Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 27(1): 559 – 577 (2023)
www.ejabf.journals.ekb.eg

Climate Scenarios and their Influence on the European Sardine (*Sardina pilchardus*, Walbaum 1792) Fishery Along the Moroccan Coast of the South Alboran Sea

Soufiane HASNI[1*], Sana EL ARRAF[2], Aymane KHAILI[1], Mohammed MALOULI IDRISSI[2], Amina BARAKAT[1]

[1]Biology Department, Faculty of Sciences and Technology - Tangier, Abdelmalek Essaadi University, Tétouan , Morocco
[2]National Institute for Fisheries Research, Regional Center of Tangier, Morocco

[*]**Corresponding Author: Soufiane.Hasni@etu.uae.ac.ma**

ARTICLE INFO

Article History:
Received: Nov. 21, 2022
Accepted: Feb. 19, 2023
Online: Feb. 28, 2023

Keywords:
Sardina pilchardus,
Southern Alboran Sea,
Environmental factors,
Generalized additive model,
Climate change,
RCP

ABSTRACT

Climate change has a significant impact on regional and species levels, leading to a significant drop in biomass in the Southern Alboran Sea (SAS). Hence, research should be focused on determining the regional impact of environmental fluctuations on major marine species. The European sardine (*Sardina Pilchardus*) plays an important role in marine ecology and contributes significantly to the region's economy. The present study revealed the monthly fluctuations of sardine fishery on the Moroccan coast of the Southern Alboran Sea during the period 2009-2021, its relationship with four oceanographic variables (SST, SLA, Phy, and Zoo), and future predictions using two representative concentration pathways (RCPs) scenarios (2.6 and 8.5) for the period 2022-2100. Generalized additive models (GAMs) were built to investigate the links between environmental factors and the species' landing per unit effort (LPUE) and relative effort, and hence analyze the possible consequences of climate change. The GAM model could account for 71.4% and 61.2% of the variance in the LPUE and effort, respectively. Under the RCP 2.6 and RCP 8.5 scenarios, the expected LPUE and effort of the European sardine showed different patterns. In addition, the predicted future potential landing for the period 2022-2100 shows a reduction. According to the study, fishing pressure must be kept at a low and healthy level to maintain a long-term sustainable fishery and mitigate the impact of climate change on the European sardines.

INTRODUCTION

Marine and estuarine fish and fisheries are and will continue to be influenced by greenhouse gases (**Roessig *et al.*, 2004**). Marine communities makes qualitative and quantitative projections of marine ecosystem responses to the environmental changes caused by the greenhouse gasses based on climate change projections from the Intergovernmental Panel on Climate Change (IPCC) (**Bindoff *et al.*, 2007; Hollowed *et al.*, 2013**). The climate change manifests itself in the oceans by increasing inland ocean temperatures (**Blunden *et al.*, 2018; Cheng *et al.*, 2019**), raising sea levels (**Nerem *et al.*,**

2018), a dramatic shift in oceanic stratification, circulation, light availability in the surface ocean, dissolved oxygen, and salinity (**Daw *et al*., 2009; Denman *et al*., 2011; Doney *et al*., 2012**), all these factors caused the changes in primary production (**Sarmiento *et al*., 2004**), which influence the food web (**Brander, 2003**).

Environmental variables(such as temperature, salinity and food variability) might have a substantial impact on the abundance and dispersion of small pelagic fish (SPF), SPF with rapid production rates is highly susceptible to the impact of climate change (**Rijnsdorp *et al*., 2009; Muhling *et al.*, 2017**). **Sund *et al*. (1981)**, and **Fréon and Misund, (1999)** revealed that pelagic species can sense temperature changes, which lead them to migrate to regions that are more suitable to their metabolism or locations where there is a larger availability of prey. The sardine diet has consisted of both zooplankton and phytoplankton (**Costalago *et al*., 2012, 2014; Barroeta *et al*., 2017**). Thus, changes in plankton primary and secondary productions might have an impact on larval survival and spawner's health (**Brosset *et al*., 2015, 2016**).

According to **FAO (2016, 2018)**, 40% of the total fish captured are represented by Small pelagic fish (SPF) stocks such as European sardine (Sardina pilchardus) with (186,100 tons/year), since the 1990s, the Mediterranean has seen a decrease in the biomass and landings of several species (**Vasilakopoulos *et al*., 2014**). The warming of the Mediterranean Sea is expected to keep increasing which causes its deterioration (**Salat *et al*., 2019**). This calls into doubt the distribution and abundance of SPF in this area in the future, a matter of ecological and economic concerns (**Pennino *et al*., 2020; Gordó-Vilaseca *et al*., 2021**).

Thus, the process is frequently guided by ecological modelling approaches in general and species distribution models (SDM) in particular (**Gordó-Vilaseca *et al*., 2021**). Generalized Additive Models (GAM) can provide the possibility to examine the interactions between the response and the independent variable. This study's main objective was to determine how the European Sardine Fishery responded to changes in the relevant environmental factors in the SAS, specifically Sea Surface Temperature (SST), Sea Level Anomaly (SLA), the concentration of phytoplankton (Phy) and Zooplankton (Zoo). In this paper, GAM was implemented to the weighted Landing Per Unit Effort (LPUE), relative Effort, and environmental datasets to study the impacts of environmental factors on the fisheries for European Sardine and to predict the fishery's potential pattern under RCP scenarios 2.6 and 8.5.

MATERIALS AND METHODS

1. *Study area*

The study area comprised the Southern Alboran Sea (SAS) (Moroccan shores) (35-36N and 2-5W), which is considered part of the South-Western Mediterranean (**Fig. 1**).

Sardina pilchardus is the most important small pelagic fish (SPF) targeted by the purse-seiners in this area, according to logbook data from 2009 to 2022, with an average catch of 8400 tons per year and about 6,385,903 US dollars per year.

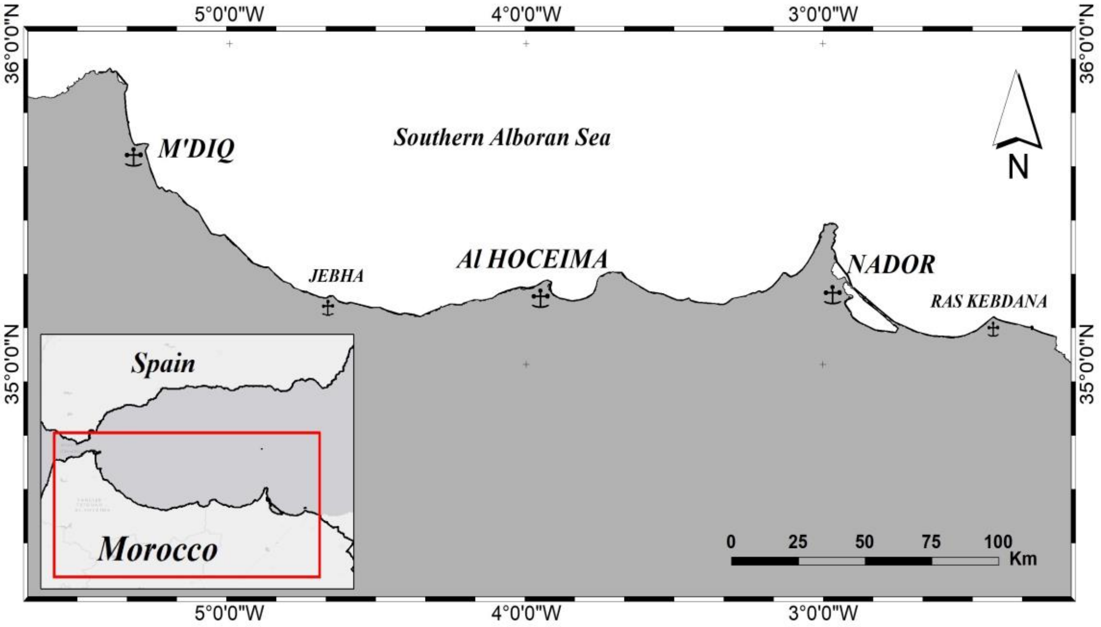

Figure 1. Study area along the Southern Alboran Sea.

