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Environmental Factors Changes and Its Association with the Catches Fluctuations of Atlantic Chub Mackerel (*Scomber colias*, Gmelin, 1789) in the South Alboran Sea (Western Mediterranean Sea)

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ABSTRACT

Based on data from 37 years of catches and environmental satellites in addition to model observations from 1983 to 2020, this study assessed the potential impact of changing oceanographic conditions on the Atlantic chub mackerel (*Scomber colias*) population in the southern Alboran Sea. To determine the best potential predictors, as well as building the best models to explain the variation of this species's abundance, forward stepwise regression was applied to environmental predictors, viz. sea surface salinity (SSS), sea surface temperature (SST), surface chlorophyll a (Chl-a), U and V wind components, NAO index, and the velocity of Atlantic jets represented by sea level difference (SLD). Then, linear models (LMs) were built and ranked by their AICc values to choose the best predictive models. The findings demonstrate that this species was vulnerable to a variety of environmental conditions, such as variations in sea salinity, temperature, currents, and wind patterns, which can affect both the species' abundance and how it was exploited by fisheries. This study emphasized the enormous impact of the Atlantic jet on the dynamics of small pelagic fish populations in the Alboran Sea, underscoring the need of taking oceanographic processes into account while managing these resources. However, it can be challenging to foresee how small pelagic species will be impacted by climate change due to the lack of long-term monitoring programs, data sources, and the complexity of environmental changes. Therefore, future research should be prioritized to better understand how environmental changes affect these species and their habitats.

INTRODUCTION

Small pelagic fish species play a vital role in marine ecosystems and are a critical food source for larger predatory species and human populations **(Tacon *et al.*, 2013)**. However, the negative impact of climate change and associated environmental changes on these species is a growing concern **(Ramírez *et al.*, 2021)**. Recent studies have shown that the distribution and abundance of small pelagic species, such as anchovies and sardines, are influenced by environmental parameters, including sea surface temperature, ocean acidification, and wind patterns **(Checkley *et al.*, 2009)**.

The effects of climate change on small pelagic species are complex and can vary depending on the species and their life history strategies. For example, some species may be able to adapt to changing environmental conditions through shifts in their distribution or by modifying their life history traits **(Chavez *et al.*, 2003; Hazen *et al.*, 2013)**. However, other species may face increased mortality, reduced productivity, and declines in population **(Planque *et al.*, 2018)**.

Global warming and its associated environmental changes are impacting a wide range of small pelagic marine species, including *Scomber colias* (Atlantic chub mackerel), a highly migratory and economically important species, distributed along the North Atlantic, and the Mediterranean. Recent studies have shown that mackerel populations are influenced by oceanographic parameters, such as sea surface temperature and prey availability **(Blanchard *et al.*, 2012; Barange *et al.*, 2014)**. Consequently, this is of concern since climate change is expected to have a profound effect on these parameters and ultimately the distribution, abundance and productivity of this specie populations **(Cheung *et al.*, 2013)**.

In light of these concerns, this study aimed to assess the impact of environmental changes on the distribution and population dynamics of the Atlantic chub mackerel, with the aim to provide knowledge that improves the management and conservation measures of this important species. Furthermore, this study will explore the potential impacts of extractive fishing on this species populations and the importance of incorporating these impacts into management strategies. Climate change and extractive fishing are two of the main drivers of changes in marine ecosystems, and their combined effects may have significant impacts on the Atlantic chub mackerel populations **(Fulton *et al.*, 2005; Worm *et al.*, 2006)**.

Additionally, this article addressed the challenges and limitations in predicting the effects of environmental changes on this Atlantic mackerel population and the difficulty in separating the effects of climate change from other drivers such as fishing. The modeling study and its comparison with the existing literature highlight the importance of further research to improve our understanding of how environmental changes trigger the Atlantic chub mackerel population in the Alboran Sea.

MATERIALS AND METHODS

1. Study area

The study area is in the southern side (southward of parallel 36º N) of the Alboran Sea, and small pelagic fish from Morocco's Mediterranean fishing fleet are landed at four main ports: Mdiq, Al Hoceima, Nador, and Raskebdana (Fig. 1).

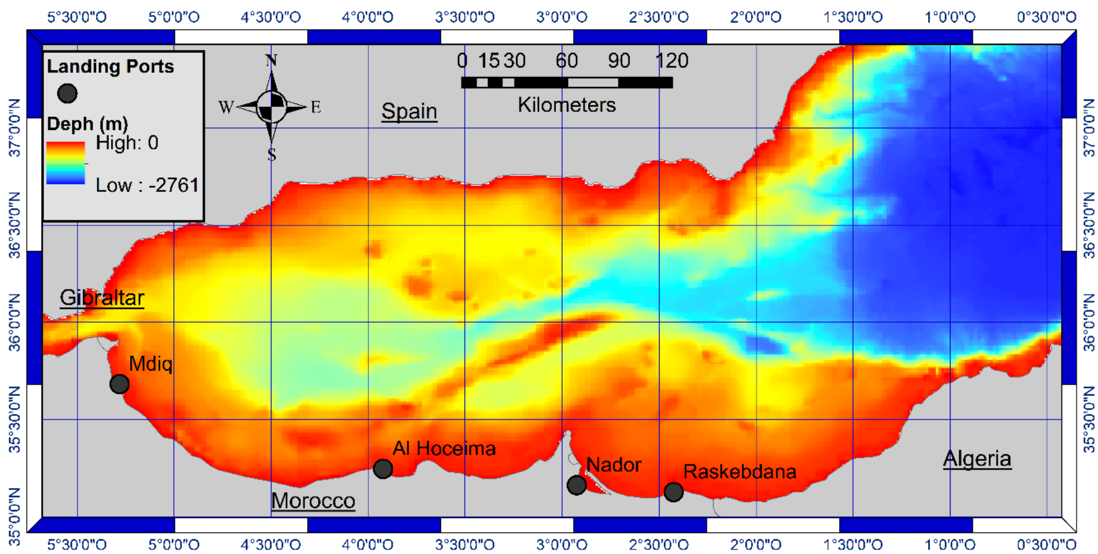

Fig. 1. Map of the studied area, with the four mean landing ports of the small pelagic species

2. Fisheries data

Small pelagic species' official landings and catches data in the south Alboran Sea were retrieved from the National Fisheries Office (ONP). Since this segment accounts for more than 95% of the catch of those species and represents an ongoing historical fishing effort across the study's period, we exclusively used commercial purse seine landing data for this analysis **(INRH, 2019)**.

Landing data for the Atlantic chub mackerel can be used as a proxy for the species' abundance due to the year-round operation of this fishing activity and the purse seine boats' preparedness to fish regardless of the weather **(INRH, 2019)**. Landing data are presented in tons, and landing per unit effort (LPUE) is determined by dividing the year's landing by the fishing effort (number of fishing days). This metric will be used to support the usage of landing as a substitute for this species' abundance **(Thiaw *et al.*, 2017; Jghab *et al.*, 2019,: Vargas-Yáñez *et al.*, 2020, Jghab *et al.*, 2023)**.

