Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 28(1): 301 – 322 (2024)
www.ejabf.journals.ekb.eg

Relationship Between Environmental Factors Changes and Anchovy Landing (*Engraulis encrasicolus*) in the South Alboran Sea

Ayman JGHAB[1, 2, 3], B. El Moumni[2], A. Reul[1], M. Vargas-Yáñez[4], M. Carmen García-Martínez[4], J. Chioua[3], F.Moya[4], S. El Arraf[3], M. Muñoz[1]

[1]Departamento de Ecología y Geología, Facultad de Ciencias, Universidad de Málaga, Campus Universitario de Teatinos, s/n, 29071 Málaga, Spain
[2]University of Abdelmalek Essaadi, Morocco
[3]National Fisheries Research Institute, Morocco
[4]Centro Oceanográfico de Málaga. Instituto Español de Oceanografía-Consejo Superior de Investigaciones Científicas (IEO-CSIC), Spain

[*]Corresponding Author: jghabayman@gmail.com

ARTICLE INFO

Article History:
Received: April 5, 2023
Accepted: Dec. 27, 2023
Online: Jan. 21, 2024

Keywords:
Anchovy,
Small pelagic,
Environmental factors,
Purse seine,
GLM,
South Alboran Sea

ABSTRACT

In the Mediterranean, one of the most prized small pelagic species is the European anchovy (*Engraulis encrasicolus*). This species has long been targeted by fishermen in the southern Alboran Sea and the Mediterranean Sea. The objective of this research was to identify any linkages that may exist between environmental changes in the southern Alboran Sea and the reported drop in anchovy landings between 1983 and 2020. The method of forward stepwise regression was used, taking into account environmental indicators, such as sea surface salinity (SSS), sea surface temperature (SST), surface chlorophyll a (Chl-a), U and V wind components, NAO index, and Atlantic jet velocity. To select the best prediction models, generalized linear models (GLMs) were created and organized based on their corrected akaike information criteria (AICc) values. Trended time data were used to create six top models, which explained 60 to 79% of the variation in anchovy landings. Temperature, salinity, and the U wind component all displayed a negative association with anchovy landings. On the other hand, the Atlantic jets' velocity as they traveled through the Strait of Gibraltar was positively correlated with anchovy landings. When the trend component was taken out; however, none of the environmental variables could explain the variations in anchovy landings. This may imply that while environmental influences have an effect over the long term, they have little effect on the inter-annual time scale. Hence, the decline in landings of this species may be due to factors other than environmental change. Overfishing may have played a substantial role in the long-term decline in landings since this species was the most targeted of the small pelagic species in the study area.

INTRODUCTION

The Mediterranean is known for its heavily populated coastal regions, which result in high levels of human pressure, especially extractive fishing. The effects of various human pressures on the environment, ecosystems, and living resources of the Mediterranean Sea, as well as their eventual effects on the fisheries sector, have been documented since the 1980s and 1990s (**FAO, 2020a)**. In fact, the Mediterranean, which has been named the most overexploited FAO fishery region in the world, has 78% of its stocks fully exploited. The Mediterranean is also more susceptible to stresses or environmental changes than other regions since it is a semi-enclosed sea **(Sherman & Adams, 2010; FAO, 2018)**.

Environmental threats, such as plastic pollution, ghost fishing, and the various impacts of climate change, which include overall warming of the ocean, more frequent warming of the upper ocean by extreme heat or cold events, the dry period increases and the river inflow decreases **(FAO, 2020a)**. Climate change and cascading effects along the trophic food web can affect the fishery, where small pelagic fish as an important link between planktonic and greater sized fishes occupies a key role **(Shannon *et al.*, 2004; Costalago *et al.*, 2014; Garrido & Van der Lingen, 2014)**. Furthermore, small pelagic fishes contribute significantly to the amount of protein extracted to feed the world population. One of the main target species are anchovies, being the most commercialized species in the world. In the Mediterranean, anchovies represent 18% of the total catches, and the European anchovy (*Engraulis encrasicolus*) is the most fished species among them **(FAO, 2020b).**

In the socio-economic framework, the fishing sector plays a very important role for the Moroccan Mediterranean, and purse seine fishing is one of the main fishing activities in this region, along with the Atlantic region **(INRH, 2019; Darasi *et al.*, 2020)**. This fishery mainly targets small pelagic species. This activity employs more than 3,000 fishermen in about 110 active purse seiners and generates an annual turnover of about 86 million dirhams **(INRH, 2019)**. The anchovy fishery (*Engraulis encrasicolus*) was the flagship activity of this fishery, but has experienced a drastic decrease since 1983 to reach a critical level in 2020 in the Moroccan Mediterranean, despite the fact that the catch of this species has experienced a relative increase on the other side of the western Mediterranean (Spanish shore) **(GFCM, 2018)**.

While fishery activity may have most affected these species, environmental factors changes might also affect the abundance of these species. Especially for species with a seasonal reproduction triggered by environmental conditions. The development and maturation phases are synchronized with seasonal changes in climate **(Sumpter, 1990)**. This coordination ensures that the offspring are produced when the environmental conditions are most suitable for larval survival. This annual rhythm is controlled by exogenous factors that are difficult to quantify. However, the main parameters are water temperature, photoperiod, and presence of spawning substrate, water height or depth, and interactions **(Craig, 1987)**.

In the case of anchovy, temperature is the most important environmental factor triggering spawning. The thermal margin within which anchovy spawning takes place is at ranges from 15 to 24°C. It is wider than for the sardine, and the optimum is also narrower, between 18 and 23°C **(Furnestin, 1959; Fernández-Corredor *et al.*, 2021; Lima *et al.*, 2022)**.

With regard to salinity, numerous authors have discussed its impact on the reproduction and migration of the sardine and the anchovy. However, concerning anchovy, salinity has a minor impact since the anchovy frequents both strongly salted and more diluted waters. In fact, different species of anchovy tend to spawn in areas of river flow where salinity is low; for this purpose, more study should be conducted on the influence of this environmental factor **(Furnestin, 1959; Sabatés, 1990)**.

Marchesiello *et al.* (2004) postulated that upwelling areas are a highly dispersive environment where nutrients, phytoplankton, zooplankton, and meroplankton can be rapidly swept away from coastal areas. Therefore, small pelagic fish in general, and anchovy in particular tend to flee from upwelling areas during spawning. **Roy (1992)** and **Kuyawa *et al.* (1997)** estimated that larval survival is mainly related to high food concentration rather than to temperature in the spawning areas.

Although the diet of anchovies varies (mostly consisting of crustaceans, phytoplankton, polychaetes, mollusks, fish eggs, and scales) **(El Qendouci *et al.*, 2018; El-Beltagy *et al.*, 2022)**. Food supply exerts a significant impact on larval survival **(Theilacker *et al.*, 1986)**, and adult stock **(Carrera & Porteiro, 2003)**.

Thus, environmental changes such as increasing SST causing stronger thermal stratification, which might decrease primary production, could cause decreasing anchovy landings due to decreasing food availability **(Calvo *et al.*, 2011)**.

With the aim to describe the most important environmental factors triggering anchovy landings in the southern Alboran Sea, we presented the relationship between environmental factors changes and caught anchovy (*Engraulis encrasicolus),* using anchovy landing data of Morocco, and environmental data retrieved from public databases and satellite server.

MATERIALS AND METHODS

Data and methods

1- Study area

This study was conducted in the South Alboran Sea, (south western Mediterranean Sea, longitude: 6,20 W ; 2. and latitude 35 N ; 36,5 N). This zone encompasses four main small pelagic fishery landing ports of the Mediterranean Moroccan coast: M’diq, Al Hoceima, Nador and Ras Kebdana) (Fig. 1).