2. *Oceanographic Data*

The data of oceanographic variables along the Southern Alboran Sea (SAS), were downloaded from **Coopernicus Marine Service** (CMEMS website), and **Climate4Impact** and monthly averaged. The data source, as well as the period, and resolution were shown in **Table 1.**

Table 1. Environmental variables data source used in this paper.

Variable	*Units*	*Spatial*	*Period*	*Source*
SST	°C	0.042°	1998 -2021	**Coopernicus Marine Service**
Phy	mmol.m^{-3}	0.042°	1999 -2021	
SLA	m	0.125°	1998 -2021	
Zoo	mmol. m^{-3}	1°	1998 -2021	**Climate4Impact**

The radiative forcing on Earth at the end of the twenty-first century would increase by 2.6 W.m^{-2} and 8.5 W.m^{-2}, respectively, under different climate change scenarios, RCP 2.6 and RCP 8.5 (**Meinshausen *et al*., 2011; Alexander *et al*., 2018; Maynou *et al*., 2020**). These scenario data were gathered from the IS-ENES (Infrastructure for the European Network for Earth System Modelling) project's CMIP5 climate model (**https://climate4impact.eu**/).

3. *Catch and Effort data*

The fishing Effort associated with LPUE is a crucial factor in fish stock assessments to assess fish stock status for efficient management as it is highly correlated to fishing mortality (**Hussain *et al.*, 2021**). Thus, the response variables in the current study were Effort and LPUE. For that, sardine catch and Effort data were collected from the fisheries laboratory of the Moroccan National Institute of Fisheries Research, which covered the landing of the Southern Alboran sea's (SAS) main ports (**Fig. 1**). The fishery data were daily available from 2009 to 2020, including daily SPF captures (in kg), landing ports, and daily fishing Effort by each fleet. The monthly Landings Per Unit Effort (LPUE) was calculated by dividing monthly landings by fishing Efforts. Monthly sardine landings, monthly fishing Effort, and monthly LPUE are all included in the scope of this research.

$$LPUE = \frac{\sum Landing}{\sum Effort}$$

4. *Construction of GAM models*

The GAM is a semi-parametric extension of the GLM that accepts smooth components and additive functions. GAMs can manage relationships between response and predictor variables that are non-linear and non-monotonic (**Guisan *et al.*, 2002**). The following is how the GAM equation was implemented:

$$g(Y) = a + \sum_{i=1}^{n} S_i(X_i) + \varepsilon$$

Where g is the link function, Y is the response variable (LPUE and Effort), X_i is the predictor variable (Months, SST, SLA, Phy, and Zoo), S_i is a spline smoothing function for each model predictor X_i, a is model constants, and ε is a random error (**Wood, 2017**).

The "mgcv" package uses "R" to build GAM in this case (**Wood, 2017**). To predict the LPUE and Effort distribution of the Sardine, all models used environmental factors as predictor variables. The model was constructed step by step, with the lowest Akaike Information Criterion (AIC) score being used to select predictor variable sets.

5. *Model selection, validation and prediction*

In GAM, when various predictor variables are added, the deviance explained and Akaike's Information Criterion (AIC) both vary. The predictor variable's contribution, the significance of the p-value, the highest deviance explained values, the highest adjusted R-square (R-sq) values, and the lowest AIC values were used to choose the adequate models (**Johnson and Omland, 2004**).

Yen *et al*. (2016) used GAM models to forecast the catch potential of *Skipjack Tuna* in the western and central Pacific Ocean under various RCP scenarios. Similarly, **Aneesh Kumar *et al*. (2020)** used GAM models to identify the effect of seawater salinity and temperature on the variety of *Thunnini* species' larval abundance in Indian waters. Thus, GAM models are effective tools for forecasting future processor performance. The current study used GAM models with methods from the R software's mgcv package to calculate LPUE, Effort and catch. 70% of the data was used to assess the variance between predicted and original values to evaluate the models' prediction performance. This was evaluated based on the root mean squared error (RMSE), the best prediction performance is correlated with a lower RMSE.

6. *Future Landing estimation*

The Landing potential of European sardines from 2022 to 2100 was calculated by the equation below:

$$LA(m) = LP(m) * EF(m)$$

where EF(m) and LP(m) are respectively the predicted Effort and LPUE for relevant months of the period from 2022 to 2100.

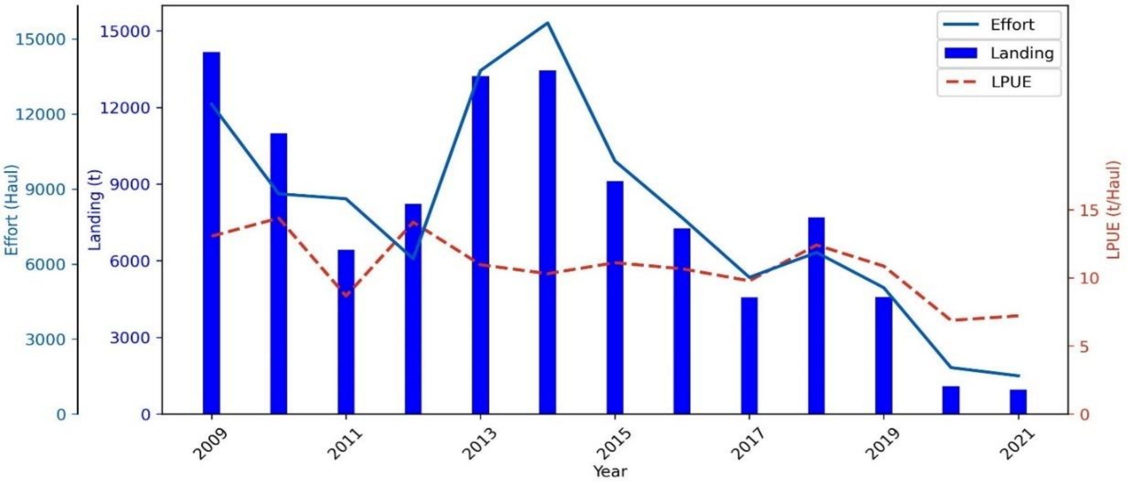

Figure 2. Fishery trend of European Sardine along the SAS during 2009–2021.

RESULTS

1. *European sardine fishery changes*

Since 2009, there have been considerable fluctuations in the sardine fishery along the coast of Morocco in the SAS, as shown in **Fig. 2**. The highest landing of European sardine was in the year 2009 with 14168,7t. After 2009, the fishery had a drastic decline and reached a low point in 2021. Then, there was a step increase in the fishery landing and Effort from 2012 to 2014. Finally, the later years witnessed a gradual decrease to reach a minimum value with 948t and 1529 haul respectively of the landing and Effort in 2021. For the LPUE, there have been slight fluctuations with a maximum value of 14,38 t/Haul in 2010 and a minimum value in 2021 with 7.2 t/Haul.

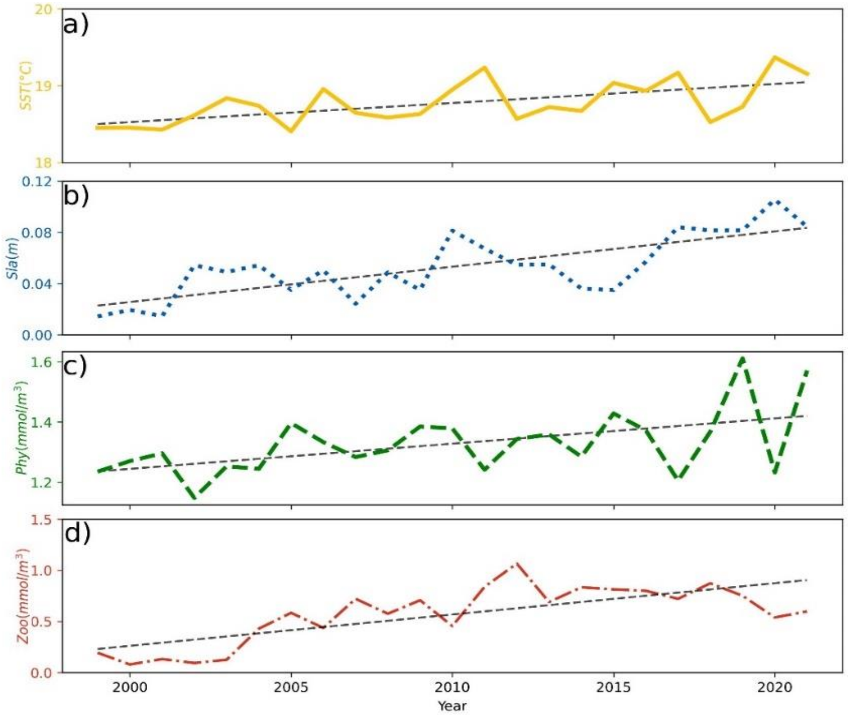

Figure 3. Trend of environmental variables along the SAS; (a) Sea Surface Temperature (SST), (b) Sea Level Anomaly (SLA), (c) Phytoplankton concentration (Phy), and (d) Zooplankton concentration (Zoo) during 2009 to 2021.