This study employed information from the main small pelagic fishing ports of Mdiq, Al Hoceima, Nador, and Al Ras Kebdana. Both yearly and monthly Mackerel landing time series are taken into account in this investigation. Data on capture and effort for small pelagic species have only been available since 2009. This significantly reduces the length of the time series being studied, which makes it challenging to determine how environmental elements are correlated.

Therefore, we utilized landings rather than LPUE in the modeling; however, changes in the Atlantic mackerel landings may just be the effect of changing fishing effort and not truly reflect changes in stock abundance. Landing data may be used as a proxy for abundance data to prolong the time series if landing data are well correlated with LPUE data, and no discernible change in fishing activity is detected **(Hidalgo *et al.*, 2011; Ruiz *et al.*, 2013; Thiaw *et al.*, 2017; Jghab *et al.*, 2019; Jghab *et al.*, 2023)**.

In order to use a longer time series (landing data), we conducted a regression analysis between landings and LPUE on the monthly (Fig. 2) and annual (Fig. 3) time series. The results showed that LPUE may be predicted using monthly, inter-annual variation, (R^2= 0.75, P< 0.05) and annual data (R^2= 0.61, P< 0.05) from landing data. Such a strong relationship between LUPE and landings in the study region has previously been described in the area **(Vargas-Yáñez *et al.*, 2019; Jghab *et al.*, 2019)**. Similar associations have also been explored in Vigo (Iberian Atlantic Coast) and Tarragona (NW Mediterranean) **(Lloret *et al.*, 2004)**.

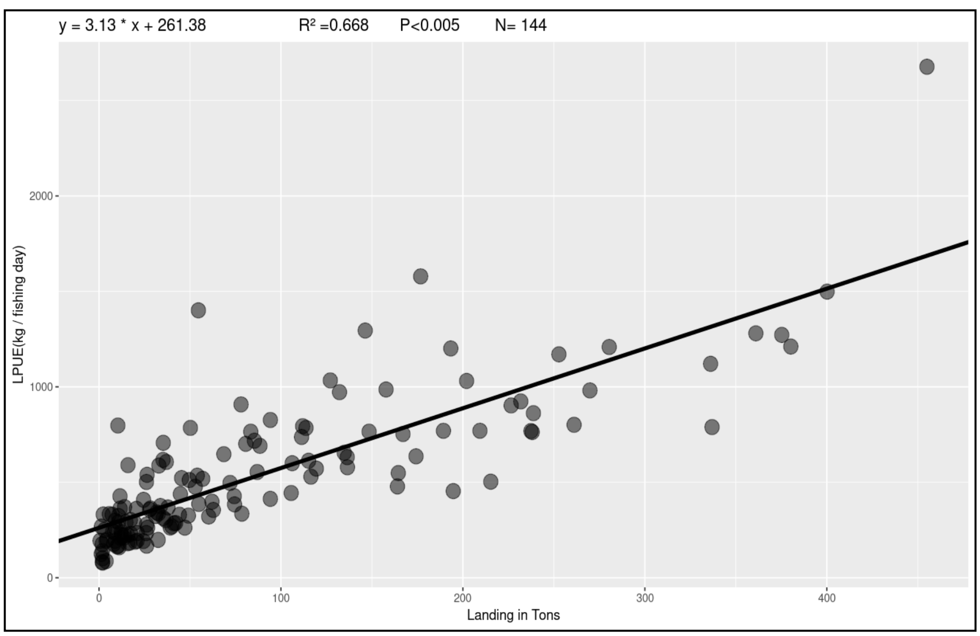

Fig. 2. Monthly LPUE data plotted against landing of Atlantic chub mackerel, regression line and equation in the south Alboran Sea

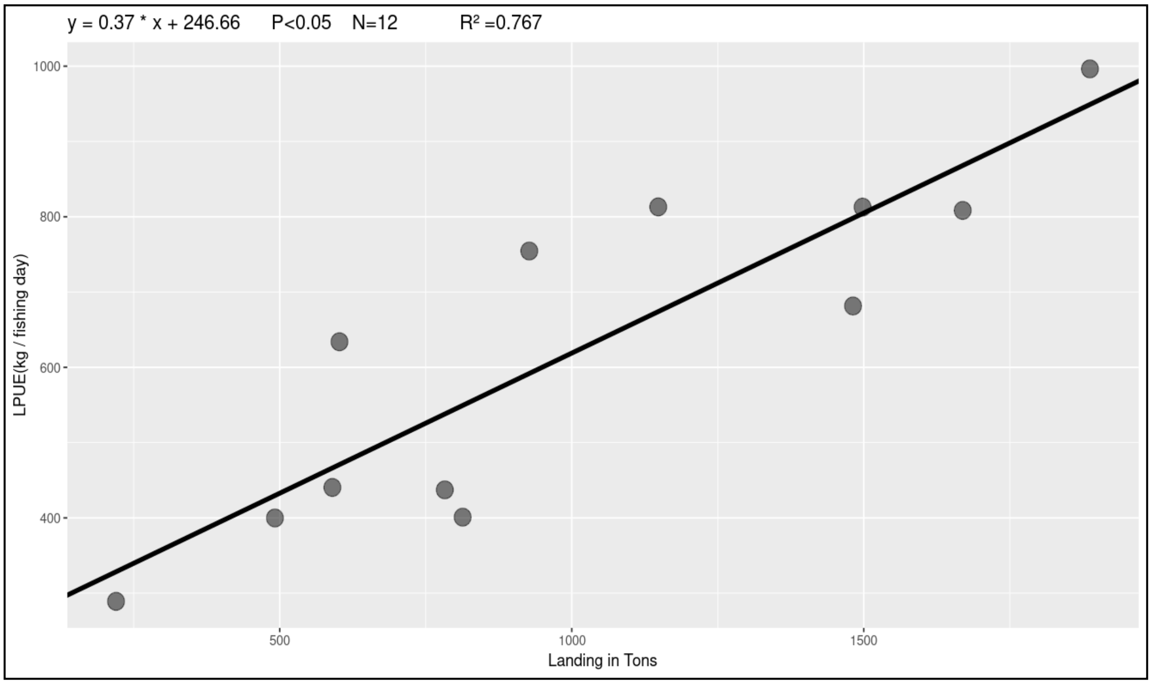

Fig. 3. Yearly LPUE data plotted against landing of Atlantic chub mackerel, regression line and equation in the south Alboran Sea

3. Climate data

The environmental parameters that may affect the occurrence, recruitment, and dispersion of this mackerel species were taken into consideration in this paper from a several data bases. The factors considered include the North Atlantic oscillation (NAO), sea surface temperature (SST), sea surface salinity (SSS), sea surface chlorophyll-a concentration (Chl-a), west-east (u), south-north (v), and current component. The SST, SSS, and Chl-a data were averaged over the southern Alborán Sea from 5.5 to 2°W and from 35 to 36°N.