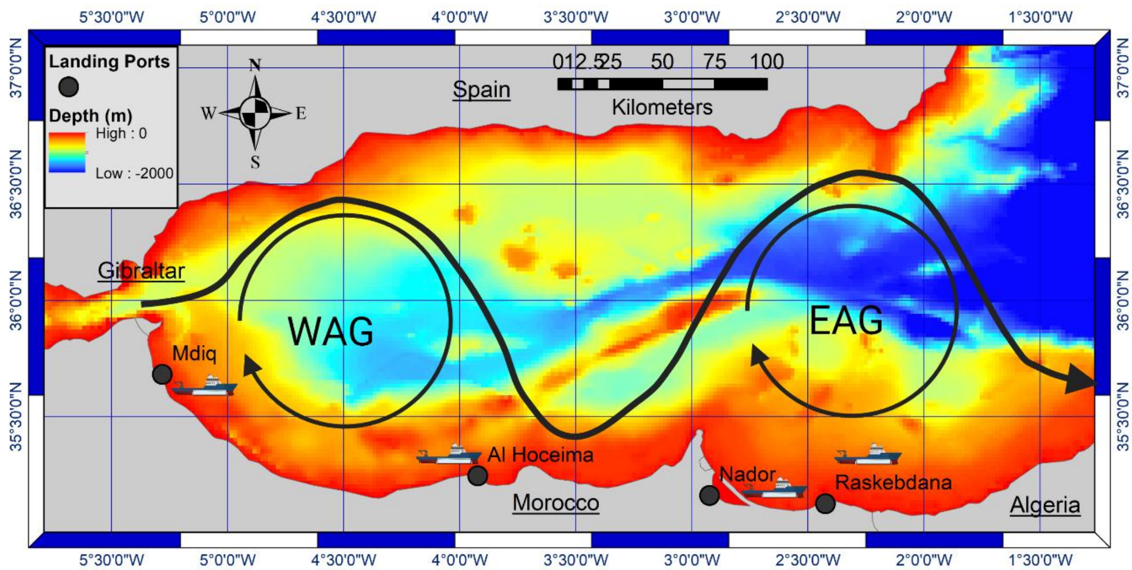

Fig. 1. Bathymetry, main circulation pattern and most important small pelagic fishery landing ports along the Moroccan coast (south Alboran Sea)

2- Catch data

Anchovy historical landings from 1983 to 2020 data were obtained from the National Office of Fisheries, while landing per unit effort (LPUE) was calculated from 2009 to 2020 using formula I:

$$\text{(I)} \qquad LPUE = \frac{Landing\ (in\ tonnes)}{Fishing\ effort\ (fishing\ days)}$$

Since daily landings data are only available starting in 2009, LPUE could only be estimated from that year.

The principal small pelagic fishing ports of M'diq, Al hoceima, Nador, and Al Ras Kebdana were used in this study. This study considered both monthly and yearly anchovy landing time series. The yearly time series were calculated as the sum of the monthly average of each year.

Several studies have demonstrated that catch landing data and LPUE are reliable indicators of the quantity of small pelagic fish in the fishing ground **(Thiaw *et al.*, 2017; Jghab *et al.*, 2019; Vargas- Yáñez *et al.*, 2020)**. Therefore, LUPE can be employed to estimate the abundance of the target species.

Nevertheless, in this study area, the anchovy catches and effort statistics are accessible since 2009. This dramatically shortens the time series under analysis and makes it difficult to draw conclusions about the correlations between environmental factors. The available time series would be longer if landings were used instead of LPUE, however shifts in sardine landings might just be the result of shifting fishing effort and not actually reflect shifts in stock abundance. If landing data are highly linked with LPUE data and no significant change in fishing activity is noted, landing data may be utilized as a proxy for abundance data to extend the time series **(Hidalgo *et al.*, 2011; Ruiz *et al.*, 2017; Thiaw *et al.*, 2017; Jghab *et al.*, 2019)**.

In order to get a longer time series, we conducted a regression analysis between landings and LPUE on the annual and monthly time series (Fig. 2). The results supported that LUPE can be estimated from landing data for annual data (R^2= 0.61, P< 0.05), and monthly inter-annual variation (R^2= 0.75, P< 0.05) (Fig. 2). Similar significant relationships have been previously described **(Guisande *et al.*, 2004; Vargas-Yáñez *et al.*, 2017; Guisande *et al.*, 2019; Jghab *et al.*, 2019)** in the study region, and in Vigo (Iberian Atlantic Coast), and Tarragona (NW Mediterranean) **(Lloret *et al.*, 2004)**.

As a result, we estimated anchovy abundance and used anchovy landings as a proxy for LPUE data in this study.

3- Environmental data

The environmental factors taken into account in this work that may have an impact on anchovy occurrence, recruitment, and dispersion comes from a variety of sources. Sea surface temperature (SST), sea surface salinity (SSS), sea surface chlorophyll-a concentration (Chl-a), west-east (U), south-north (V) current component, and north Atlantic oscillation (NAO) are all taken into consideration as variables. From 5.5°W to 2°W and from 35°N to 3°N, the SST, SSS, and Chl-a data were averaged over the southern Alborán Sea.

The daily sea surface temperature data from NOAA's high-resolution SST data on the NOAA/OAR/ESRL PSD were downloaded from 1981 to 2020 **(Reynolds *et al.*, 2007)**. This dataset has a spatial resolution of 0.25° 0.25°. Data on salinity was obtained from the Copernicus Maritime Environmental Monitoring Service range from 1987 to 2020 **(Simoncelli *et al.*, 2014)**. This dataset has a resolution of 0.063° 0.063°. Moreover, daily chlorophyll data were downloaded from the Copernicus website for the period of 1997 to 2020 **(Volpe *et al.*, 2012)**. On the NOAA/OAR/ESRL PSD website in Boulder, Colorado, USA, daily wind data with a resolution of 2.5° 2.5° (u, west-east, and v, south-north components) were obtained from NCEP reanalysis **(Kalnay *et al.*, 1996)**.

Using a regular grid, the monthly and yearly averages of SST, SSS, and surface Chl-a were calculated. Grid sites between 5.5°W and 2°W and south of 36°N were chosen, and annual averages were taken to depict changes in variables affecting the southern Alboran Sea. In this manner, the South Alboran Sea's annual time series for SST, SSS, and Chl-a were obtained.

There are no long-term time data for the Atlantic Jet Velocity (AJ). According to **Garcia-Lafuente *et al.* (1998)** and **Vargas- Yáñez *et al.* (2002)**, it can be assumed that the sea level differential between AJ and both sides of the strait is in geostrophic equilibrium to get around this restriction, following formula (II):

$$\text{(II)} \qquad u = g\Delta\xi/fL$$

Where, L is the cross-strait distance; u is the Atlantic current velocity component through the strait; g is the gravitational acceleration (9.8ms-2); f is the Coriolis parameter at 36°N latitude (8.510-5 s-1), and Δξ is the difference in sea level between Algeciras and Ceuta. According to this formula, the difference in sea level between Algeciras and Ceuta can be used as a reliable predictor of variations in flow velocity. The tide network of the Permanent Service for Mean Sea Level Difference (SLD) and the Spanish Institute of Oceanography is the source of the monthly sea level time series for Algeciras and Ceuta (www.psmsl.org). From 1981 to 2018, a monthly time series of strait sea level variations was created.

Finally, the National Center for Atmospheric Research provided winter (December–March) and yearly NAO indices for this purpose.