2. *Environmental variability*

The trend of environmental factors represented in (**Fig. 3**) depicts a fluctuation along the SAS. The SST, SLA, Phy, and Zoo averages (**Figs. 3a**, **3b**, **3c** and **3d**) show a gradual increase respectively between 2000 and 2021. The highest SST, SLA, Phy and Zoo average values were observed respectively in 2020, 2020, 2019, and 2006. While, the lowest values were witnessed respectively in 2005, 1999, 2002, and 1998.

3. *Future environmental projections*

The future temporal fluctuations of environmental factors in the SAS region under two scenarios (RCP 2.6 and RCP 8.5) are presented in **Fig. 4**. For RCP 2.6, the SST is expected to rise until 2070, then stabilize until 2100, and the SLA remains to rise, the Phy and Zoo are positively correlated, and predicted to decrease slightly until 2070, then increase slightly till the end of the 21st century. Whereas for RCP 8.5, the SST and the SLA are expected to rise until 2100, and the Phy and Zoo are predicted to gradually decrease till the end of the 21st century.

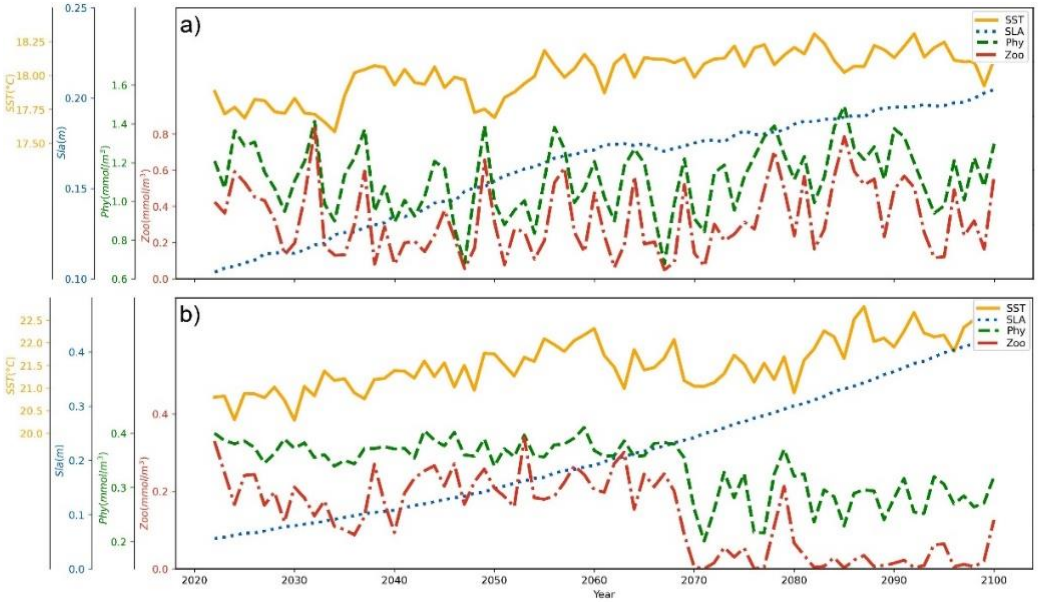

Figure 4. Evolution of the climate change scenarios (a) RCP 2.6 and (b) RCP 8.5 for the period 2022 - 2100; (yellow) Sea Surface Temperature (SST), (bleu) Sea Level Anomaly (SLA), (green) Phytoplankton concentration (Phy), and (red) Zooplankton concentration (Zoo).

Table 2. Assessment of p-value, df, DE, and the AIC of each variable for the LPUE and Effort model.

	Variable	*P-value*	*df*	*DE %*	*AIC*
LPUE model	*S(Months)*	$<2e^{-16}$ ***	5.267	47.1	9.3
	S(SST)	$3.9e^{-06}$ ***	2.661	21.4	37.4
	S(SLA)	$<2e^{-16}$ ***	2.282	31.6	18.6
	S(Phy)	$8.7e^{-07}$ ***	1	18.4	38.1
	S(Zoo)	$<2e^{-16}$ ***	2	25.8	27.5
Effort model	*S(Months)*	0.0009 ***	4.269	17.1	1950.3
	S(SST)	0.0008 ***	1.645	10.9	1953.4
	S(SLA)	0.032 *	3.674	10.3	1959.1
	S(Phy)	$4.6e^{-06}$ ***	1.378	18.8	1940.4
	S(Zoo)	$9.1e^{-05}$ ***	2.001	13.4	1949.5

Table 3. DE, Adj-R², and AIC values of LPUE and Effort selected GAM models.

Model	*DE (%)*	*Adj-R²*	*AIC*
LPUE ~ S(Months) + S(SLA) + S(Zoo)	48	0.446	7.21
LPUE ~ S(Months) + S(SLA) + S(SST)	48.9	0.457	9.93
LPUE ~ S(Months) + S(SLA) + S(SST) + S(Zoo)	49	0.459	6.99
LPUE ~ S(Months) + S(SLA) + S(SST) + S(Zoo) + S(Phy)	50.8	0.461	6.51
Effort ~ S(Phy) + S(Months) + S(Zoo)	24.6	0.206	1940.2
Effort ~ S(Phy) + S(Months) + S(SST)	22.9	0.2	1939.5
Effort ~ S(Phy) + S(Months) + S(Zoo) + S(SST)	23.7	0.204	1939.5
Effort ~ S(Phy) + S(Months) + S(Zoo) + S(SST)+ S(SLA)	37.3	0.317	1924.2

4. *The interactions with environmental factors*

The relationships between LPUE and the Effort of the European Sardine and environmental conditions in the SAS were investigated in this paper. The environmental factors included in models, their degree of freedom (*df)*, Deviance explained (*DE*), p-values, and AIC are shown in **Table 2**. Given the relevance of the predictor variables revealed in the LPUE and Effort models, all these factors must be included in the model (**Table 3**). The models with the highest *DE* and *adj-R²*, and the lowest AIC were selected as the best.