Daily sea surface temperature data were obtained from 1981 to 2020 from NOAA's high-resolution SST data on the NOAA/OAR/ESRL PSD **(Reynolds *et al.*, 2007)**. The spatial resolution of this dataset is 0.25° x 0.25°. The Copernicus Maritime Environmental Monitoring Service provides salinity data from 1987 through 2020 **(Simoncelli *et al.*, 2014)**. The resolution of this dataset is 0.063° x 0.063°. Additionally, daily Chl-a data for the years 1997 to 2020 was collected from the Copernicus website **(Volpe *et al.*, 2012)**. Daily wind data, with a resolution of 2.5° x 2.5° (u, west-east, and v, south-north components), were collected from NCEP reanalysis **(Kalnay *et al.*, 1996)** and posted on the NOAA/OAR/ESRL PSD website in Boulder, Colorado, USA.

We made use of the sea level difference (SLD) between Algeciras and Ceuta as a credible predictor of changes in the flow velocity of these incoming water jets as a proxy for nutrient-rich waters moving from the Strait of Gibraltar to the research area **(García-Lafuente *et al.*, 1998; Vargas-Yáñez *et al.*, 2002)**. The monthly sea level time records for Algeciras and Ceuta are sourced from the tide network of the Permanent Service for Mean Sea Level and the Spanish Institute of Oceanography (www.psmsl.org). A monthly time series of sea level changes in the Strait of Gibraltar was made from 1981 to 2018 **(Jghab *et al.*, 2023)**.

4. Data analysis

4.1 Modeling and stepwise selection

4.1.1 Complete time series

Most of the aforementioned environmental data has an impact on the spatial distribution, growth, and captures of this species. Linear models (LM) should not mix several predictive variables, and their numbers should be as low as possible to maintain the degree of freedom in the analysis **(Burnham & Anderson, 2002)**.

Cross-correlation analysis and scatterplots were used to choose the most promising possible significant predictors which were SST, SSS, Chl-a, SLD, NAO, U wind, and V wind components. The annual cumulative catches of mackerel (tons.year^{-1}) were regressed on these potential factors, and variables that demonstrated correlation significance with the highest F statistic at the 0.05 level were considered to be the significant predictor variables for the LM models. The investigation was stopped for further predictors with significant values greater than 0.1 (Fig. 4). The most effective linear models were chosen by performing a forward stepwise analysis on the potential predictors. For this initial model selection and analysis, the entire time series from the first year to the last year was considered, and no trend was removed. The generated predictive models were ranked, and the model with the lowest akaike information criteria-corrected (AICc) was chosen as the best model **(Burnham & Anderson, 2002; Vargas-Yáñez *et al.*, 2009; Jghab *et al.*, 2019)**.

The landing of Atlantic mackerel (M) was modeled using formula (1):

$$(1)\ M(t) = \sum_{i=0}^{k} \alpha_i \times P_i(t) + \sum_{j=0}^{k} \beta_j \times P_j(t-1) + \beta + \epsilon(t)$$

Where, M is the landing of Atlantic mackerel (tons.year^{-1}); P_i stands for predictors (SST, CHL-A, SLD, SSS, Uwind, Vwind, SLD, NAO) with no time lag, while P_j represents predictors with a one-year lag; α and β are the coefficients, and t is the time of years. Random variables that reflect errors are ϵ(t).

4.1.2 Detrende time series

A straight line was fitted to the time series of the environmental predictor and Atlantic mackerel landings using the least squares fit method. The slope displays the annual change rate on average. A confidence interval at the 95 percent level for the slope was generated after confirming that the residuals' distributions were normal (Kolmogorov-Smirnov tests) **(Zar, 1984)**.

On the detrended residuals, the same forward stepwise method was used to choose the environmental predictors and create LM predictive models. Mackerel landing and environmental potential factors were de-trended using this formula (2):

$$\textbf{(2)} \qquad M(t) = \alpha 0 + \alpha 1 t + Xa(t)$$

Where, M is the landing of de-trended residuals (tons.year^{-1}); α0 and α1 are the coefficients (intercept, slope), and t is the time of years. Random variables that reflect errors are ϵ(t).

The detrended mackerel landing was then modeled using the following formula (3):

$$\textbf{(3)} \qquad Xa = \sum_{i=1}^{k} \alpha_i \times X_{i(t)} + \alpha_i \times X_{i(t-1)} + \epsilon_{(t)}$$

Where, slope and intercept are α1 and α0, respectively, represent the regression coefficients, and Xa is the detrended mackerel landing (tons year^{-1}). The symbols Xi(t), and Xi(t-1) stand for the de-trended predictors time series with and without one year lag, respectively, and ϵ for the residual errors. Table (1) exhibits the slopes, R^2 and *P*-value, at 95% confidence intervals for each predictor variable and the landing of mackerel.

Fig. (4) depicts an overview of the steps and data analysis procedure used in this study **(Jghab *et al.*, 2019)**.

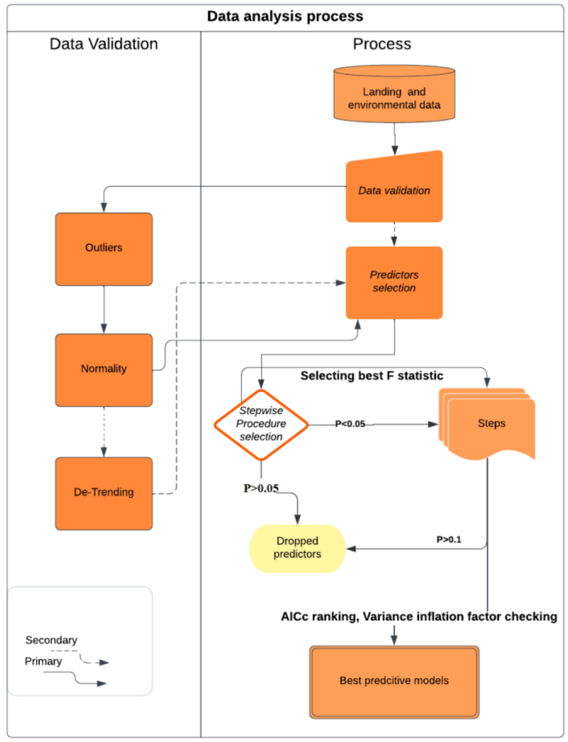

Fig. 4. Flowchart of the data analysis procedure used

RESULTS

1. Tendency of the environmental predictors and landing data

1.1 Environmental predictor's time-evolution

To determine the trends of these environmental factors over time, we used regression analysis against time. The results showed that SST, SSS, and Chl-a increased significantly over time with slopes of 0.02581C° year^{-1}, 0.00638psu year^{-1}, and 0.00601mg m^{-3}/ year , respectively, with R^2 values ranging from 0.422 to 0.622 and $P <$ 0.05.