4- Modeling

4.1 Exploratory data analysis

The majority of the aforementioned environmental data has an impact on the distribution, growth, and captures of this species. To maintain the degree of freedom in the analysis, generalized linear models (GLM) should not combine many predictive variables, and their number should be as small as possible **(Burnham & Anderson, 2002)**. The best potential significant predictors were chosen using scatterplots and cross correlation analysis. SST, SSS, CHL-A, SLD, U wind, and V wind components were all examined. Anchovy mean catches were regressed on these prospective factors, and variables that showed correlation significance at the 0.05 level were thought to be viable predictor variables for the GLM models. Other predictors with significance levels higher than 0.1 were eliminated from the study.

4.2 Modeling time series

The prospective predictors were subjected to a forward stepwise analysis in order to determine the best linear models; the anchovy landing were modeled according to formula (III):

$$\text{(III)} \qquad L\,(t) = \sum_{i=0}^{k} \quad \alpha_i \times P_i(t) + \sum_{j=0}^{k} \quad \beta_j \times P_j(t-1) + \ \beta \ + \epsilon(t)(1)$$

Where, Pi are predictors with no time lag and Pj are with a one-year lag; α and β are the coefficients; L is the landing of anchovies, and t is the time of years: here is missing something (SST, CHL-A, SLD, SSS, Uwind, Vwind, SLD, NAO). Random variables that reflect errors are ∑(t).

A *P*-value of 0.05 probability was used to add a new predictor to the model, while a *P*-value of 0.1 was used to remove it from the model. The forward stepwise approach involves calculating the partial F for each predictor at each stage **(Draper & Smith, 1981)**.

4.3.1 Modeling complete time series

The whole time series (initial year-final year) were used for this initial model selection and analysis, and no trend was discarded **(Vargas- Yáñez *et al.*, 2009; Vargas- Yáñez *et al.*, 2017, Jghab *et al.*, 2019)**. The following technique was used to choose the best models: one year of the time series (including the response and predictors) was suppressed. The remaining n-1 data were subjected to a multiple linear regression. Partial F-values were obtained for each predictor at each step of a forward stepwise method. Predictors with a F< 0.05 were included, and predictors with a F > 0.1 were excluded from the model.

The forward stepwise regression chooses a different model for each stage and is taken into consideration as a candidate model. Only the significant predictors had been chosen at the conclusion of the stepwise regression, and a collection of candidate models had been produced by using a multiple linear regression. According to **Burnham and Anderson (2002)**, the AICc (Corrected Akaike Information Criteria) were calculated to determine the optimum model. The candidate model with the lowest AICc was chosen as the best model. Then, a cross-validation approach was used to validate the final model **(Francis, 2006; Lavin *et al.*, 2007; Vargas- Yáñez *et al.*, 2009; Jghab *et al.*, 2019)**.

The remaining n-1 data were used to estimate the anchovy landings for each year in the time series using the chosen model. The default estimate, which was considered to be the average value of the time series, was compared to the prediction (using the n-1 data for the estimation). The percent variation explained (PVE) by the model (formula IV) can be used to evaluate the model's confidence:

$$\text{(IV)}\, PVE = \frac{(MSE\ default - MSE\ model)}{MSE\ default}$$

The mean squared error (MSE) indicates how much better the model performs than the baseline forecast. As the time series were not de-trended at this level, there are correlations between the anchovy landing and predictors on both an inter-annual and a long-term scale.

4.3.2 Modeling de-trended time series

4.3.2.1 Linear trends

Using the least squares fit method, a straight line was fitted to the times series of the environmental predictor and anchovy landings. The slope shows the average annual change rate. After ensuring that the residuals distributions were normal, a confidence interval at the 95% confidence level for the slope was calculated. This was done to determine the significance of the trend (Kolmogorov-Smirnov tests) **(Zar, 1984)**.

Using formula (V), the anchovy landing and the environmental potential predictors were de-trended:

$$\text{(V)} \qquad A(t) = \alpha 0 + \alpha 1 t + Za(t)$$

Following this, the de-trended anchovy landing was modeled according to formula (VI):

$$\text{(VI)} \qquad Za = \sum_{i=1}^{k} \alpha_i \times Z_{i\,(t)} + \alpha_i \times Z_{i\,(t-1)} + \epsilon_{(t)}$$

Where, Za is the de-trended anchovy and $\alpha 1$ and $\alpha 0$ are the slope and intercept. Zi stands for the time series of de-trended predictors, αi for the regression coefficient, and ϵ for the residual errors.

The slope, R-square, and *P*-value for each predictor variable and anchovy landing are displayed in Table (1) at 95% confidence intervals.

Table 1. Slope, linear trends intercept, explained variance (R^2) and *P*-value for the variables with statistically significant linear trends. (ANCH is Anchovy landing, and ACHMEAN is the yearly average of anchovy landing)

Value	Intercept	Slope	R^2	*P*-value
SST	-32.7838	0.02581	0.6217	<0.001
SAL	23.5619	0.00638	0.4756	<0.001
CHLA	-11.7822	0.00601	0.4221	<0.001
UWIND	-39.1741	0.01970	0.1362	<0.05
VWIND	-31.2058	0.01519	0.4463	<0.001
NAO	26.7379	-0.01294	0.0337	0.269
ANCH	555729.525	-275.7737	0.6726	<0.001
ANCHMEAN	41500.2455	-20.5691	0.62944	<0.001
SLD	3668.4212	-1.8245	0.4799	<0.001

RESULTS

1.Time series analysis

The estimation of LPUE from landing data was validated by the results of the linear regression between landing (tons) and LPUE. The regression was significantly correlated for yearly variation (R2= 0.61, *P*< 0.05), and highly correlated for monthly inter-annual variation (R2= 0.75, *P*< 0.05) (Fig. 2).

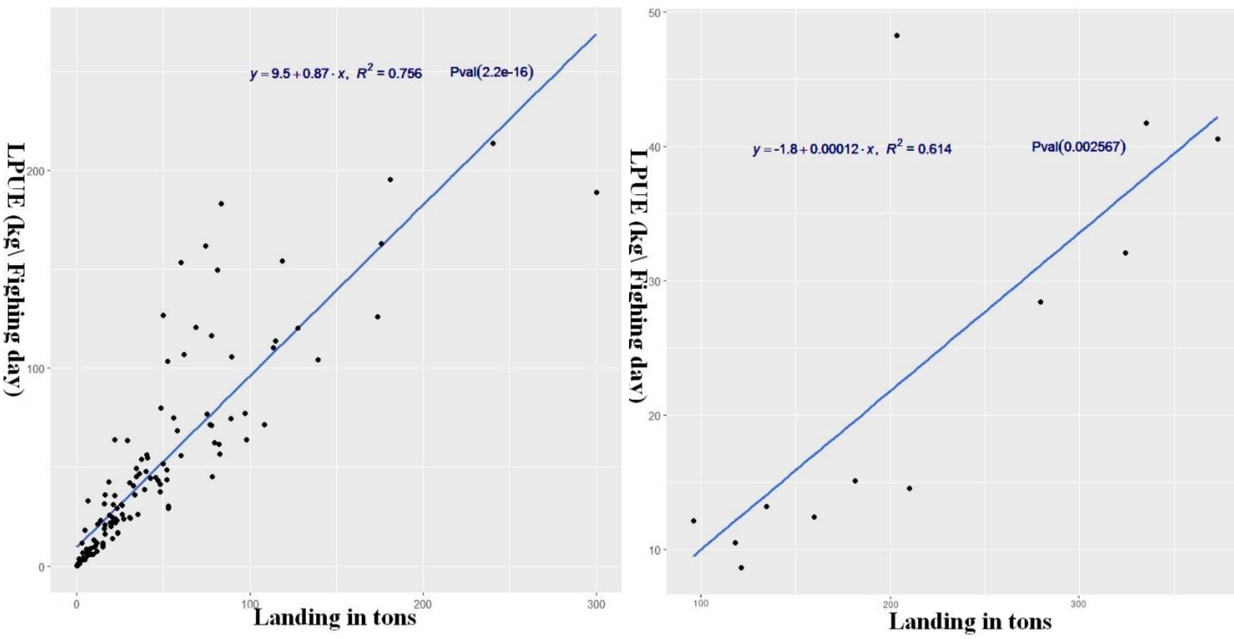

Fig. 2. Relationship between LPUE and landing (Yearly landing (left), and monthly landing (right) of anchovy in tons versus landing per unit effort (LPUE) calculated in kg per fishing days

1.1. Landing time series evolution

1.1.1. Landing seasonal patterns

Anchovy catches peak in the winter, peaking in March and April with mean monthly catches of 26.6 and 24 tones, respectively. This indicates that there may be some seasonality in the species' catch (Fig. 3). From March to July, the record for monthly anchovy landings is relatively high, which coincides with this species' spawning season in the South Alboran Sea, which is from April to September **(INRH, 2019)**. This can be explained by the fact that this species moves to the surface during the spawning season, making it more accessible to purse seiners **(Albert & Tournier, 1971)**.