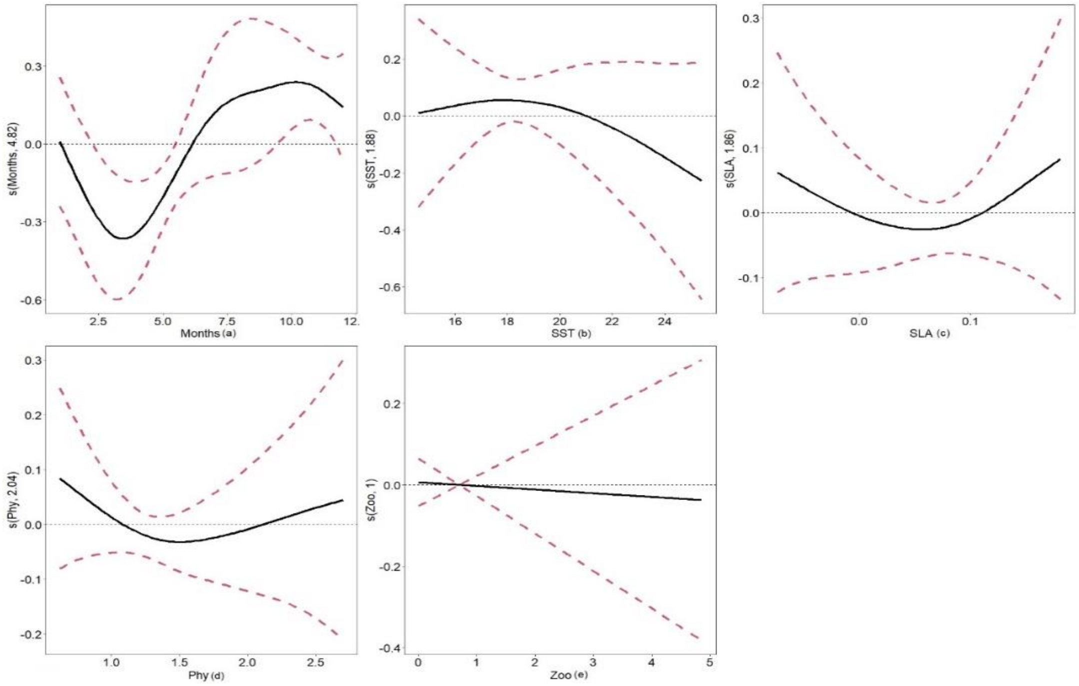

Figure 5. Relationships between environmental variables and *Sardina pilchardus* LPUE derived from the best GAM models between 2009 and 2020 showing the effect of Months (a), SST (b), SLA (c), Phy (d) and Zoo (e). The dashed line intervals represent 95 percent point-wise prognostic.

The model evaluation results for the LPUE and Effort models are illustrated in **Figs. 5** and **6**. The correlation between predicted and actual values were significant, with 71.4% for the LPUE model (**Fig. 7a**), and 61.2% for the Effort model (**Fig. 7b**).

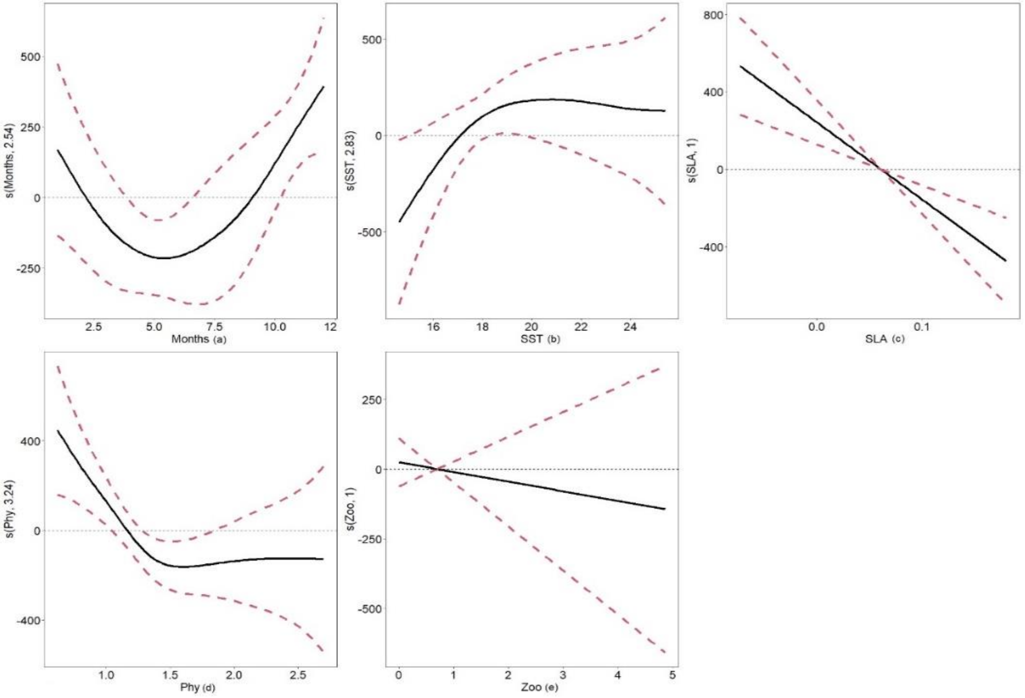

Figure 6. Relationships between environmental variables and *Sardina pilchardus* Effort with 95% ci derived from the best GAM models between 2009 and 2020 showing the effect of Months (a), SST (b), SLA (c), Phy (d) and Zoo (e). The dashed line intervals represent 95 percent point-wise prognostic.

The predicted GAM plots for all variables in the LPUE model are presented in **Fig. 5**. The LPUE increases when the SST is between 15 and 21° C (**Fig. 5a**). Furthermore, an increase in SST above 21°C reduces the LPUE significantly. A positive effect on European Sardine LPUE is observed at SLA below 0 m and above 0.1 m, yet at SLA between 0 m and 0.1 m, a progressive decline is noted (**Fig. 5c**). Also, a decrease in the LPUE was revealed with Phy between 1 and 2 mmol/m^3 (**Fig. 5d**). In addition, the LPUE has a positive relationship with Zoo between 0 and 0.7 mmol/m^3.

According to Effort GAM plots of the SAS shown in (**Fig. 6**), fishing Effort is expected when the SST is above 17°C, the SLA value is below 0.06m, the Phy value is below 1.2 mmol/m^3, and the Zoo value is observed below 0.7 mmol/ m^3.

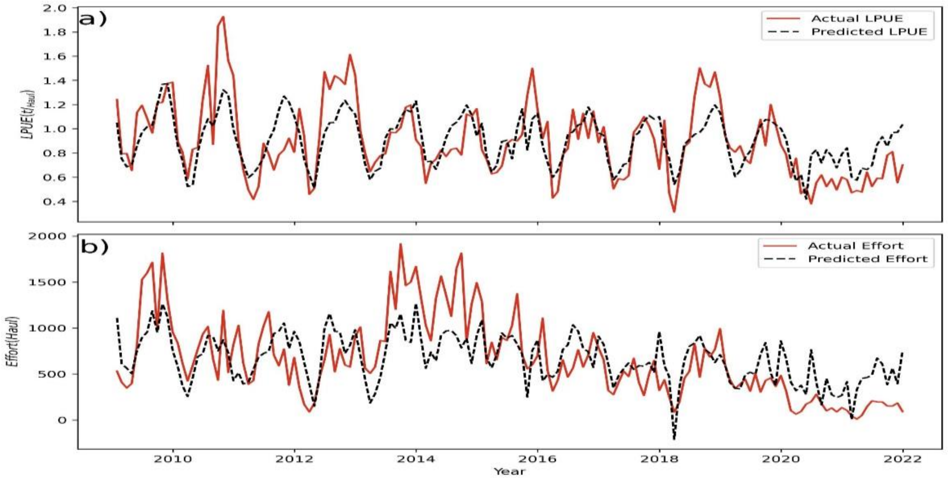

Figure 7. The model evaluation outputs for the LPUE (a) and Effort (b) GAM models for the SAS zone.

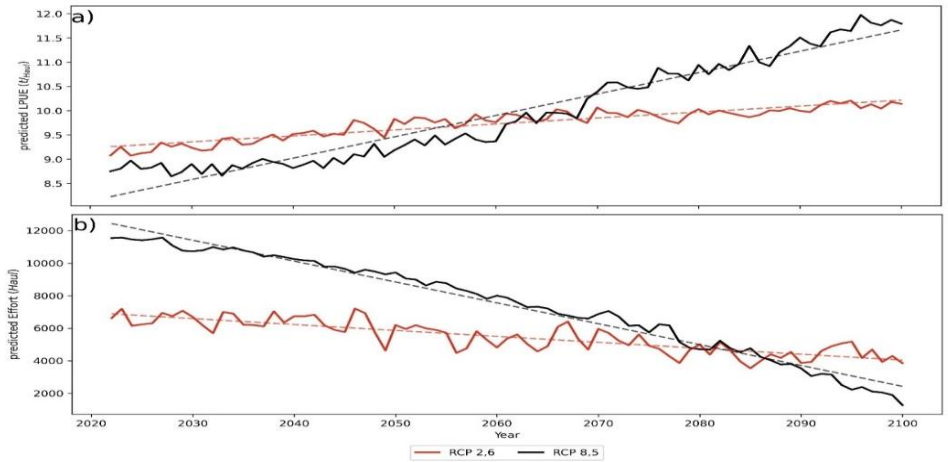

Figure 8. Predicted LPUE (a) and Effort (b) of European Sardine (*Sardina Pilchardus*) for Scenarios RCP 2.6 (Red) and RCP 8.5 (Black).