The wind factors, UWIND and VWIND, also showed a positive trend with time with slopes of 0.0197 and 0.01519, respectively, although their R^2 values were relatively low. On the other hand, NAO showed a negative trend with time, but the slope was not statistically significant (P= 0.269). SLD (mm), which represents a proxy for the nutrient rich Atlantic water jets, showed a negative trend with time with a significant slope of -1.8245mm/ year and an R^2 value of 0.48 ($P <$ 0.05). These findings suggest that several environmental factors have been changing over time, which may have significant impacts on the marine ecosystem (Table 1).

Table 1. Time-trends equations for the environmental predictors

Value	Intercept	Slope	R^2	*P*-value
SST*	-32.7838	0.02581	0.622	<0.001
SSS*	23.5619	0.00638	0.476	<0.001
Chl-a*	-11.7822	0.00601	0.422	<0.001
UWIND*	-39.1741	0.01970	0.136	<0.05
VWIND*	-31.2058	0.01519	0.446	<0.001
NAO*	26.7379	-0.01294	0.034	0.269
SLD*	3668.4212	-1.8245	0.4799	<0.001

*SST= Sea suface Temperatura, SSS=Sea surface salinity, Chl-a= Sea surface chlorophyll a, UWIND= West- east component (+ wind comes from west), VWIND south-north component (+ wind comes from the south), NAO= North Atlantic ocillation index. SLD (Sea surface difference between Cuta and Gibraltar).

1.2 Landing time-evolution

The analysis of the linear regression between abundance and time of four important commercial small fish species in the Mediterranean Sea, *Scomber colias* (Atlantic chub mackerel), *Engraulis encrasicolus* (European Anchovy), *Sardina pilchardus* (Sardine), and *Sardinella aurita* (Round sardinella), revealed significant trend evolution for these four species (Fig. 5).

Since 1983, sardine, anchovy, and sardinella have decreased in the area under study. In fact, several species have significantly declined, particularly the anchovy with a negative trend of -275 tons year^{-1} (R^2: 0.673, $P< 0.05$) and sardine (-299 tons year^{-1}, R^2: 0.285, $P< 0.05$) and with minor intensity sardinella (-39.4 tons year^{-1} R^2: 0.282, $P< 0.05$). On the other hand, mackerel appears to be the only species benefiting from the present circumstances and exhibiting a positive trend. Since 1983, this species has been growing at a rate of 20.3 tons year^{-1} (R^2: 0.157, $P< 0.05$) (Fig. 5).

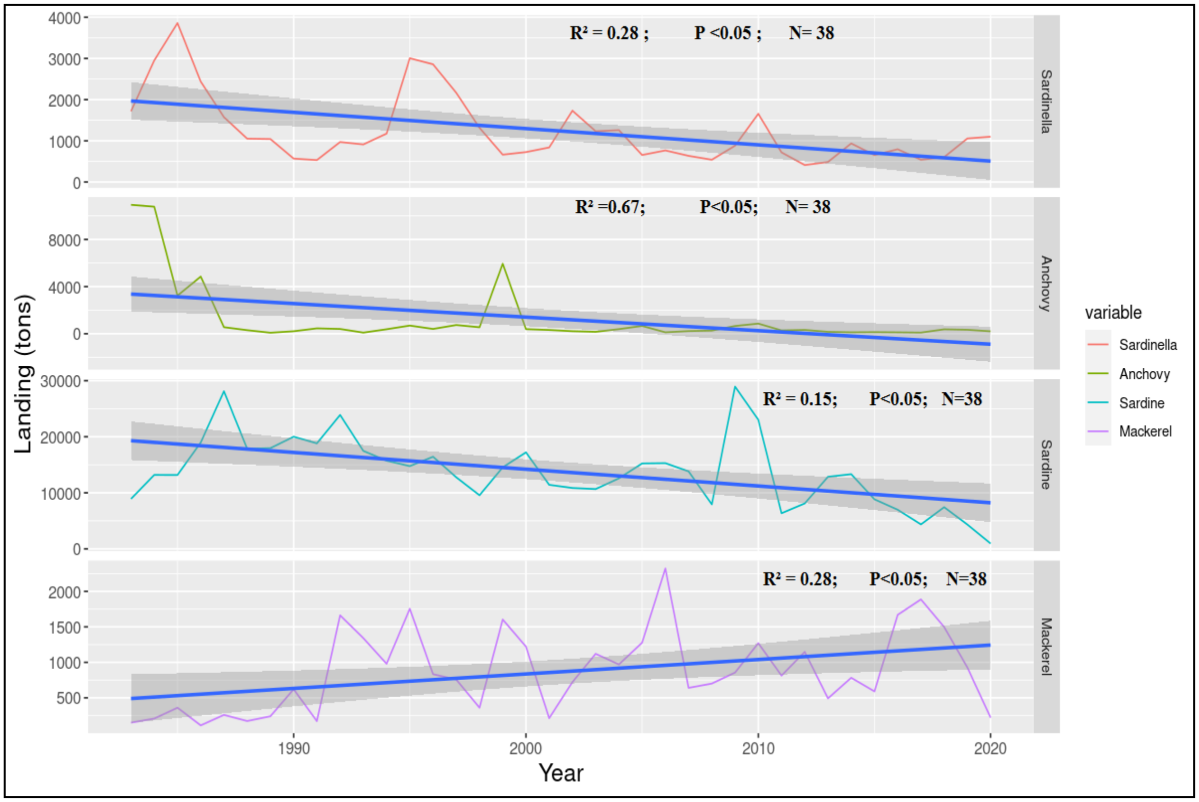

Fig. 5. Landing evolution of small pelagic species in the south Alboran Sea

1.3 Mackerel landing seasonality

The landing of the mackerel species in our study area shows a clear seasonality, with the maximum volume of catches recorded in the summer. The month with the highest landing is June with an average of 131 tons, followed by May with 121 tons (Fig. 6).

A secondary increase was observed during autumn (October), this is mainly due to unprecedented catches in this month during 2017 and 2018 (455 and 400 tons, respectively) (Fig. 6).