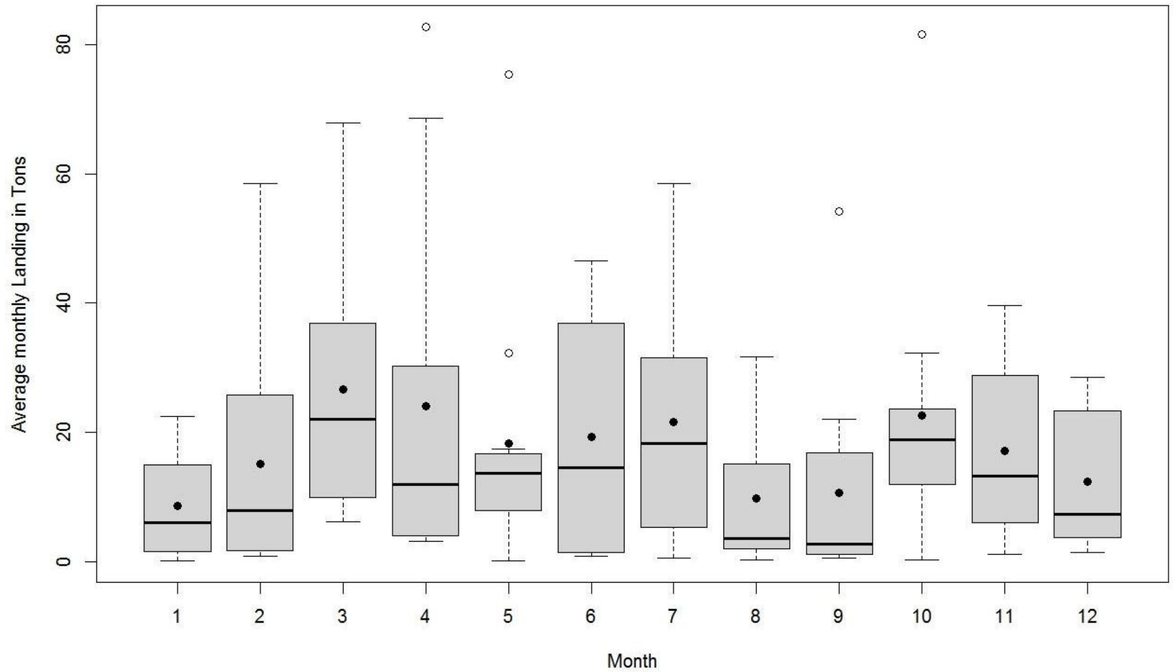

Fig. 3. Average monthly landings of anchovies in the South Alboran Sea (black dots represent mean values, black lines represent medians) (Data from 2009 to 2020)

1.1.2. Environmental factors evolution

Annual means were computed using environmental data collected on a daily and monthly basis. Fig. (4a- f) shows the yearly average environmental time series for the SSS, SST, Chl A, SLD, U, and V wind components in the South Alboran Sea. The majority of environmental elements displayed a significant long-term trend.

The highest monthly mean was recorded in August 2010 (25.29°C), while 2017 was the warmest year with an average annual temperature of 19.53°C since 1983. At that time, there has been a noticeable increase in sea surface temperature of +0.025°C year-1 (Fig. 4a). Similar results were seen for SSS, which saw a significant long-term increase of +0.0063PSU year-1 and a peak of 36.67PSU in 2010 (Fig. 4b). Moreover, the long-term rising trend for log chlorophyll a was +0.006mg m-3 year-1, peaking in 2018 at 0.43mg m-3 (Fig. 4e). The evolution of the south-nord V wind component shows a rise as well, with an average of +0.019year-1 and the highest peak being identified at -0.035 in the same year 2018 (Fig. 4f). However, the sea level difference (SLD) has had a long-term downward trend since 1983, with an average decline of 1.82 millimeters per year and a maximum of 114 millimeters recorded in 1990 (Fig. 4d). U wind, however, displayed a little positive trend of +0.0197 per year (P< 0.05) (Fig. 4c).