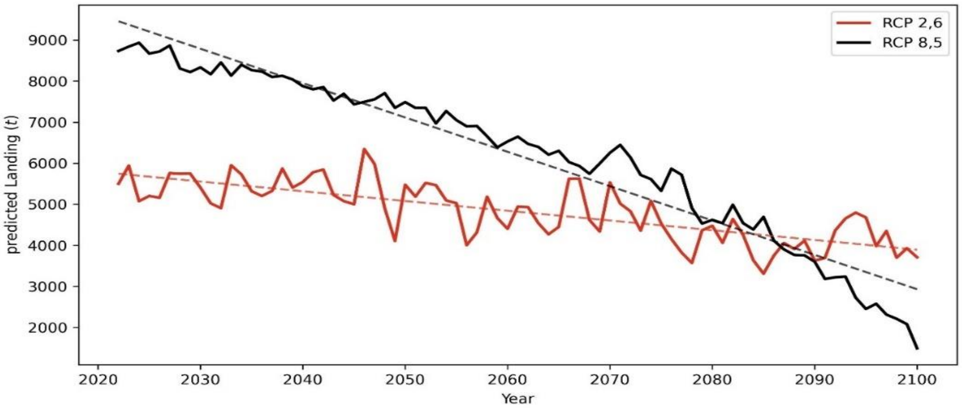

Figure 9. Predicted Landing potential of European Sardine (*Sardina Pilchardus*) for Scenarios RCP 2.6 (Red) and RCP 8.5 (Black) in the SAS Zone.

5. *European sardine expected LPUE, Effort, and Landing potential.*

The landing potential of the European sardine along the SAS for the period 2022-2100 was calculated using monthly LPUE and Effort values. The predicted LPUE obtained shows an increase for both scenarios, Furthermore, it's higher between 2022 to 2060 in RCP 2.6 when compared to RCP 8.5. Though the LPUE in RCP 8.5 shows an increasing trend compared to RCP 2.6 from 2060 towards 2100 (**Fig. 8a**). The predicted Effort drops significantly over time under both scenarios **(Fig. 8b**). Yet the RCP 8.5 shows a drastic decrease compared to the RCP 2.6. The observation of the landing potential (**Figs. 9** and **10**) shows a decline in the trend under both scenarios, with a decrease of 19% for the RCP 2.6 and 75% for the RCP 8.5.

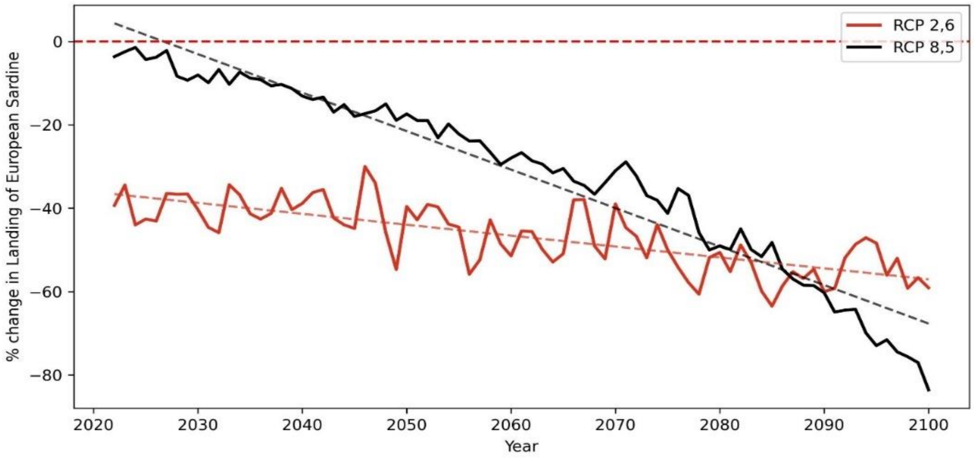

Figure 10. Annual basis percentage change in the predicted European Sardine catch compared to the 2009–2021 average.

DISCUSSION

GAM models based on data have proved to be effective at describing interactions between a fish distribution and the environment, as well as predicting future distributions (**Rutterford *et al*., 2015; Solanki *et al*., 2017; Aneesh Kumar *et al*., 2020; Hussain *et al*., 2021**). Additionally, due to the expensive costs, purse seiners only take action when a large school of fish is observed. LPUE and Effort-based models are appropriate for evaluating fisheries abundance and distribution in relation to environmental factors (**Yen *et al*., 2016**). European Sardine is considered the most important SPF along the SA coast, either ecologically or economically. The current study results, which used LPUE and Effort-based GAM models, reveal that all selected environmental factors have an impact on the SAS *Sardina pilchardus* fishery. According to the analysis, the order of environmental factors' effect on the LPUE of the European Sardine is SLA > Zoo > SST > Phy, and for Effort, it is Phy > Zoo > SST > SLA (**Table 2**). Although the weak impacts of the factors individually, the cumulative impact of all variables could explain 50% and 37% respectively of the variance in LPUE and Effort.

The findings of the GAM model show that the fish is particularly sensitive to SLA. thus, for the LPUE, the period that SLA is between 0 and 0.1 m corresponds to the period of the fishing ban (sardine breeding season) in the SAS which is between January and April, and for the SLA above 0.1 might correspond to the inner tide mixing from the Strait of Gibraltar or frontal regions, as well as the cyclonic circulation in the northern Alboran Sea, which is associated with a considerable primary production (**Garcia-Gorriz and Carr, 2001; Ruiz *et al.*, 2001; Oguz *et al.*, 2014; Jghab *et al.*, 2019**). And for the Effort, the period that SLA is between 0.05 m a significant drop in fishing Effort, which is linked to bad weather periods.

The majority of research supports that the *Sardina Pilchardus* is planktivorous and eats a variety of species (phytoplankton and zooplankton) (**Catalan *et al.*, 2010; Nikolioudakis *et al.*, 2011, 2012, 2014**). The GAM's results indicate that Zoo and Phy have a negative correlation with LPUE and Effort, which strongly suggests that it has a direct impact on sardine abundance, this correlation can be explained by the fact that the maximum values of the Concentration of Phy and Zoo are between January and April correspond to the spawning season (ban of fishing), and the minimum values correspond to the fishing season.

The GAM model's findings reveal that the European sardine is also sensitive to SST. As a result, the LPUE increase at a temperature between 15 and 21°C. Also, the Effort increase at a temperature above 17°C. Furthermore, the *Sardina Pilchardus* has a positive correlation with the SST, which shows a decrease in the landing from January to April (ban of fishing). The SST in this period is below 15°C and corresponds according to **Palomera *et al.* (2007)** and **Schismenou *et al.* (2016)** to the spawning period, which seems to be triggered in Autumn and attains its pick in Winter when waters are richer in Phytoplankton and Zooplankton and less demanding regarding metabolic cost. The rise in the landing from April to August was explained according to **Giannoulaki *et al.* (2011)** and **Schismenou *et al.* (2016)** by the growth rates increasing of juveniles and adults affected by the SST.

Using GAM models, the predicted LPUE of RCP 2.6 and 8.5 during 2022-2100 increases, which is more severe in RCP 8.5 (**Fig. 8a**). In contrast, the predicted Effort for Both RCP scenarios indicates a significant decline over time. The predicted potential landing of European Sardine under both RCP scenarios indicates a decrease through the end of the 21st century (**Hussain *et al.*, 2021**).