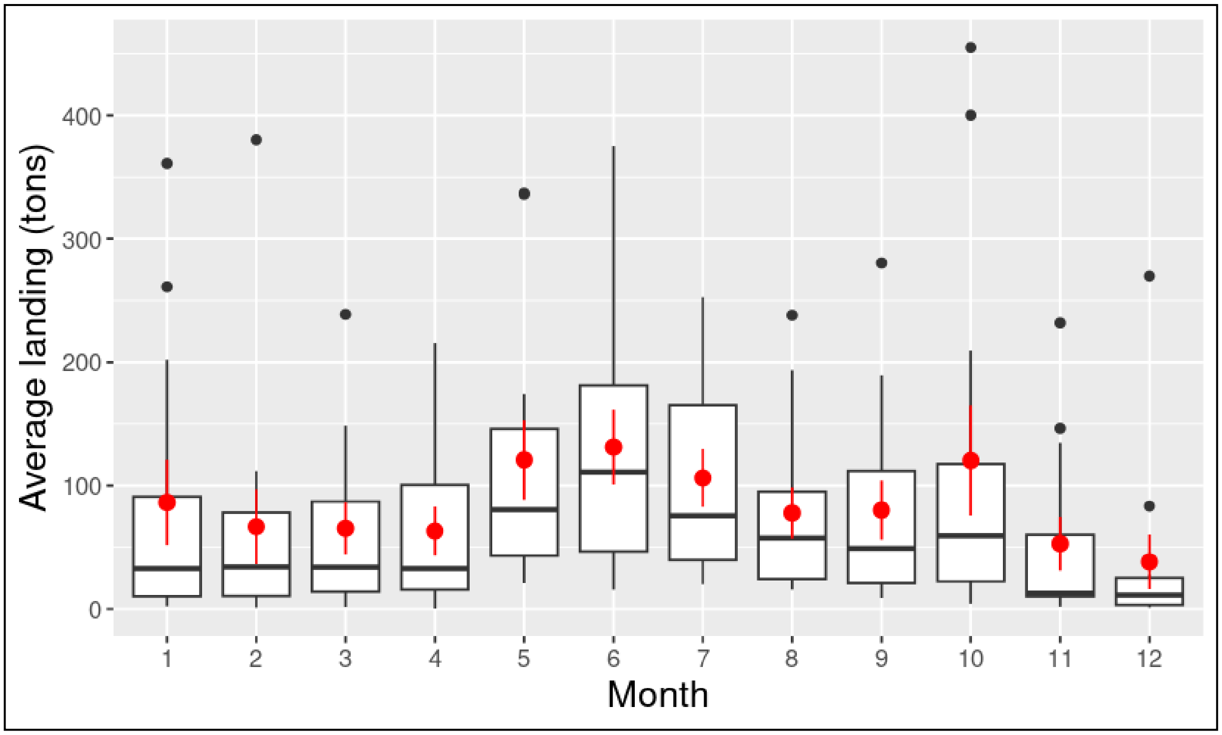

Fig. 6. Seasonality of the Atlantic chub mackerel represented by a box plot of the monthly mean. (Center lines show the medians, red dots show the means, box limits indicate the 25 and 75th percentiles, whiskers extend 1.5 times the interquartile range from the 25 and 75th percentiles, outliers are represented by black dots, and N= 144 sample points)

2. Oceanographic data analysis

2.1 Oceanographic factors evolution

Averaging daily and monthly environmental data collection, yearly means were calculated. The yearly averaged environmental time series for the south Alboran Sea's SSS, SST, Chl-a, SLD, U, and V wind components. Most environmental factors showed a strong long-term trend (Fig. 7).

The warmest year since 1983, with an average annual temperature of 19.53°C, was in 2017, while the highest monthly mean was recorded in August 2010 (25.29°C, not shown). Since 1983, the sea surface temperature had noticeably increased by +0.025°C year-1. SSS showed the highest peak of 36.67PSU in 2010 and a significant long-term increase of +0.0063PSU year^{-1}. Additionally, the log chlorophyll long-term trend was +0.006mg m^{3} year^{-1}, with its highest value in 2018 at 0.43mg m^{-3} (Fig. 7).

The South-Nord V wind component also increased over time, with an average value of +0.019 year^{-1}, and the highest peak was recorded in the same year (2018) at -0.035. In contrast, sea level difference (SLD showed a declining long-term trend since 1983, with a maximum of 114 millimeters recorded in 1990 and an average reduction of -1.82mm year^{-1} annually. On the other hand, U wind showed a somewhat positive trend of +0.0197mm year^{-1} ($P < 0.05$) (Fig. 7).

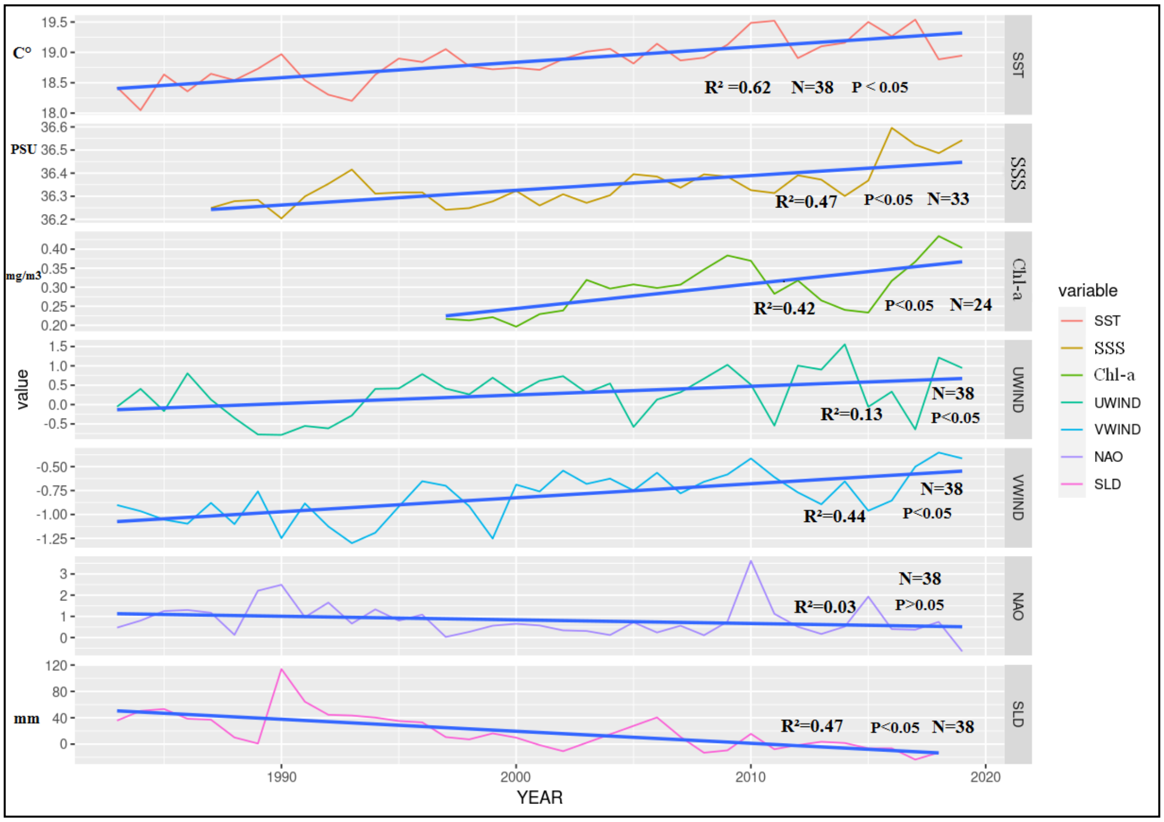

Fig. 7. Evolution of environmental predictors in the study area. (SST= Sea suface temperatura, SSS= Sea surface salinity, Chl-a= Sea surface chlorophyll a, UWIND= West- east component (+ wind comes from west), VWIND south-north component (+ wind comes from the south), NAO= North Atlantic ocillation index), SLD (Sea surface difference between Ceuta and Gibraltar)

3. Models selection results

Sea surface salinity was selected in all the models; this factor must be the most significant driver factor for the Atlantic mackerel in this region. In fact, after using the de-trended time series, SSS was still the most important predictor. It showed a positive relationship with mackerel landing, indicating that this species prefers higher salinity, and its recent increase in the region impacted this species positively (Tables 3, 4).