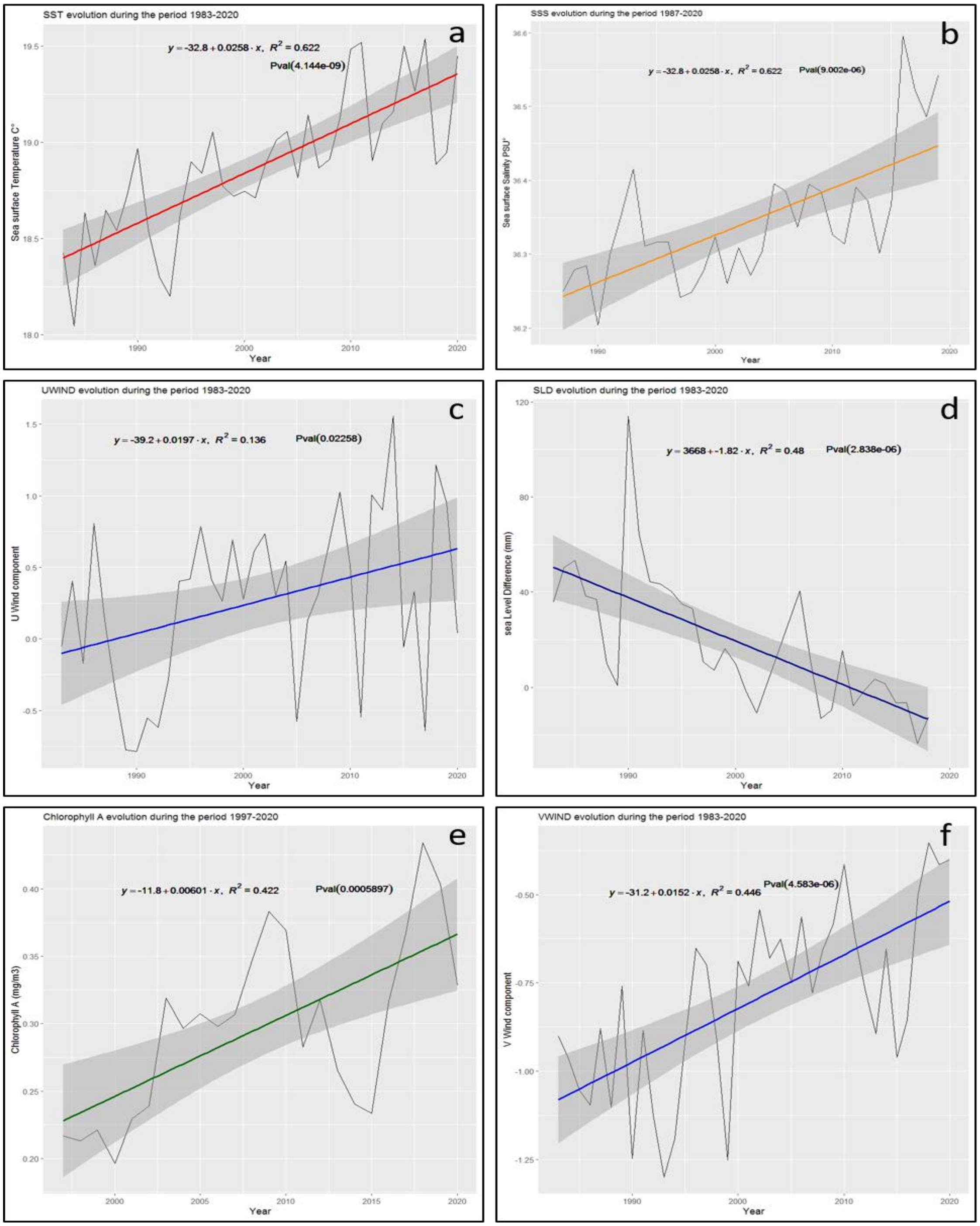

Fig. 4. Environmental factors evolution tendency in the study area showing: **a:** Sea surface temperature, **b:** Sea surface salinity, **c:** U wind component, **d:** SLD, **e:** Chlorophyll A, and **f:** V wind

2- Results of the modeling of the complete time series

Three top models were chosen according to the AICc rankings (Table 2). In all models, the whole time series with no linear trend was eliminated, which is a 38 years of landing, and environmental factors data were used. No variance inflation was seen among the predictor variables because all the variables chosen in the best models have a VIF< 5. According to the forward stepwise multiple regression and resulting model, SST, SSS, U WIND, and SLD are the four environmental characteristics that were taken into account. A maximum of three parameters were permitted for each model. The next step was to rank the created models using the akaike information criterion modified for small samples data (AICc) (Figs. 5, 6 &Table 2)

The model number 6 was one of the finest choices, it includes SST, SSS, and SLD. This model was chosen since it had the lowest AICc (533.6) and all of its predictive variables had *P*-values that were less than 0.05. This model can be expressed as:

$$Model\ 6:\ L\ anchvovy\ (t) = 361046 - 2390\ SST(t-1) - 8627\ SSS(t-1) + \ 23.5\ SLD\ (t)$$

This model highlights the possible negative effect of the temperature, salinity with one-year lag and the positive influence of SLD (proxy of Atlantic flow jets) on the abundance/landings. While, SLD shows a favorable link with the anchovy landing in the South Alboran Sea, two predictive metrics (SST and SS) do not.

Models 1 and 2 are two further intriguing models. Both models include SST, SSS, and U wind, but model 3 additionally includes V wind with a one-year lag. These two models have the highest R2 among the top six models, but they have the second-lowest AICs at 558.8 and 559.1, respectively (0.77, and 0.79). SST, SSS, and U wind have a negative connection with anchovies both models, thus an increase of these variables could have a detrimental impact on anchovy catches. The two models' respective formulas are as follows:

$$Model\ 1:\ L\ anchvovy\ (t) = 410414 - 3311\ SST(t) - 9483\ SSS(t) - 1205\ Uwind$$

$$Model\ 2:\ L\ anchvovy\ (t) = \ 395423 - 2843\ SST(t) - 9345\ \ SSS(t) - 1118\ Uwind - \ 1323\ Vwind\ (t-1)$$

Table 2. Best models selected using forward stepwise regression (the six best models are ranked by their corrected respective AIC (AICc); (t-1 represents a retrospective term of one year, P Val is *P*-value, and PVE is percent variance explained)

Models	SST	SSS	SLD	UWIND	VWIND	NAO	CHL A	SST -1	SSS -1	UWIND t-1	VWIND t-1	SLD t-1	AICc	R^2	P Val
6			X					X	X				533.6	0.68	5.92E-07
1	X	X		X									558.9	0.77	1.30E-09
2	X	X		X							X		559.1	0.79	2.59E-09
5				X				X	X				560.9	0.74	9.20E-09
4								X	X	X			564.1	0.71	3.73E-08
3	X	X											571.0	0.65	1.39E-07

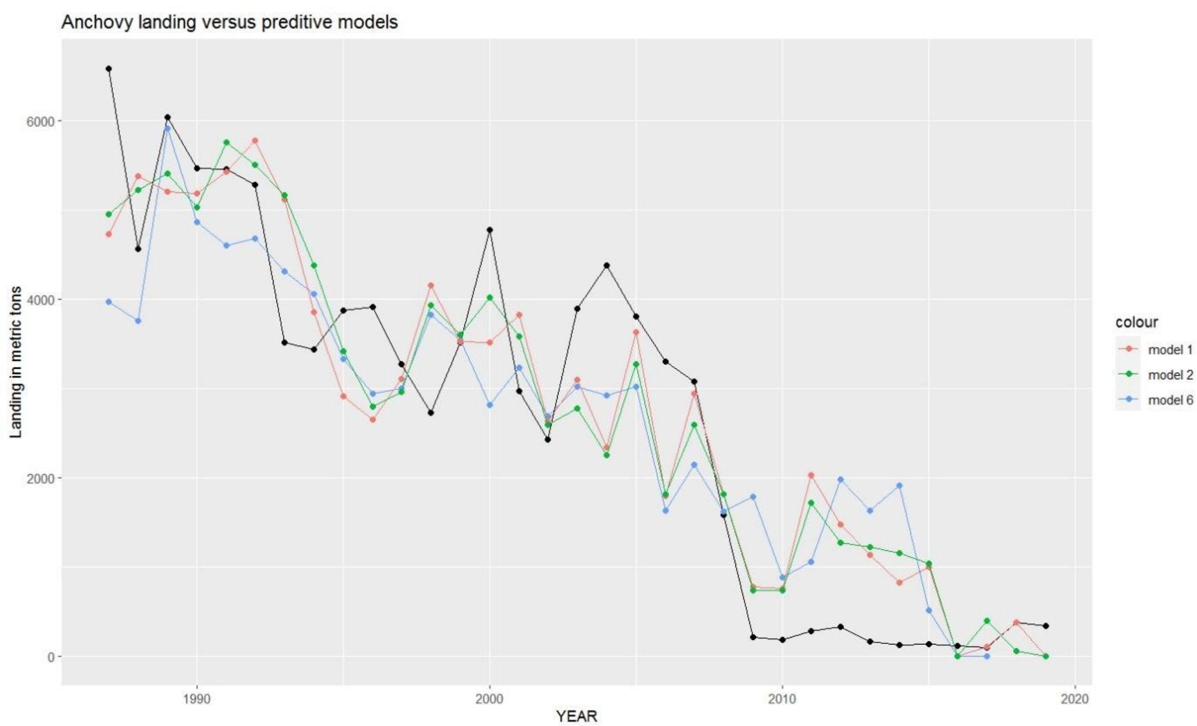

Fig. 5. The three best predictive models (6, 1, and 2) versus anchovy landing (black line) data from 1983 to 2020