The increased fishing Effort at the beginning of the upcoming years might cause a drastic decline in the prey population of SPF like sardines and mackerel (**Vivekanandan *et al.*, 2005; Boyd *et al.*, 2020; Hussain *et al.*, 2021**). This might eventually lead to a rise in SPF biomass, followed by a phase shift and stable or dropping landings (**Pauly *et al.*,**

1998) which explains the decrease (**Fig. 9**) in the European Sardine landing under both scenarios. Similar findings were also reported for Indian oil sardine (**Sajna *et al.*, 2019a, b**) and Indian mackerel (**Hussain *et al.*, 2021**) which show a decrease in Effort, an increase in LPUE and a drop in landing potential under RCP scenarios (RCP 2.6 and 8.5).

Furthermore, under RCP 2,6 a significant decrease (-19%) in catch potential towards 2100. Otherwise, under RCP 8.5, a drastic drop in landing potential (-75%) towards 2100. The catch variation within RCP projections shows how sensitive the fish are to various climatic variables, such as SST, SLA, Phy, and Zoo (**Pörtner and Peck, 2010; Pankhurst and Munday, 2011; Zacharia *et al.*, 2020**). Additionally, given the unfavorable habitat factors provided by RCP 8.5, the requirement for increasing plankton production to maintain the grazing population won't be satisfied after the pelagic population achieves maximum biomass. Additionally, compared to the same years of the RCP 8.5, the RCP 2.6 scenario shows lower SST (18 C), SLA below 20 cm, higher Phy (>1.40 mmol/m^3), and higher Zoo (>0.8 mmol/m^3), which could offer the Species a better condition of surviving. The disparity in landing potential also suggests the need for fishery management since RCP 2.6 is more controllable and sustainable than RCP 8.5 (**Hussain *et al.*, 2021**).

Although LPUE has increased, it cannot be interpreted as an indication of the species' abundance since research has shown that LPUE alone is not a reliable indicator of fish abundance (**Gillis and Peterman, 1998; Maunder *et al.*, 2006; Beverton and Holt, 2012**). One of the most prevalent forms of non-proportionality which imply increased LPUE values as abundance drops is known as "hyperstability", which can occur a biomass overestimation (**Swain and Sinclair, 1994; Maunder *et al.*, 2006; Hilborn and Walters, 2013**). **Fonteneau *et al.*(1999)** predict that areas with greater CPUE, lower Effort, and fewer catches will have lower fish biomass than those with lower CPUE, higher Effort, and lower catches. Additionally, it has been shown that the greatest indicator of low biomass is typically thought to be reduced Effort (**Fonteneau *et al.*, 1999; Harley *et al.*, 2001**). According to relevant data (**Fig. 2**), the landing and Effort of the European sardine indicate an early rise followed by a strong decline, while the LPUE is stable. This suggests that the biomass of European Sardines is slowly disappearing in the study area, which may be due to climate change, increased resource exploitation, or a combination of both. Additionally, **Lotze *et al.* (2018)** and **Boyce *et al.* (2020)** suggest that 'trophic amplification' may lead fish and marine mammals to be more vulnerable to climate change by causing more severe decreases compared to phytoplankton.

Being an SPF, the European Sardine plays an important role in food webs by transporting energy from plankton and other tiny animals to larger fish, seabirds, and marine mammals. Furthermore, because European sardine is considered a cheap delicacy that increases the protein intake of poor men (**Shyam *et al.*, 2015**), it plays a vital role in fish food security in the SAS region. In addition to financial loss, the decline in European sardine abundance also reduces fishing activity and employment days. As a result, it is predicted that the decreased sardine landing in both climate scenarios in the fishery would have an impact on the economy, the environment, and food security. This highlights the urgent need for sustainable fishing methods.

CONCLUSION

The paper describes the variations and trends in environmental variables along the SA coast. The European Sardine fisheries predictions indicate that in the absence of the acclimatization of that species, it could result in a decrease in the distribution and abundance throughout the Mediterranean coast, which would have an impact on the fishery. Since Sardine is an important fish stock resource and a species of fish that is principally consumed in Southern Alboran cities, its catch variations in connection to climate change are concerning and indicate the immediate need for sustainable exploitation of the resources. The present study also demonstrates that Data-driven GAM models have shown to be effective tools for examining connections between a fish distribution and the environment and are similarly significant in distribution prediction in the future. The GAM model projections may be improved to get more precise forecasts for fisheries management by adding more predictor variables and then refining the model.

FUNDING

This study was written as part of a PhD program financed by Abdelmalek Essaadi University's thematic project on the blue economy in the Tangier – Tetouan - Alhoceima area (Mediterranean coast).

ACKNOWLEDGEMENT

We are grateful to Abdelmalek Essaadi University for the valuable funding, Dr. Mohsine BENNANI MECHITA (Abdelmalek Essaadi University), Mr. Aymane JGHAB (National Institute for Fisheries Research), Mr. Mohamed KEZNINE (Abdelmalek Essaadi University), and Ms. Yousra LAHMIYED (Ibn Tofail University) for their valuable discussions, comments, and advice on the manuscript. We also would like to especially thank the National Institute for Fisheries Research for their reception and their collaboration in the fisheries laboratory as part of a doctoral internship.

REFERENCES

Alexander, M.A. ; Scott, J.D. ; Friedland, K.D. ; Mills, K.E. ; Nye, J.A. ; Pershing, A.J. ; Thomas, A.C. (2018). Projected sea surface temperatures over the 21st century: Changes in the mean, variability and extremes for large marine ecosystem regions of Northern Oceans. Elementa. https://doi.org/10.1525/elementa.191

Aneesh Kumar, K. V. ; Deepa, K.P. ; Muhammed Rafeeq, M.M. ; Sree Renjima, G. ; Manjebrayakath, H. ; Smitha, B.R. ; Saravanane, N. ; Prabhakaran, M.P. ; Sanjeevan, V.N. ; Sudhakar, M. (2020). Near reef abundance and on–offshore distribution of tuna larvae around Minicoy Island in Lakshadweep Sea, India. Mar. Biol. Res. 16, 77–92. https://doi.org/10.1080/17451000.2019.1704018

Barroeta, Z. ; Olivar, M.P. ; Palomera, I. (2017). Energy density of zooplankton and fish larvae in the southern Catalan Sea (NW Mediterranean). J. Sea Res. 124, 1–9. https://doi.org/10.1016/j.seares.2017.04.008

Beverton, R.J.H. ; Holt, S.J. (2012). On the dynamics of exploited fish populations. Springer Science & Business Media.

Bindoff, N.L. ; Willebrand, J. ; Artale, V. ; Cazenave, A. ; Gregory, J.M. ; Gulev, S. ; Hanawa, K. ; Le Quere, C. ; Levitus, S. ; Nojiri, Y. (2007). Observations: oceanic climate change and sea level.

Blunden, J. ; Hartfield, G. ; Arndt, D.S. ; DUNN, R.J.H. ; TYE, M.R. ; Blenkinsop, S. ; Donat, M. ; Durre, I. ; Ziese, M. ; Cooper, O.R. (2018). State of the Climate in 2017. Bull Am Meteorol Soc 99, Si-S310. https://doi.org/10.1175/2018BAMSStateoftheClimate.1

Boyce, D.G. ; Lotze, H.K. ; Tittensor, D.P. ; Carozza, D.A. ; Worm, B. (2020). Future ocean biomass losses may widen socioeconomic equity gaps. Nat. Commun. 11. https://doi.org/10.1038/s41467-020-15708-9

Boyd, R. ; Thorpe, R. ; Hyder, K. ; Roy, S. ; Walker, N. ; Sibly, R. (2020). Potential Consequences of Climate and Management Scenarios for the Northeast Atlantic Mackerel Fishery. Front. Mar. Sci. 7. https://doi.org/10.3389/fmars.2020.00639

Brander, K. (2003). Fisheries and climate, in: Marine Science Frontiers for Europe. Springer, pp. 29–38.

