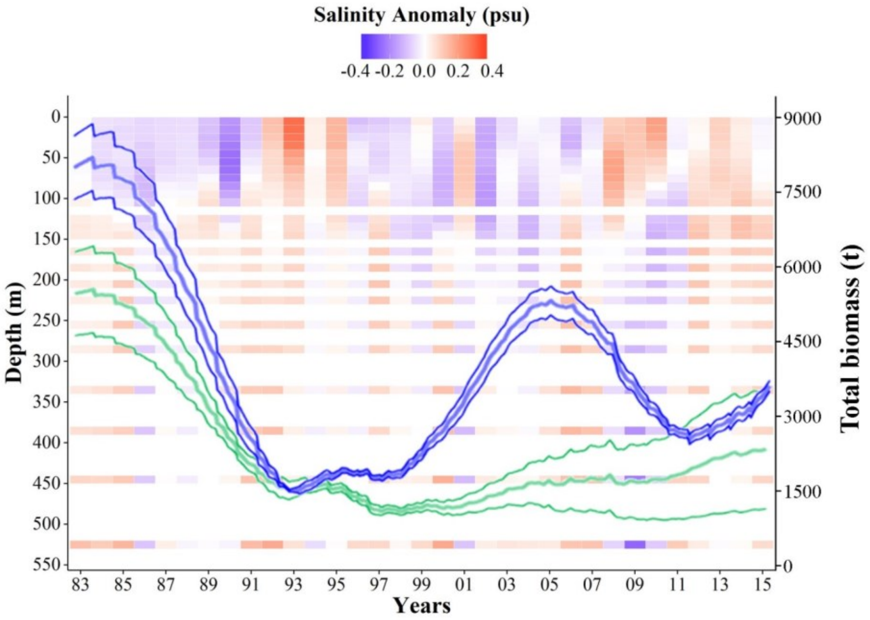
Salinity Anomaly (psu)
-0.4 -0.2 0.0 0.2 0.4
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
550
Total biomass (t)
9000
7500
6000
4500
3000
1500
0
83
85
87
89
91
93
95
97
99
01
03
05
07
09
11
13
15
Years

Figure 4

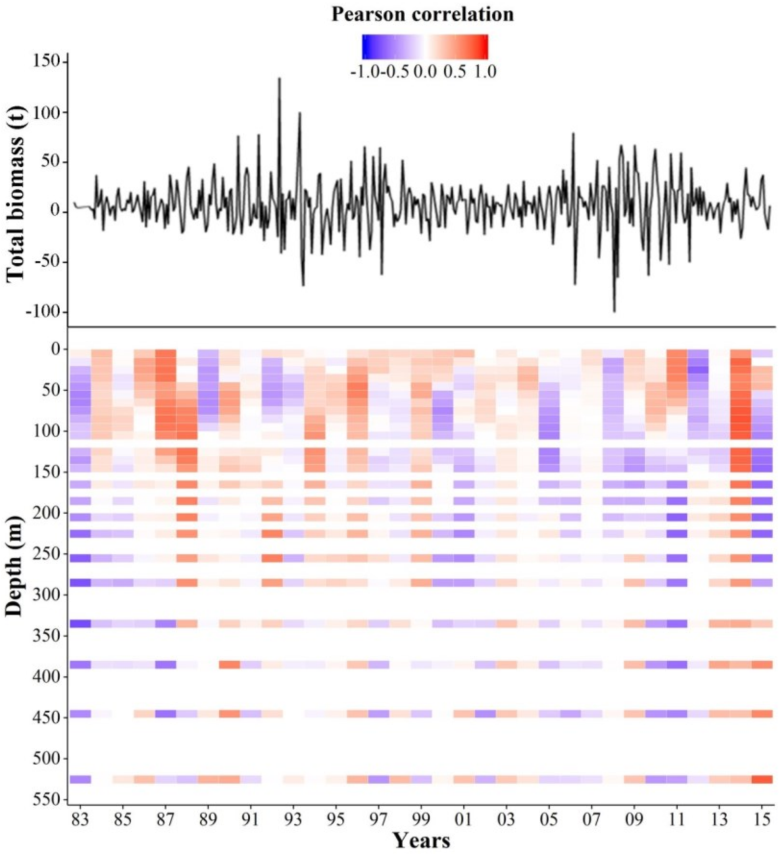
Pearson correlation
-1.0 -0.5 0.0 0.5 1.0
Total biomass (t)
150
100
50
0
-50
-100
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
550
83
85
87
89
91
93
95
97
99
01
03
05
07
09
11
13
15
Years

Figure 5

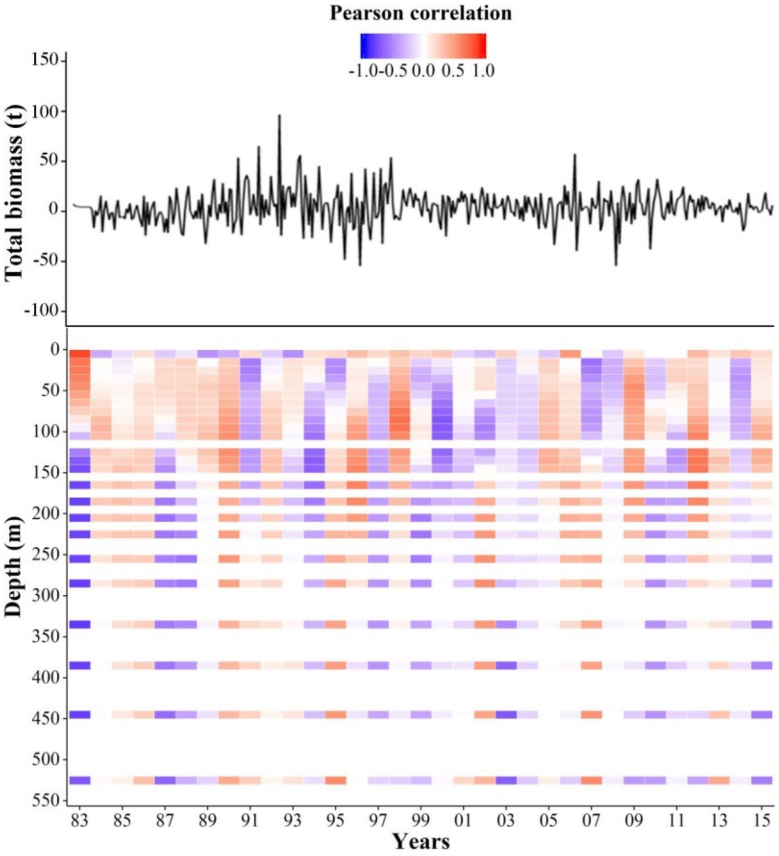
Pearson correlation
-1.0
-0.5
0.0
0.5
1.0
Total biomass (t)
150
100
50
0
-50
-100
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
550
83
85
87
89
91
93
95
97
99
01
03
05
07
09
11
13
15
Years

Figure 6