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Research Article

Stock status of *Sardina pilchardus* (Walbaum, 1792) in the Alboran Sea: A case study of Ghazaouet Fishery, Algeria

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Abstract

The European pilchard (*Sardina pilchardus*) plays a crucial role along the Algerian coast, forming a significant part of the local fisheries industry. However, overfishing has resulted in a decline in their population, which has had adverse effects on the fishery sector. This study was conducted to evaluate the current mortality rate and exploitation rate of the sardine *S. pilchardus* and investigate its growth and length-weight relationship along the Ghazaouet coast. A sample of 1576 specimens was collected from commercial purse seine catches on the western Algerian coast (Ghazaouet fishing grounds). The total length (TL) of the specimens ranged from 9.6 to 21.4 cm with an average of 14.6±1.86 cm, and the total weight (TW) varied between 6.2 and 57.8 g with an average of 25.4±9.57 g. The estimated growth parameters using the Von Bertalanffy approach have an asymptotic length $L\infty$=21.26 cm, growth coefficient K=0.77 year^{-1}, and age at zero length t_0=-0.17 year. The results of the study showed that the length-weight relationship had an isometric growth (b=2.99) with a high correlation (r=0.95). The sex ratio showed no dominance between males and females (F+M/M=0.5). The instantaneous rate of total mortality (Z) was estimated to be 1.79 per year, with natural mortality (M) estimated at 0.65 year^{-1}. Fishing mortality (F) and exploitation (E) were estimated at 1.14 and 0.64 year^{-1}, respectively. Based on these results, the sardine stock in the southwestern Mediterranean Sea (western Algerian coast) is under higher fishing pressure. Consequently, it is imperative to implement management strategies that ensure sustainable levels of harvesting.

Introduction

For centuries, fishing of the European Pilchard, *Sardina pilchardus* (Walbaum, 1792), has been of paramount economic importance along the Mediterranean coast. It is one of the most extensive fish stocks caught in fisheries, and it is practiced by boats that rarely remain at sea for more than 12 hours (Chouvelon *et al.*, 2014). The sardine *S. pilchardus* is a pelagic fish that belongs to the family of Clupeidae. It is a primary target species of the commercial fishery along the Algerian coasts, representing the most abundant fish species in the landings of the port of Ghazaouet (Alboran Sea) (Handjar *et al*., 2019). In 2018, sardine catches in Ghazaouet reached 7517 tonnes, i.e., 74.84% of global fish production, according to the Ministry of Fishing and Fisheries Products. In 2020, the total output of sardine in Algeria was 18050 tonnes, of which 1371 tonnes corresponded to Ghazaouet (MFFP, 2021). However, a decline of 81% in sardine production was observed in 2020 compared to the maximum output in 2018.

To ensure the preservation and the sustainability of the sardine stocks, numerous studies were conducted on sardine populations in the Mediterranean, including those by Sala *et al*. (2001), who used acoustic surveys to assess the spatial distribution and biomass of sardine populations in the western Mediterranean. They found that the sardine stock was at a historically low level, which they attributed to overfishing and environmental changes. In a study conducted by Demestre *et al*. (2015), a modelling approach was employed to evaluate the effects of fishing pressure and environmental variability on sardine populations in the western Mediterranean, revealing that fishing pressure was the main driver of sardine declines and suggesting the need for a more sustainable fishing management strategy.

Other studies have focused on the impact of fishing on sardine populations and their habitats. Coll *et al*. (2007) studied the effects of fishing on the structure and dynamics of sardine populations in the western Mediterranean, showing that fishing pressure was altering the age structure and size of sardine populations. Guidetti *et al*. (2009) investigated the effects of fishing on the distribution and habitat use of sardine populations in the Mediterranean, which reduces the size and quality of sardine habitats.