Brosset, P. ; Ménard, F. ; Fromentin, J.M. ; Bonhommeau, S. ; Ulses, C. ; Bourdeix, J.H. ; Bigot, J.L. ; Van Beveren, E. ; Roos, D. ; Saraux, C. (2015). Influence of environmental variability and age on the body condition of small pelagic fish in the Gulf of Lions. Mar. Ecol. Prog. Ser. 529, 219–231. https://doi.org/10.3354/meps11275

Brosset, P. ; Le Bourg, B. ; Costalago, D. ; BĂnaru, D. ; Van Beveren, E. ; Bourdeix, J.H. ; Fromentin, J.M. ; Ménard, F. ; Saraux, C. (2016). Linking small pelagic dietary shifts with ecosystem changes in the Gulf of Lions. Mar. Ecol. Prog. Ser. 554, 157–171. https://doi.org/10.3354/meps11796

Catalán, I.A. ; Folkvord, A. ; Palomera, I. ; Quílez-Badía, G. ; Kallianoti, F. ; Tselepides, A. ; Kallianotis, A. (2010). Growth and feeding patterns of European anchovy (Engraulis encrasicolus) early life stages in the Aegean Sea (NE Mediterranean). Estuar. Coast. Shelf Sci. 86, 299–312. https://doi.org/10.1016/j.ecss.2009.11.033

Cheng, L. ; Abraham, J. ; Hausfather, Z. ; Trenberth, K.E. (2019). How fast are the oceans warming? Science (1979) 363, 128–129.

Costalago, D. ; Navarro, J. ; Álvarez-Calleja, I. ; Palomera, I. (2012). Ontogenetic and seasonal changes in the feeding habits and trophic levels of two small pelagic fish species. Mar. Ecol. Prog. Ser. 460, 169–181. https://doi.org/10.3354/meps09751

Costalago, D. ; Palomera, I. ; 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. https://doi.org/10.1016/j.seares.2014.02.008

Daw, T. ; Adger, W.N. ; Brown, K. ; Badjeck, M.-C. (2009). Climate change and capture fisheries: potential impacts, adaptation and mitigation.

Denman, K. ; Christian, J.R. ; Steiner, N. ; Pörtner, H.O. ; Nojiri, Y. (2011). Potential impacts of future ocean acidification on marine ecosystems and fisheries: Current knowledge and recommendations for future research. ICES J. Mar. Sci. 68, 1019–1029. https://doi.org/10.1093/icesjms/fsr074

Doney, S.C. ; Ruckelshaus, M. ; Emmett Duffy, J. ; Barry, J.P. ; Chan, F. ; English, C.A. ; Galindo, H.M. ; Grebmeier, J.M. ; Hollowed, A.B. ; Knowlton, N. ; Polovina, J. ; Rabalais, N.N. ; Sydeman, W.J. ; Talley, L.D. (2012). Climate change impacts on marine ecosystems. Ann. Rev. Mar. Sci. 4, 11–37. https://doi.org/10.1146/annurev-marine-041911-111611

FAO (2016). The state of mediterranean and black sea fisheries. FAO, Rome.

FAO (2018). The State of World Fisheries and Aquaculture 2018-Meeting the sustainable development goals. Fish. Aquac. Dep. Food Agric. Organ. United Nations, Rome.

Fonteneau, A. ; Gaertner, D. ; Nordstrom, V. (1999). An overview of problems in the CPUE-abundance relationship for the tropical purse seine fisheries. Collect. Vol. Sci. Pap. ICCAT 49, 259–276.

Fréon, P. ; Misund, O.A. (1999). Dynamics of pelagic fish distribution and behaviour: effects on fisheries and stock assessment. Fishing News Books Oxford.

Garcia-Gorriz, E. ; Carr, M. (2001). Physical control of phytoplankton distributions in the Alboran Sea: a numerical and satellite approach. J. Geophys. Res. Ocean. 106, 16795–16805.

Giannoulaki, M. ; Pyrounaki, M.M. ; Liorzou, B. ; Leonori, I. ; Valavanis, V.D. ; Tsagarakis, K. ; Bigot, J.L. ; Roos, D. ; Felice, A. de, Campanella, F. ; Somarakis, S. ; Arneri, E. ; Machias, A. (2011). Habitat suitability modelling for sardine juveniles (Sardina pilchardus) in the Mediterranean Sea. Fish. Oceanogr. 20, 367–382.

Gillis, D.M. ; Peterman, R.M. (1998). Implications of interference among fishing vessels and the ideal free distribution to the interpretation of CPUE. Can. J. Fish. Aquat. Sci. 55, 37–46. https://doi.org/10.1139/f97-206

Gordó-Vilaseca, C. ; Pennino, M.G. ; Albo-Puigserver, M. ; Wolff, M. ; Coll, M. (2021). Modelling the spatial distribution of Sardina pilchardus and Engraulis encrasicolus spawning habitat in the NW Mediterranean Sea. Mar. Environ. Res. 169, 105381. https://doi.org/10.1016/j.marenvres.2021.105381

Guisan, A. ; Edwards, T.C. ; Hastie, T. (2002). Generalized linear and generalized additive models in studies of species distributions: Setting the scene. Ecol. Modell. 157, 89–100. https://doi.org/10.1016/S0304-3800(02)00204-1

Harley, S.J. ; Myers, R.A. ; Dunn, A. (2001). Is catch-per-unit-effort proportional to abundance? Can. J. Fish. Aquat. Sci. 58, 1760–1772.

Hilborn, R. ; Walters, C.J. (2013). Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Springer Science & Business Media.

Hollowed, A.B. ; Barange, M. ; Beamish, R.J. ; Brander, K. ; Cochrane, K. ; Drinkwater, K. ; Foreman, M.G.G. ; Hare, J.A. ; Holt, J. ; Ito, S. (2013). Projected impacts of climate change on marine fish and fisheries. ICES J. Mar. Sci. 70, 1023–1037.

Hussain, S.V. ; Ulahannan, Z.P. ; Joseph, D. ; Somasekharan, A. ; Girindran, R. ; Benny, S. ; Ninan, R.G. ; Valappil, S.T. (2021). Impact of climate change on the fishery of Indian mackerel (Rastrelliger kanagurta) along the Kerala coast off the southeastern Arabian Sea. Reg. Stud. Mar. Sci. 44. https://doi.org/10.1016/j.rsma.2021.101773

Jghab, A. ; Vargas-Yañez, M. ; Reul, A. ; Garcia-Martínez, M.C. ; Hidalgo, M. ; Moya, F. ; Bernal, M. ; Ben Omar, M. ; Benchoucha, S. ; Lamtai, A. (2019). The influence of environmental factors and hydrodynamics on sardine (Sardina pilchardus, Walbaum 1792) abundance in the southern Alboran Sea. J. Mar. Syst. 191, 51–63. https://doi.org/10.1016/j.jmarsys.2018.12.002

Johnson, J.B. ; Omland, K.S. (2004). Model selection in ecology and evolution. Trends Ecol. Evol. https://doi.org/10.1016/j.tree.2003.10.013

Lotze, H.K. ; Tittensor, D.P. ; Bryndum-Buchholz, A. ; Eddy, T.D. ; Cheung, W.W.L. ; Galbraith, E.D. ; Barange, M. ; Barrier, N. ; Bianchi, D. ; Blanchard, J.L. (2018). Ensemble projections of global ocean animal biomass with climate change. BioRxiv 467175.

Maunder, M.N. ; Sibert, J.R. ; Fonteneau, A. ; Hampton, J. ; Kleiber, P. ; Harley, S.J. (2006). Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES J. Mar. Sci. 63, 1373–1385. https://doi.org/10.1016/j.icesjms.2006.05.008

Maynou, F. ; Sabatés, A. ; Ramirez-Romero, E. ; Catalán, I.A. ; Raya, V. (2020). Future distribution of early life stages of small pelagic fishes in the northwestern Mediterranean. Clim. Change 161, 567–589. https://doi.org/10.1007/s10584-020-02723-4

Meinshausen, M. ; Smith, S.J. ; Calvin, K. ; Daniel, J.S. ; Kainuma, M.L.T. ; Lamarque, J.-F. ; Matsumoto, K. ; Montzka, S.A. ; Raper, S.C.B. ; Riahi, K. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Clim. Change 109, 213–241.

Muhling, B. ; Lindegren, M. ; Clausen, L.W. ; Hobday, A. ; Lehodey, P. (2017). Impacts of climate change on pelagic fish and fisheries. Clim. Chang. Impacts Fish. Aquac. A Glob. Anal. 2, 771–814.