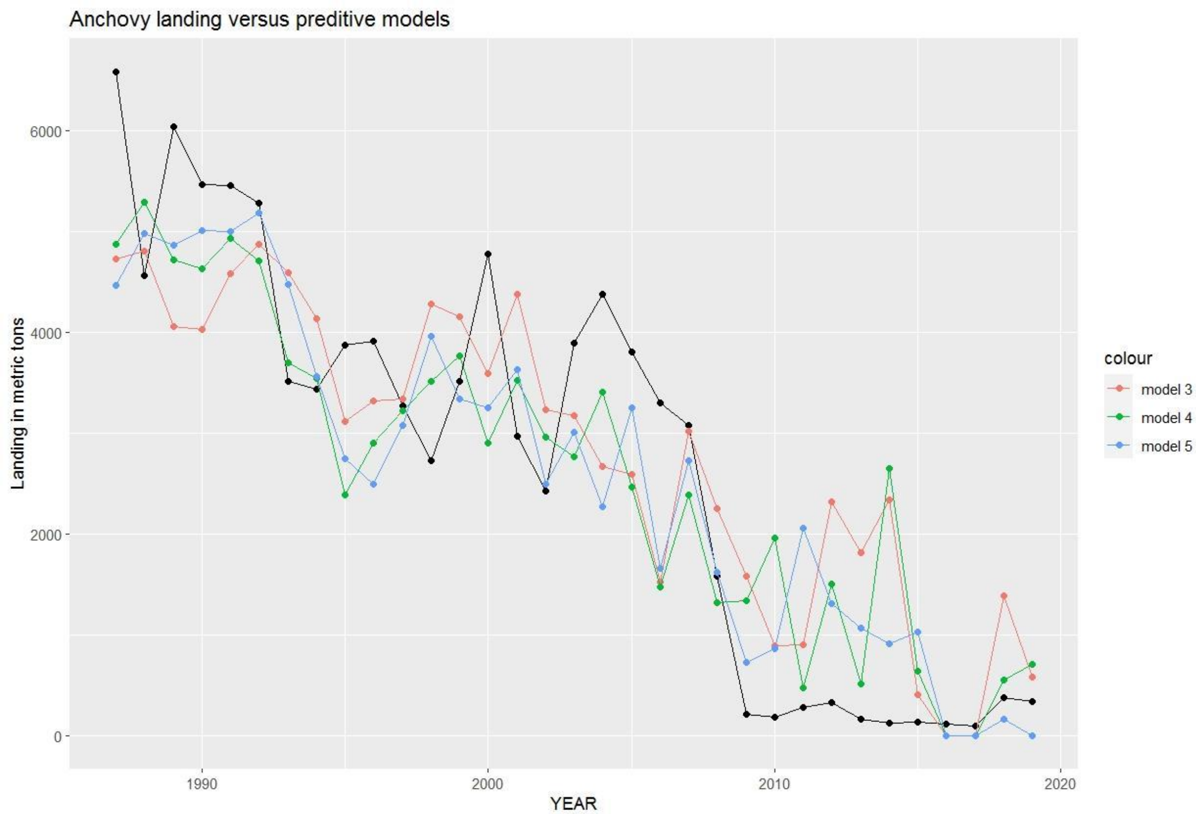

Fig. 6. The last three predictive models (3, 4, and 5) versus anchovy landing (black line) data from 1983 to 2020

3- Results of the modeling of the de-trended time series

The same stepwise technique was used to de-trended time series; however, no predictive factor was significant since every variable had a *P*-value greater than 0.5.

This could be explained by the fact that the inter-annual variability of the capture of this species in our study area could not be explained by environmental factors.

DISCUSSION

According to the study's findings, environmental factors were explained between 60 and 79% of the overall variance in the anchovy landing using trended time series, and the majority of the models created were statistically significant.

The sea surface temperature was selected in almost all the significant models, and it displays a negative relationship. This finding is coherent with **Huret *et al.* (2019)**, who expounded that temperature along with food is the main trigger of the timing of growth and reproduction of anchovy. In fact, SST has a considerable impact on the number and dispersion of anchovies, according to earlier research **(Guzman-Mora & Mullin, 1997; Chavez *et al.*, 2003)**. Additionally, it has been demonstrated that anchovy's vertical distribution and migration are significantly influenced by sea surface salinity (SSS) **(Lluch-Belda *et al.*, 1986)**.

The second important predictor, sea surface salinity, had a negative correlation with anchovy landing, as already described in previous studies **(Quattrocchi *et al.*, 2016; Pennino *et al.*, 2020; Fernández-Corredor *et al.*, 2021)**. This environmental variable appears to impact the spawning success of this species **(Zorica *et al.*, 2013; Quattrocchi *et al.*, 2016)**.

A positive and strong U wind exhibited a negative link with anchovy landing, which may be explained by how it affects the distribution of primary production and, in turn, indirectly the recruitment of this species. The westward wind component predominated in the majority of the models. It has been demonstrated that small pelagics in the Portuguese waters increases in response to favorable and powerful westward winds **(Teixeira *et al.*, 2015)**. Moreover, the wind's direction is crucial since the eastern breezes cause upwelling in the South of Alboran, which may increase the amount of anchovies.

The species of anchovy known to inhabit nutrient-rich waters supplied by coastal river waters or wind-driven upwelling **(Checkley *et al.*, 2017)**. It is accurate since the Alboran Sea's westerlies in the North and easterlies in the South drive Ekman transport and upwelling, respectively **(Sanchez-Garrido & Nadal, 2022)**. Additionally, it has been described that high wind speed during the spawning time is linked to a high rate of larval mortality **(Peterman & Bradford, 1987)**.

Ruiz *et al.* (2013) and **Jghab *et al.* (2019)** revealed that the velocity and Atlantic jet entrance of the Alboran Sea is one of the environmental factors with the greatest influence on sardine abundance and other pelagic species in this area. Furthermore, this study identified the AJ as an important environmental variable that affect small pelagic fish. The association between increased AJ velocity and anchovy is favorable. **Ruiz *et al.* (2013)** first brought attention to the relationship between small pelagic abundance and AJ flows. They argued that the high kinetic energy flowing from the Atlantic increases primary production in the northern part of the Alboran Sea, while decreasing the anchovy larval dispersion, whereas this is not the case in the southern part. As a result, the AJ kinetic energy may become weaker with a little effect on the dispersion of larvae but still increases primary production in the South of Alboran **(Garcia & Carr, 2001; Oguz *et al.*, 2014)**.

Since the majority of environmental factors and anchovy landing in the Mediterranean Sea showed a distinct trend, an emphasis was recorded on the correlation observed in our models. Using the de-trended time series, no relation between the anchovy abundance and environmental variable were found. Thus, while SST, SSS, U and V can be used to predict anchovy abundance along a seasonal cycle, long term trends cannot be predicted.

This might be due to two factors: (i) The environmental data have no significative trend during the analyzed time period (38 years), and (ii) there are other, more important factors affecting the decline of anchovy abundance in the southern Alboran Sea, for example elevate fishing pressure since it is the most targeted species of the small pelagic species in the research area. On the other hand, **Baez *et al.* (2022)** suggested that combined effect of multiple regional and global climatic oscillations provides the best explanation of variability in anchovy and sardine abundance in GSA6.

CONCLUSION

We analyzed 38 years' worth of anchovy landing data to assess whether environmental factors had an impact on the catch of anchovies and, consequently, the abundance of this species in the South Alboran Sea.

Six models that predicted between 60 and 79% of the variation in anchovy landing were found to be highly significant when trended temporal data were modelled. SST, SSS, and U wind were the main environmental factors influencing anchovy abundance.

The environmental factors, however, were unable to account for fluctuations in anchovy landings when the trend component was removed. This may suggest that, although having an impact over the long term, environmental factors have little impact on the inter-annual time scale. Hence, factors other than environmental change may be to blame for the decrease in landings of this species. Since this species was the most targeted of the small pelagic species in the research area, overfishing of this species is one probable factor that may have significantly contributed to the long-term reduction in landings.

Acknowledgment

Authors want to acknowledge the department of fisheries and the National Office of Fisheries for providing anchovy official catch data. M. Muñoz, acknowledges support by "Plan Propio Universidad de Málaga".