In addition to the impact of fishing, other studies have investigated the role of environmental variability on sardine populations in the Mediterranean. Palomera *et al*. (2010) used a coupled physical-biological model to assess the impact of environmental variability on sardine populations in the western Mediterranean, which affects the distribution and abundance of sardine populations. Another study by García-March *et al*. (2015) used a climate envelope model to investigate the response of sardine populations to climate change in the eastern Mediterranean, where sardine populations are shifting their distribution in response to changing environmental conditions.

The sardine stock is of significant economic and nutritional value importance along the Mediterranean coasts and requires careful management to ensure the sustainability of fisheries. Further studies and monitoring of sardine populations are necessary to develop effective management strategies. Several studies (*e.g.,* Sala *et al*., 2001; Coll *et al*., 2007; Guidetti *et al*., 2009; Palomera *et al*., 2010; Demestre *et al*., 2015; García-March *et al*., 2015) have indicated that effective fishing management strategies should take into account both fishing pressure and environmental factors in order to promote the long-term viability of sardine populations.

The "blue economy national strategy" (2020-2030) outlines issues and strategic axes that aim to improve and protect marine ecosystems, contribute to Algerian food security, and support social and economic resilience, among other objectives. This aligns with the Algerian government's goals and its international commitments to the "blue economy" and sustainable development goals. Therefore, studies on commercial fishing stock assessments are deemed necessary to establish appropriate management practices (Handjar *et al*., 2019).

The present investigation aims to enhance our comprehension of the *S. pilchardus* stock on the Algerian west coast, part of the Alboran Sea. This study includes detailed analyses of biological data, growth parameters, and mortality rates to understand the changes in the population structure under fishing pressure. The results will provide an accurate representation of the dynamics of the *Sardina pilchardus* stock to improve fishery management in the region.

Materials and methods

Location of study

The study presented herein, where sampling activities took place, was situated on the west coast of Algeria, a significant region within the 'Alboran Sea' Balearic division as designated by the Food and Agriculture Organization (FAO) in 2015 (Fig. 1). This area was carefully chosen for the collection of sardine specimens due to its persistent status as the main landing place for this species, exceeding the country's sardine output for many years. The study site is geographically located at coordinates 35°06'21"N / 1°51'41"W, providing a precise indication of its specific location. These coordinates were instrumental in ensuring the accuracy and precision of our data collection efforts.

Data collection

A total of 1576 individuals were sampled between December 2018 and February 2020 (15 months); 550 females and 548 males were determined; the remaining 478 individuals were either immature or indeterminate. Using thermos-insulated containers, the obtained specimens were promptly transported to the laboratory of the technical training school in fishing and aquaculture in Ghazaouet. Afterward, sub-samples were taken and used to record biometric characterisation, *e.g*., total length (Lt), total weight (Wt), and biological index determination, *e.g.*, sex determination, maturity stage, gonad weight (Wg), and eviscerated weight (We) (Fig. 2).

Data analysis

Total length (TL) and body weight (BW)

All samples of individuals of *S. pilchardus*, i.e., 1576, were divided into size classes of 50 mm intervals (Baldé *et al*., 2022). Total length (TL) is measured using a 0.1 cm precision caliper (Ichtyometer) to calculate size-frequency distributions and estimate growth parameters (Fig. 2). The body weight (BW) is measured to the nearest 0.1 g (Kern PCB 1000-1 Precision Balance).