Nerem, R.S. ; Beckley, B.D. ; Fasullo, J.T. ; Hamlington, B.D. ; Masters, D. ; Mitchum, G.T. (2018). Climate-change–driven accelerated sea-level rise detected in the altimeter era. Proceedings of the national academy of sciences 115, 2022–2025. https://doi.org/10.1073/pnas.171731211.

Nikolioudakis, N. ; Palomera, I. ; Machias, A. ; Somarakis, S. (2011). Diel feeding intensity and daily ration of the sardine Sardina pilchardus. Mar. Ecol. Prog. Ser. 437, 215–228. https://doi.org/10.3354/meps09275

Nikolioudakis, N. ; Isari, S. ; Pitta, P. ; Somarakis, S. (2012). Diet of sardine Sardina pilchardus: an ‘end-to-end’field study. Mar. Ecol. Prog. Ser. 453, 173–188.

Nikolioudakis, N. ; Isari, S. ; Somarakis, S. (2014). Trophodynamics of anchovy in a non-upwelling system: Direct comparison with sardine. Mar. Ecol. Prog. Ser. 500, 215–229. https://doi.org/10.3354/meps10604

Oguz, T. ; Macias, D. ; Garcia-Lafuente, J. ; Pascual, A. ; Tintore, J. (2014). Fueling plankton production by a meandering frontal jet: a case study for the Alboran Sea (Western

Mediterranean). PLoS One 9, e111482.

Palomera, I. ; Olivar, M.P. ; Salat, J. ; Sabatés, A. ; Coll, M. ; García, A. ; Morales-Nin, B. (2007). Small pelagic fish in the NW Mediterranean Sea: An ecological review. Prog. Oceanogr. 74, 377–396. https://doi.org/10.1016/j.pocean.2007.04.012

Pankhurst, N.W. ; Munday, P.L. (2011). Effects of climate change on fish reproduction and early life history stages. Mar. Freshw. Res. 62, 1015–1026. https://doi.org/10.1071/MF10269

Pauly, D. ; Christensen, V. ; Dalsgaard, J. ; Froese, R. ; Torres, F. (1998). Fishing down marine food webs. Science (80-.). 279, 860–863. https://doi.org/10.1126/science.279.5352.860

Pennino, M.G. ; Coll, M. ; Albo-Puigserver, M. ; Fernández-Corredor, E. ; Steenbeek, J. ; Giráldez, A. ; González, M. ; Esteban, A. ; Bellido, J.M. (2020). Current and Future Influence of Environmental Factors on Small Pelagic Fish Distributions in the Northwestern Mediterranean Sea. Front. Mar. Sci. 7. https://doi.org/10.3389/fmars.2020.00622

Pörtner, H.O. ; Peck, M.A. (2010). Climate change effects on fishes and fisheries: towards a cause-and-effect understanding. J. Fish Biol. 77, 1745–1779.

Rijnsdorp, A.D. ; Peck, M.A. ; Engelhard, G.H. ; Möllmann, C. ; Pinnegar, J.K. (2009). Resolving the effect of climate change on fish populations. ICES J. Mar. Sci. 66, 1570–1583.

Roessig, J.M. ; Woodley, C.M. ; Cech, J.J. ; Hansen, L.J. (2004). Effects of global climate change on marine and estuarine fishes and fisheries. Rev. fish Biol. Fish. 14, 251–275.

Ruiz, J. ; Echevarrıa, F. ; Font, J. ; Ruiz, S. ; Garcıa, E. ; Blanco, J.M. ; Jiménez-Gómez, F. ; Prieto, L. ; González-Alaminos, A. ; Garcıa, C.M. (2001). Surface distribution of chlorophyll, particles and gelbstoff in the Atlantic jet of the Alborán Sea: from submesoscale to subinertial scales of variability. J. Mar. Syst. 29, 277–292.

Rutterford, L.A. ; Simpson, S.D. ; Jennings, S. ; Johnson, M.P. ; Blanchard, J.L. ; Schön, P.J. ; Sims, D.W. ; Tinker, J. ; Genner, M.J. (2015). Future fish distributions constrained by depth in warming seas. Nat. Clim. Chang. 5, 569–573. https://doi.org/10.1038/nclimate2607

Sajna, V.H. ; Zacharia, P.U. ; Benjamin, L. ; Rojith, G. ; Mini, K.G. (2019a). Climate change impact on the feeding habits of Indian mackerel observed along the Kerala coast. J. Mar. Biol. Assoc. India 61, 13–21.

Sajna, V.H. ; Zacharia, P.U. ; Liya, V.B. ; Rojith, G. ; Somy, K. ; Joseph, D. ; Grinson, G. (2019b). Effect of climatic variability on the fishery of Indian oil sardine along Kerala coast. J. Coast. Res. 86, 184–192.

Salat, J. ; Pascual, J. ; Flexas, M. ; Chin, T.M. ; Vazquez-Cuervo, J. (2019). Forty-five years of oceanographic and meteorological observations at a coastal station in the NW Mediterranean: a ground truth for satellite observations. Ocean Dyn. 69, 1067–1084. https://doi.org/10.1007/s10236-019-01285-z

Sarmiento, J.L. ; Slater, R. ; Barber, R. ; Bopp, L. ; Doney, S.C. ; Hirst, A.C. ; Kleypas, J. ; Matear, R. ; Mikolajewicz, U. ; Monfray, P. (2004). Response of ocean ecosystems to climate warming. Global Biogeochem. Cycles 18.

Schismenou, E. ; Palmer, M. ; Giannoulaki, M. ; Alvarez, I. ; Tsiaras, K. ; Triantafyllou, G. ; Somarakis, S. (2016). Seasonal changes in otolith increment width trajectories and the effect of temperature on the daily growth rate of young sardines. Fish. Oceanogr. 25, 362–372.

Shyam, S.S. ; Rahman, M.R. ; Antony, B. (2015). Sardine economy of Kerala: paradigms and perspectives. Int. J. Fish. Aquat. Stud. 2, 351–356.

Solanki, H.U. ; Bhatpuria, D. ; Chauhan, P. (2017). Applications of generalized additive model (GAM) to satellite-derived variables and fishery data for prediction of fishery resources distributions in the Arabian Sea. Geocarto Int. 32, 30–43. https://doi.org/10.1080/10106049.2015.1120357

Sund, P.N. ; Blackburn, M. ; Williams, F. (1981). Tunas and their environment in the Pacific Ocean: a review. Ocean. Mar. Biol. Ann. Rev 19, 443–512.

Swain, D.P. ; Sinclair, A.F. (1994). Fish distribution and catchability: What is the appropriate measure of distribution? Can. J. Fish. Aquat. Sci. 51, 1046–1054. https://doi.org/10.1139/f94-104

Vasilakopoulos, P. ; Maravelias, C.D. ; Tserpes, G. (2014). The alarming decline of mediterranean fish stocks. Curr. Biol. 24, 1643–1648. https://doi.org/10.1016/j.cub.2014.05.070

Vivekanandan, E. ; Srinath, M. ; Kuriakose, S. (2005). Fishing the marine food web along the Indian coast. Fish. Res. 72, 241–252. https://doi.org/10.1016/j.fishres.2004.10.009

Wood, S.N. (2017). Generalized additive models: An introduction with R, second edition, Generalized Additive Models: An Introduction with R, Second Edition. CRC Press. https://doi.org/10.1201/9781315370279

Yen, K.-W. ; Su, N.-J. ; Teemari, T. ; Lee, M.-A. ; Lu, H.-J. (2016). Predicting the catch potential of Skipjack tuna in the western and central Pacific Ocean under different climate change scenarios. J. Mar. Sci. Technol. 24, 2.

Zacharia, P.U. ; Sajna, V.H. ; Rojith, G. ; Roshen, G.N. ; Joseph, D. ; Kuriakose, S. ; George, G. (2020). Climate change drivers influencing indian mackerel fishery in south-eastearabian sea off Kerala, India. Indian J. Fish. 67, 1–9. https://doi.org/10.21077/ijf.2020.67.3.92802-01