Disclaimer

The authors of the study affirm that there were no financial or commercial ties that might be viewed as having a potential conflict of interest.

REFERENCES

Albert, Y. and Tournier, H. (1971). La reproduction de la sardine et de l'anchois dans le golf du lion. Revue Institut Pêches Maritime. 35 (1): 1971. P 57-75

Borja, A.; Uriarte, A.S.; Egana, J.; Motos, L. and Valencia, V. (1996). Relationships between anchovy (Engraulis encrasicolus) recruitment and environment in the Bay of Biscay (1967–1996). Fisheries Oceanography, 7(3-4): 375-380.

Burnham, K.P. and Anderson, D.R. (2002). Model selection and multimodel inference: a practical-theoretical approach. J. Wildl. Manag. https://doi. org/10.1007/b97636.

Calvo, E.; Simó, R.; Coma, R.; Ribes, M.; Pascual, J.; Sabatés, A.; Gili, J.M. and Pelejero, C. (2011). Effects of climate change on Mediterranean marine ecosystems: the case of the Catalan Sea. Climate Research, 50(1), pp.1-29.

Carrera, P. and Porteiro, C. (2003). Stock dynamic of the Ierian sardine (Sardina pilchardus, Walb.) and its implication on the fishery off Galicia (NW Spain) .Scientia Marina 67 (supl.1): 245-258.

Chavez, F.P.; Ryan, J.; Lluch-Cota, S.E. and Ñiquen, C.M. (2003). From anchovies to sardines and back: multidecadal change in the Pacific Ocean. Science, 299(5604): 217-221.

Checkley Jr, D. M.; Asch, R.G. and Rykaczewski, R.R. (2017). Climate, anchovy, and sardine. Annual Review of Marine Science, 9: 469-493.

Costalago, D.; Palomera, I. and Tirelli, V. (2014). Seasonal comparison of the diets of juvenile European anchovy Engraulis encrasicolus and sardine Sardina pilchardus in the Gulf of Lions. J. Sea Res. 89 (mayo): 64–72. https://doi.org/10.1016/j.seares.2014.02.008.

Craig, J.F. (1987). The biology of perch and related fish, Croom Helm, London. 333 p

Csirke, J. (1995). Fluctuations in abundance of small and mid-size pelagics. Sci. Mar., 59(3– 4): 481-490 pp.

Darasi, F.; Mehanna, S. and Aksissou, M. (2020). The Coastal Fisheries in Tangier port: Catch assessment and Current Status. Egyptian Journal of Aquatic Biology and Fisheries, 24(2): 495-506.

Draper, N.R. and Smith. H. (1981). Applied regression analysis, 661-81.

El Qendouci, M.; Amenzoui, K.; Baali, A.; El Qoraychy, I. and Yahyaoui, A. (2018). Diet of anchovy Engraulis encrasicolus (Engraulidae) in Moroccan Atlantic coast. Aquaculture, Aquarium, Conservation and Legislation, 11(4): 1388-1398.

El-Beltagy, K.; Elmor, E.M. and Ali, A. (2022). Food and Feeding Habits of the European Anchovy (Engraulis encrasicolus) (Linnaeus, 1758) Inhabiting Port Said, Mediterranean Coast, Egypt. Egyptian Journal of Aquatic Biology and Fisheries, 26(4): 637-644.

FAO, G. (2020). The state of Mediterranean and Black Sea fisheries. Rome: FAO.

FAO. (2018). El estado mundial de la pesca y la acuicultura 2018. Cumplir los objetivos de desarrollo sostenible. Roma. Licencia: CC BY-NC-SA 3.0 IGO

FAO. (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome. https://doi.org/10.4060/ca9229en

Fernández-Corredor, E.; Albo-Puigserver, M.; Pennino, M.G.; Bellido, J. M. and Coll, M. (2021). Influence of environmental factors on different life stages of European anchovy (Engraulis encrasicolus) and European sardine (Sardina pilchardus) from the Mediterranean Sea: A literature review. Regional Studies in Marine Science, Volume 41: 2021, 101606, ISSN 2352-4855, https://doi.org/10.1016/j.rsma.2020.101606.

Francis, R. C. (2006). Measuring the strength of environment–recruitment relationships: the importance of including predictor screening within cross-validations. ICES Journal of Marine Science, 63(4): 594-599.

Furnestin, J. (1959). La reproduction de la sardine Sardina pilchardus et de l'anchois Engraulis encrasicolus des côtes Atlantiques du Maroc. Revue des Travaux de l'Institut des Pêches Maritimes, 23(1): 79 – 104

García-Lafuente, J.; Cano, N.; Vargas-Yáñez, M.; Rubín, J.P.; Hernández-Guerra, A. (1998). Evolution of the Alboran Sea hydrographic structures during July 1993. Deep-Sea Res. I 45: 39–65.

Garrido, S.; and Van-der-Lingen, C.D. (2014). Feeding biology and ecology. Biology and ecology of sardines and anchovies, 122-189.

GFCM. (2018). Working Group on Stock Assessment of Small Pelagic Species (WGSASP).

Guzman-Mora, A. G. and Mullin, M.M. (1997). Influence of sea surface temperature on the distribution of Pacific sardine (Sardinops sagax) and northern anchovy (Engraulis mordax) off Baja California, Mexico. CalCOFI Reports, 38: 111-117.

Hidalgo, M.; Rouyer, T.; Molinero, J. C.; Massutí, E.; Moranta, J.; Guijarro, B. and Stenseth, N. C. (2011). Synergistic effects of fishing-induced demographic changes and climate variation on fish population dynamics. Marine Ecology Progress Series, 426: 1-12. https://doi.org/10.1016/j.rsma.2022.102709.

Huret, M.; Tsiaras, K.; Daewel, U.; Skogen, M. D.; Gatti, P.; Petitgas, P. and Somarakis, S. (2019). Variation in life-history traits of European anchovy along a latitudinal gradient: a bioenergetics modelling approach. Marine Ecology Progress Series, 617 : 95-112.

INRH. (2019). Rapport national sur la situation des stocks de petits pélagiques et leur exploitation au niveau de la zone marocaine a l'échéance 2019

Jghab, A.; Vargas-Yañez, M.; Reul, A.; Garcia-Martínez, M.C.; Hidalgo, M.; Moya, F. and Lamtai, A. (2019). The influence of environmental factors and hydrodynamics on sardine (Sardina pilchardus, Walbaum 1792) abundance in the southern Alboran Sea. Journal of Marine Systems, 191: 51-63.

Báez, J.C.; Pennino, M.G.; Czerwinski, I.A.; Coll, M.; Bellido, J.M.; Sánchez-Laulhé, J.M. and García-Soto, C. (2022). Long term oscillations of Mediterranean sardine and anchovy explained by the combined effect of multiple regional and global climatic indices. Regional Studies in Marine Science, 56: 102709.

Kalnay, E.; Kanamitsu, M.; Kistler, R.; Collins, W.; Deaven, D.; Gandin, L.; Iredell, M.; Saha, S.; White, G.; Woollen, J.; Zhu, Y.; Leetmaa, A.; Reynolds, R.; Chelliah.; M.; Ebisuzaki, W.; Higgins, W.; Janowiak, J.; Mo, K.C.; Ropelewski, C.; Wang, J.; Jenne, R. and Joseph, D. (1996). The CEP/NCAR 40-year reanalysis project. Bull. Am. Meteorol. Soc. 77: 437–470.

Kuyawa R.; Mamcarz A. and Kucharczyk D. (1997). Effect of temperature on embryonic development of asp (Aspius aspiusL). Polskie Archiwum Hydrobiologii 44:139–143.