The second most present predictor in the models resulting from the stepwise analysis was anchovy landing (Table 3). For some reason, this other small pelagic species was positively related to mackerel in both using original and de-trended time series. This positive correlation was not observed with sardine catches since it was not selected in any significant model (Tables 4, 5).

SLD serving as a proxy for the rich Atlantic water jet entering from the strait of Gibraltar seems to be another limiting factor for mackerel since higher values indicate more Atlantic nutrient-rich jets entering the Alboran Sea (Table 3). Actually, the Atlantic water entering the Mediterranean showed a positive correlation with mackerel landing; this can be explained by the fertilizing effect of the AJ (Tables 4, 5)

Sea surface temperature is the third selected environmental parameter; it was selected only using the complete time series, but not using the de-trended data set. This factor also showed a positive relationship with the species thogh it was dropped using the de-trended data, indicating that the effect of this factor on this species is observed only in the inter-annual (seasonal) scale (Tables 3, 4).

On the other hand, Chl-a and V wind were selected only using de-trended time series, and showed two opposite effects (Table 3). For V wind, a positive correlation on mackerel was observed which may imply that northward wind affects mackerel abundance positively. While, high Chl-a seems to have a negative impact on this species (Table 4).

The stepwise approach chose none of the predictors with a one-year lag (all the predictors were from the same year). This could imply that large changes in the environmental predictors chosen may have a quick and instantaneous impact on the abundance of this species.

Table 2. The best models generated by the stepwise analysis and their selected parameters. (md are de-trended models, ANCH is anchovy landing, MAQUR is mackerel landing and SAR is sardine landing, (t-1 are data with one year lag)

Variable	m 1	m 2	m3	md1	md2	md3	md4	md5
SSS	X	X	X	X	X	X	X	X
SST		X	X					
CHL-a						X	X	
VWIND							X	X
UWIND								
NAO								
ANCH	X	X	X	X	X	X	X	X
MAQUR								
SAR								
SLD			X		X	X	X	X
SSS (t^{-1})								
SST (t^{-1})								
CHL-a (t^{-1})								
VWIND (t^{-1})								
UWIND (t^{-1})								
NAO (t^{-1})								
ANCH (t^{-1})								
MAQUR (t^{-1})								
SAR (t^{-1})								
SLD								

All the predictors of the models selected using trended and de-trended time series showed low VIF (less than 5, calculated according to reference to R package, not shown). This means that no variance inflation was detected among predictors.

Using the forward stepwise regressions analysis, three best models using complete time series were generated and ranked according to their AICc. The model number 3 had the lowest AICc and the highest R^2 (0.49) (Table 3)

This model can be written as follow:

$$Model\ m3:$$

$$Mackerel\ Landing(t) = -206900 + 5388\ SSS(t) + 0.12\ ANCH(t) + 618SST(t) + 4.25SLD\ (t)$$

The models highlight the positive relationship between the increase of water jets, salinity, and temperature on this species. The models present also a positive association of anchovy with the landing of A. mackerel.

After using de-trended data, five models were produced following the same stepwise procedure. These models predicted better the A. mackerel landings ranging R^2 between 0.27 to 0.71 (Table 4). For the best model showing the lowest AICc of 329.3 and the highest R^2 (0.71), the model includes SSS, SLD, V wind, Chl-a and anchovy landing (Model md4):

$$Model\ md4:$$

$$Mackerel\ Landing\ dt\ (t) = 126 + 3568\ SSS\ dt(t) + 0.2\ ANCH\ Landing\ dt(t) + 9.8\ SLD\ dt(t) - 1056\ Chla\ dt(t) + 1357\ VWIND\ dt\ (t)$$

*Where, dt: is de-trended data

The models using predictor from the same year (t), with no time lag effect, suggested that the influence of the environmental change on this species can occur during the same year.

Table 3. Best predictive models generated by forward stepwise selection using the original time series

Model	Function	R	*P*-value	AICc
m1	Mackerel landing~ -177300 + (4900 *SSS) + (0.08*ANCH)	0.3348	0.002208	504.487
m2	Mackerel landing ~ -197700 + (5160*SSS)+(0.14*ANCH)+ (567*SST)	0.4071	0.001501	503.4856
m3	Mackerel landing ~ -206900 + 5388*SSS+ 0.12*ANCH+ 618*SST+ 4.25* SLD	0.4896	0.001593	487.9221

Table 4. Best predictive models generated by forward stepwise selection using the de-trended time series

Model	Function	R	*P* value	AICc
md1	Mackerel Landing det ~ 104.5 + (3506* SSS)+ (0.105*ANCH)	0.2739	0.00822	503.68
md2	Mackerel Landing det ~ 139.2 + (4163*SSS det)+ (0.12*ANCH det) +(6.5* SLD det)	0.4329	0.00106	484.13
md5	Mackerel Landing det~145.8+(4375*SSS det)+ (0.13*ANCH det)+ (7.6*SLD det)+ (382.1*VWIND det)	0.4514	0.00214	486.12
md3	Mackerel Landing det~ 120.2 +(2737*SSS det)+ (0.1385*ANCH det)+ (9.4*SLD det)+ (2123*Chl-a det)	0.5841	0.00345	333.56
md4	Mackerel Landing det ~ 126 +(3568* SSS det)+(0.2*ANCH det)+ (9.8*SLD det)+ (-1056*Chl-a det)+ (1357*VWIND det)	0.7193	0.00053	329.30

The three models were generated using complete time series, predicted from 30 to 48% of the variance of the mackerel landing, nevertheless they could generate the overall trend and evolution of the catch of this species. The maximum landing of 2008 is only partially explained by the three models, in contrast the second peak of 2016 was perfectly predicted (Fig. 8).

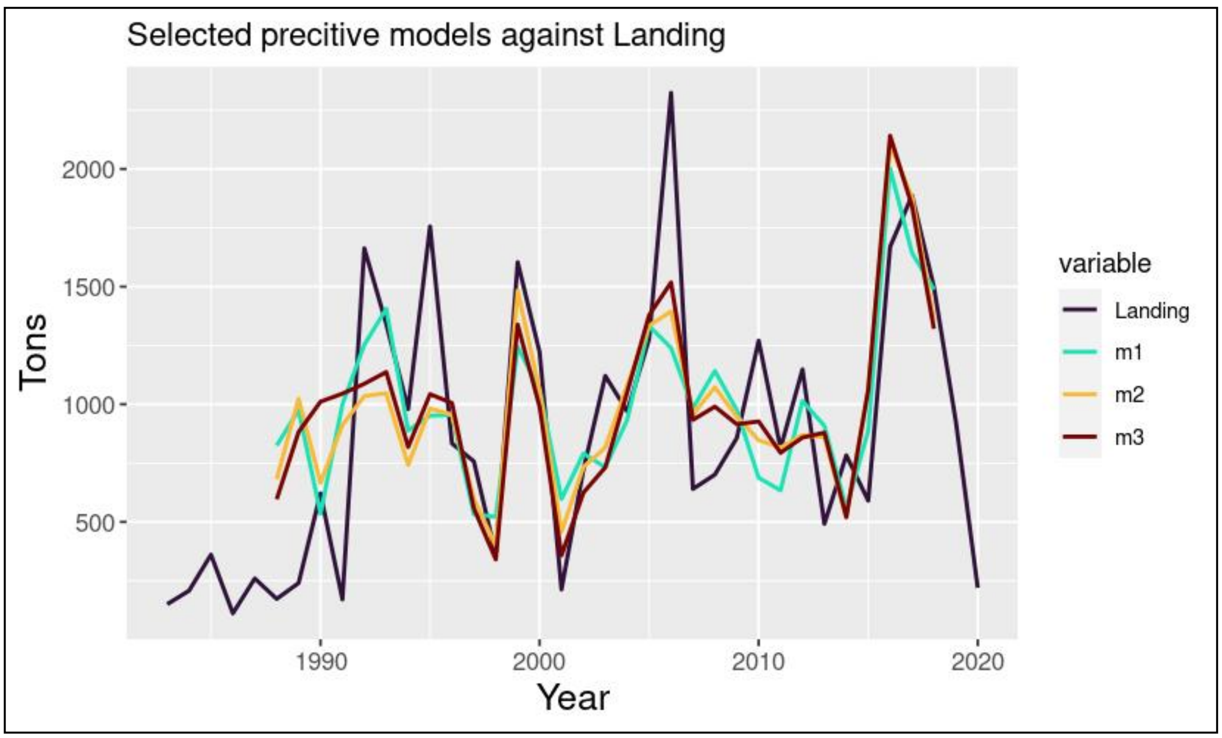

Fig. 8. Best three models predictions using original time-series plotted against landing values of the Atlantic chub mackerel

For the five best models generated using de-trended time series, they predicted from 28 to 71% of the landing variance. Explaining the overall evolution, tendency and variance of the catch of this species. As observed in the previous models, the maximum landing of 2008 could not be totally explained by none of the five models. Thus, other factors, not included in the model, may have caused this irregular increase (Fig. 9).

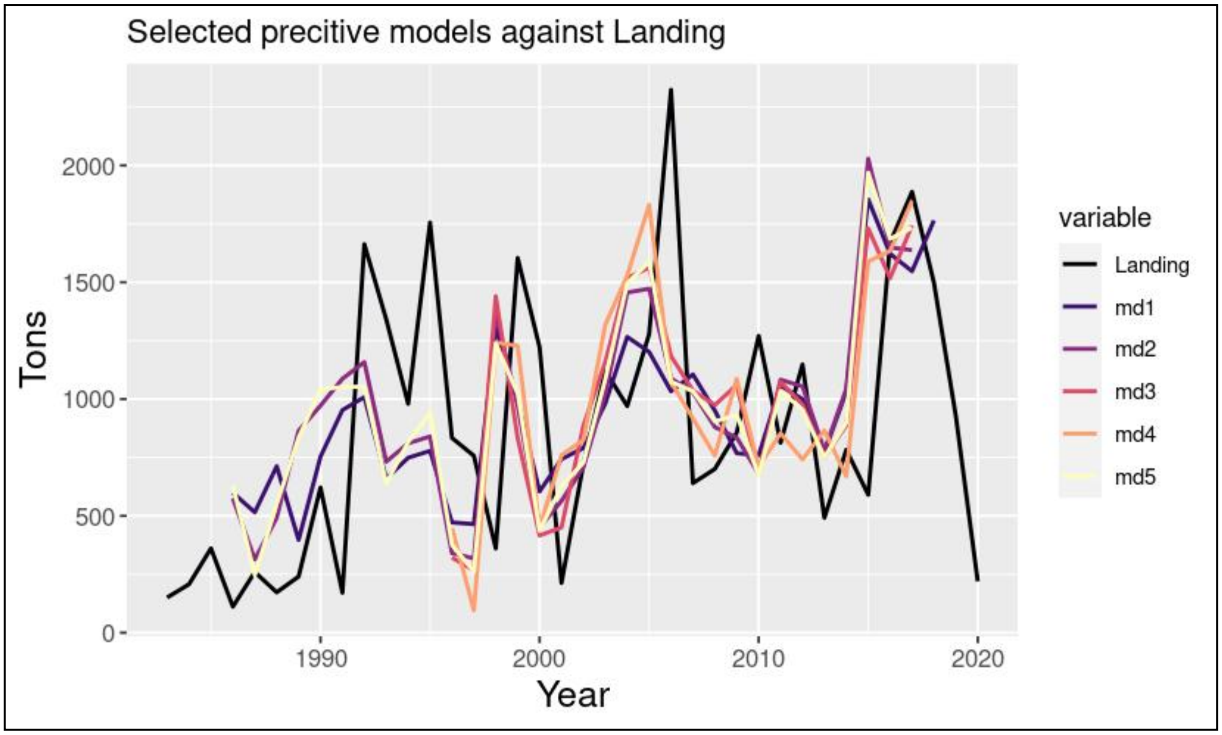

Fig. 9. Best five models selected using de-trended time series plotted against landing values of the Atlantic chub mackerel

DISCUSSION

Few studies have been conducted on the effects of environmental conditions on the Atlantic mackerel, a species of mackerel that is found in abundance throughout the world's oceans. A significant variable influencing the abundance of Mackerel is SSS. Changes in SSS can have an impact on the species' distribution and abundance even though it is known to live in waters with a wide range of salinity levels **(Radlinski *et al.*, 2013)**. Our finding coincides with **Lui *et al.* (2023)** describing that higher SSS was linked to greater mackerel biomass and abundance in the eastern North Atlantic. Mackerel's physiological adaptations to endure salinity variations are probably what contribute to the SSS's beneficial effects on it. In particular, A. mackerel can control its bodily fluids to maintain osmotic balance in varying salinities and has a high tolerance for saltwater **(ICES, 2021)**. As a result, raising SSS may be advantageous for this species population. In contrast, other studies found that declining populations of mackerel have been associated with an extreme increase in sea salinity in some areas such as the case for the study of **Wang *et al.* (2016)**. Nevertheless, **Doray *et al.* (2018)** research demonstrated a correlation between low salinity rich nutrient waters in the Bay of Biscay and enhanced mackerel biomass.