Lavín, A.; Montero-Ventas, X.; Ortiz De Zárate, V.; Abaunza, P. and Cabanas, J.M. (2007). Environmental variability in the North Atlantic and Iberian waters and its influence on horse mackerel (Trachurus trachurus) and albacore (Thunnus alalunga) dynamics. ICES J. Mar. Sci. 64 (3): 425–438. https://doi.org/10.1093/icesjms/fsl042.

Lima, A.R.; Baltazar-Soares, M.; Garrido, S.; Riveiro, I.; Carrera, P.; Piecho-Santos, A.M., and Silva, G. (2022). Forecasting shifts in habitat suitability across the distribution range of a temperate small pelagic fish under different scenarios of climate change. Science of the Total Environment, 804: 150167.

Lloret, J.; Palomera, I.; Salat, J. and Sole, I. (2004). Impact of freshwater input and wind on landings of anchovy (Engraulis encrasicolus) and sardine (Sardina pilchardus) in shelf waters surrounding the Ebre (Ebro) River delta (north-western Mediterranean). Fish. Oceanography. 13 (2): 102–110.

Lluch-Belda, D.A.; Magallón, F.J. and Schwartzlose, R.A. (1986). Large fluctuations in the sardine fishery in the Gulf of California: possible causes. CalCOFI Rep, 27(1): 136-140.

Marchesiello, P.; Herbette, S.; Nykjaer, L. and Roy, C. (2004). Eddy-driven dispersion processes in the Canary Current upwelling system: comparison with the California system. Globec international newsletter, 10(1): 4-7.

Morgan, A. C. and Burgess, G. H. (2005). Fishery-dependent sampling: total catch, effort and catch. Management techniques for elasmobranch fisheries, (474): 182.

Oguz, T.; Macias, D.; Garcia-Lafuente, J.; Pascual, A. and Tintore, J. (2014). Fueling Plankton Production by a Meandering Frontal Jet: A Case Study for the Alboran Sea (Western Mediterranean). PLOS ONE 9(12): e116653. https://doi.org/10.1371/journal.pone.0116653 View correction

Peterman, R. M. and Bradford, M. J. (1987). Wind speed and mortality rate of a marine fish, the northern anchovy (Engraulis mordax). Science, 235(4786): 354-356.

Quattrocchi, F.; Mamouridis, V. and Maynou, F. (2016). Occurrence of adult anchovy in Catalonia (NW Mediterranean) in relation to sea surface conditions.

Reynolds, R. W.; Smith, T.M.; Liu, C.; Chelton, D. B.; Casey, K.S. and Schlax, M. G. (2007). Daily high-resolution-blended analyses for sea surface temperature. Journal of climate, 20(22): 5473-5496.

Riveiro, I.; Guisande, C.; Maneiro, I.; and Vergara, A.R. (2004). Parental effects in the European sardine Sardina pilchardus. Marine Ecology Progress Series, 274: 225-234.

Roy, C. (1992). Réponses des stocks de poissons pélagiques à la dynamiques des upwelling en Afrique de l'ouest : Analyse et modélisation. Etudes et Thèses, ORSTOM, Paris. 146 pp.

Ruiz, J.; Macías, D.; Rincón, M.M.; Pascual, A.; Catalán, I.A. and Navarro, G. (2013). Recruiting at the edge: Kinetic energy inhibits anchovy populations in the Western Mediterranean. PLoS One, 8(2): e55523. https://doi.org/10.1371/journal.pone.0055523

Sabatés, A. (1990). Changes in the heterogeneity of meso-scale distribution patterns of larval fish associated with a shallow coastal haline front. Estuarine, Coastal and Shelf Science, 30: 131-140.

Sanchez-Garrido, J.C. and Nadal, I. (2022). The Alboran Sea circulation and its biological response: A review. Impacts of Environmental Variability Related to Climate Change on Biological Resources in the Mediterranean, 95.

Shannon, L.J.; Field, J.G. and Moloney, C.L. (2004). Simulating anchovy–sardine regime shifts in the southern Benguela ecosystem. Ecological modelling, 172(2-4): 269-281.

Sherman, K. and Adams, S. (2010). Sustainable Development of the World's Large Marine Ecosystems during Climate Change: A commemorative volume to advance sustainable development on the occasion of the presentation of the 2010 Goteborg Award. Switzerland: IUCN; 2010

Simoncelli, S.; Fratianni, C.; Pinardi, N.; Grandi, A.; Drudi, M.; Oddo, P. and Dobricic, S. (2014). Mediterranean Sea Physical Reanalysis (MEDREA 1987–2015) (Version 1) (set). E.U. Copernicus Marine Service Informationhttps://doi.org/10.25423/medsea_reanalysis_phys_006_004.

Skalski, J.R.; Ryding, K.E. and Millspaugh, J. (2005). Wildlife demography: analysis of sex, age, and count data. Elsevier. (636 p).

Sumpter, J.P. (2019). General concepts of seasonal reproduction. In Reproductive seasonality in Teleosts, 13-32: CRC Press.

Teixeira, C.M.; Gamito, R.; Leitao, F.; Murta, A.G.; Cabral, H.N.; Erzini, K. and Costa, M.J. (2016). Environmental influence on commercial fishery landings of small pelagic fish in Portugal. Regional Environmental Change, 16: 709-716.

Theilacker, G.H.; Kimball, A.S. and Trimmer, J.S. (1986). Use of an ELISPOT immunoassay to detect euphausiid predation on larval anchovy. Marine Ecology Progress. Series, 30: 127-131.

Thiaw, M.; Auger, P.A.; Ngom, F.; Brochier, T.; Faye, S.; Diankha, O. and Brehmer, P. (2017). Effect of environmental conditions on the seasonal and inter-annual variability of small pelagic fish abundance off North-West Africa: The case of both Senegalese sardinella. Fisheries Oceanography, 26(5): 583-601.

Vargas-Yáñez, M.; García-Martínez, M.C.; Moya, F.; Balbín, R.; López-Jurado, J.L.; Serra, M.; Zunino, P.; Pascual, J. and Salat, J. (2017). Updating temperature and salinity mean values and trends in the Western Mediterranean: the RADMED project. Progress in Oceanography. 157: 27–46. https://doi.org/10.1016/j.pocean.2017.09.004.

Vargas-Yáñez, M.; Giráldez, A.; Torres, P.; González, M.; García-Martínez, M.D. C. and Moya, F. (2020). Variability of oceanographic and meteorological conditions in the northern Alboran Sea at seasonal, inter-annual and long-term time scales and their influence on sardine (Sardina pilchardus Walbaum 1792) landings. Fisheries Oceanography, 29(5): 367-380.

Vargas-Yáñez, M.; Moya, F.; García-Martínez, M.; Rey, J.; González, M. and Zunino, P. (2009). Relationships between Octopus vulgaris landings and environmental factors in the northern Alboran Sea (Southwestern Mediterranean). Fish. Res. 99: 159–167.

Vargas-Yáñez, M.; Plaza, F.; García-Lafuente, J.; sarhan, T.; Vargas, J.M. and Vélez-belchi, P. (2002). About the seasonal variability of the Alboran Sea circulation. J. Mar. Syst. 35: 229–248.

Volpe, G.; Colella, S.; Forneris, V.; Tronconi, C. and Santoleri, R. (2012). The mediterranean ocean colour observing system–System development and product validation. Ocean Science, 8(5): 869-883.

Zar, J.H. (1984). Biostatistical Analysis, 2nd edition. Prentice-Hall, Inc., Englewood Cliffs (718 p).

Zorica, B.; Vilibić, I.; Keč, V.Č. and Šepić, J. (2013). Environmental conditions conducive to anchovy (Engraulis encrasicolus) spawning in the Adriatic Sea. Fisheries Oceanography, 22(1): 32-40.