Thus, not salinity itself but oceanographic processes such as fertilization, dispersion or origin of the water mass might be the underlying reason of the positive relation between SSS and A. mackerel abundance/ biomass.

Mackerel abundance and dispersion may benefit from rising temperatures. The ecological temperature range of mackerel tends to move more northward as temperatures rise, presenting the species with better climatic conditions. According to a study by **Jansen *et al.* (2016)**, the abundance and biomass of this species considerably increased in the Greenland waters, with rising sea surface temperature (SST). **Agnalt (1989)** showed that mackerel grew and matured more favorably when temperatures rose within the optimum window. These findings imply that ocean warming brought on by climate change may result in a possible rise of A. mackerel. This is true in our case as the increase of the sea surface temperature showed a positive relationship with the increase in landing for this species. Nevertheless, in other studies, this factor seems to have a negative impact. **Watanabe *et al.* (2010)** found that variations in sea surface temperature can still affect the species' distribution and migration habits. For instance, changes in the distribution and movement of this Atlantic mackerel have been related in some places to the rising sea surface temperatures, which has resulted in population decreases in some areas **(Kim *et al.*, 2021)**.

The Atlantic jets flowing into the region have a substantial impact on animals residing in the Aboran Sea, especially the small pelagic fish species. These jets draw water from the Atlantic that is rich in nutrients, increasing primary production and, in turn, the number of small pelagic fish. **Huertas *et al.* (2012)** found a correlation between the Atlantic jet index and the quantity of sardines and anchovies in the Alboran Sea. **Ruiz *et al.* (2013)** postulated that, the flow of Atlantic water into the Alboran Sea had a considerable favorable impact on the spawning success and recruitment of anchovy, which further substantiated the positive impact. This was demonstrated also in the south Alboran Sea, where the abundance of sardine, anchovy, and in our instance, A. mackerel was positively related with incoming nutrient tich AJ **(Jghab *et al.*, 2019; Jghab *et al.*, 2023)**.

In addition, the wind speed and direction can have a considerable impact on the small pelagic species. Changes in wind speed may affect ocean currents, which may alter the distribution of food resources and the movement of larvae and eggs. For instance, increasing wind speed can increase water column mixing, which reduces phytoplankton concentrations and the amount of food that mackerel species have access to **(Ogawa *et al.*, 2011)**. The direction and speed of wind can also have a positive effect. Small pelagic species' spread and abundance can benefit from favorable wind, such as the relation observed between the northward wind and the landing of A. mackerel species in our study area. This can be explained by the fact that westerlies (+U) can cause upwelling episodes **(Sarhan *et al.*, 2000; Reul *et al.*, 2005)**, which raise primary productivity and transport nutrient-rich water to the surface, increasing the amount of food that small pelagic organisms have access to. Numerous regions, including the Canary current in the Atlantic Ocean and the Central Mediterranean Sea **(Bignami *et al*. 2017)**, have shown a similar impact as increased wind intensity and frequency can result in an increase in the biomass of small pelagic species, viz. anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*).

According to our findings, there is an improbable negative association between the ambient component Chl a (primary production indicator) and the species landing. This component has a negative correlation coefficient and was only included twice in the models. However, in their study, **Kim *et al*. (2022)** demonstrated a beneficial relationship between Atlantic mackerel & primary production.

Since there aren't many studies on mackerel, we can compare these findings to some studies on the well-known small pelagic species (sardine) in the Mediterranean. In the case of this other species, **Abdelaoui *et al.* (2017)** discovered that there is generally little correlation between the abundance of sardine species and chlorophyll in the western part of the south Alboran Sea, a limiting concentration of less than 0.46g/ l was reported despite of a favorable temperature (19°C). On the other hand, **Jghab *et al.* (2019)** found that landing residuals for the sardine were positively correlated with the chlorophyll concentration with a one-year time lag.

According to the results of our study, anchovy catch also served as a significant predictor. This conclusion can be explained by the possibility that these two species coexist in the same habitat or by the close relationship between their respective catch rates. This could also mean that these two species do not compete for prey, and that chub mackerel could feed on this species. Several studies have reported a positive relationship between anchovy and mackerel abundances, indicating that these two species co-occur and share similar ecological niches in the marine ecosystem. For instance, **Bernal *et al.* (2019)** found a strong positive correlation between anchovy and mackerel abundances in the Eastern Pacific Ocean. Similarly, **Zhang *et al.* (2022)** observed a positive relationship between the Spanish mackerel and the Japanese anchovy in the Yellow Sea. They suggested that, the presence of anchovy eggs may have a positive impact on mackerel spawning than environmental factors, indicating the importance of prey for predator's relationship between the two species during the early recruitment phase.

According to **Collette and Nauen (1983)**, **Domanevskii (1988)**, **Patokina (1988)** and **Castro *et al.* (1995)**, fish, zooplankton, and cephalopod mollusks are all part of the Atlantic chub mackerel's varied diet. The feeding range of Atlantic chub mackerel includes fish from three ecological groups, according to a study by **Gushchin *et al.* (2017)**. Juveniles of mass epipelagic species such round sardinella, Cunene horse mackerel, European anchovy, and European pilchard were included in the first category. Mesopelagic species from the Paralepididae and Myctophidae families made up the second group. Whereas, the benthic and bottom species form the third group. Crustaceans and zooplankton have been the secondary food sources for the Atlantic chub.

The distribution and abundance of the Atlantic mackerel and its prey can be influenced by a wide range of environmental conditions. As an important target species, it is important to understand the physical and trophic interactins that trigger its abundance and how A. mackerel abundance might be affected by different climat change scenarios.

CONCLUSION

The possible impacts of environmental and climate change on the Atlantic chub mackerel has been thoroughly evaluated in this study. The findings indicate that this species may be sensitive to sea salinity, temperature, currents, and wind patterns, in addition to anchovy (prey) abundance, and that changes in these variables may affect their abundance, and ultimately, fishing exploitation. These findings demonstrate the need of considering the effects of oceanographic processes in the management of these fishing resources, suggesting that the dynamics of these pelagic fish populations in the Alboran Sea are considerably influenced by the inflowing Atlantic jet.

It was noted how challenging it is to predict how small pelagic species will be affected by climate change due to the lack of established long-term monitoring programs, scarcity of data and the complexity of environmental changes. The impact of environmental changes on ecosystem function in general and small pelagic species in particular requires further research effort in the future.

The management and protection of small pelagic species require a deeper understanding of how climate change and other factors impact these species. To improve our understanding of the effects of climatic changes on these species and the ecosystems that support them, transdisciplinar and basin wide studies and models, joining northern and southern data bases, are necessary.

In conclusion, it should be noted that small pelagics are a crucial part of marine ecosystems and a considerable source of food for both human populations and larger predatory animals. Recognizing and addressing the effects of climate change and other influences on these species is crucial to ensuring their long-term survival and advancing sustainable management and conservation efforts.

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