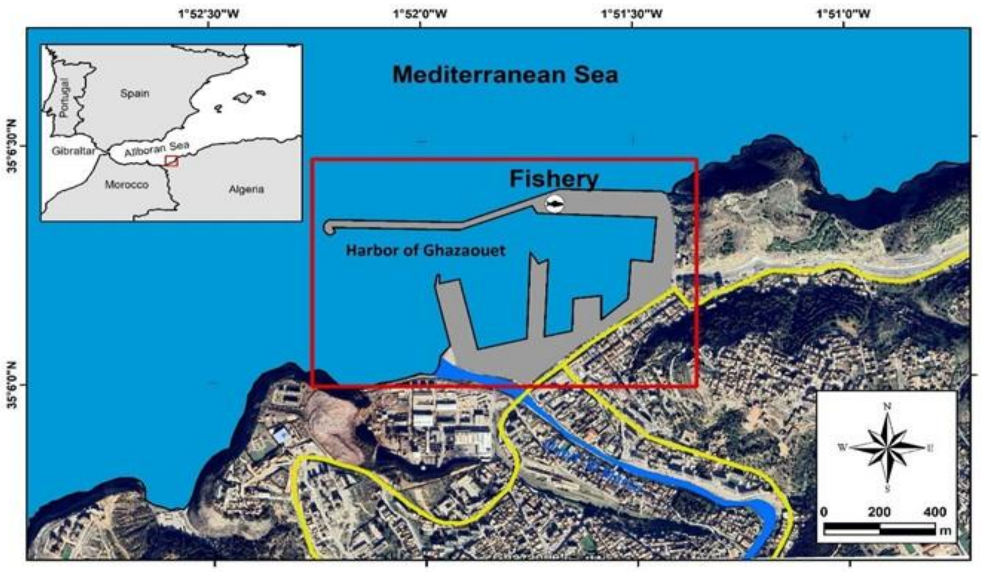

Figure 1: Sampling Fishery' Harbor of Ghazaouet', Algeria (red box).

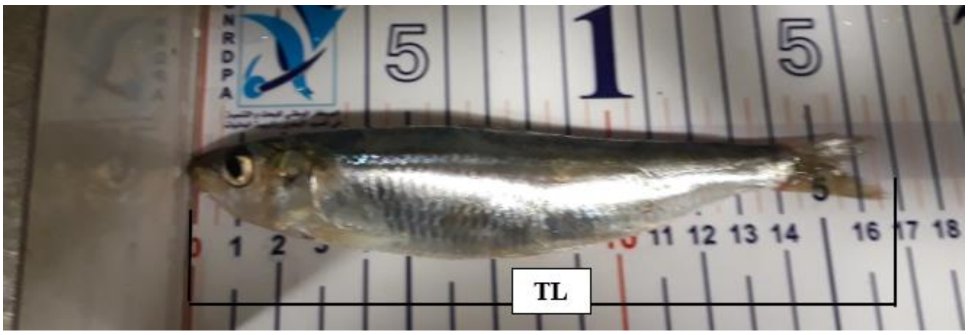

Figure 2: A specimen of *Sardina pilchardus* total length (TL) sampling.

Length-weight (L-W) relationships

The length-weight (L-W) relationship for the fish was employed to offer information on the condition of the fish and to assess if somatic growth was isometric or allometric and was estimated through the linear regression of $W=aL^b$ (Acarli *et al*., 2014). This relationship is influenced by food availability, gonad development, and reproduction (Keznine *et al*., 2020). It was assessed to estimate the changes in growth that can affect the morphology of the species. The significance of the regression was assessed by ANOVA, and the b-value for each sample was tested to be significantly different from the isometric growth (b=3). All statistical analyses were evaluated at a $p<0.05$ significance level.

Sex ratio

The sex ratio is the fraction of an individual's population of each sex, i.e., the percentage of males and females in a population. It was used to determine the overall repartition of the population in males and females (Abderrazik et al.,2016) It was calculated as follows:

$\%Females=n_2/N\times100\%$; $Males=n_1/N\times100$

N: number of total individuals (sample size); n_1: number of male individuals; n_2: number of female individuals. In this study, the sex ratio is the ratio between the number of females and males (F/M).

Gonadosomatic Index (GSI)

The GSI was used to assess the seasonality of reproduction; the monthly fluctuations in the GSI indicate the state of the gonads and the degree of sexual maturity (Znari and Mounir, 2021). The GSI was determined using the following formula:

$$GSI = Wg/We \times 100$$

Where Wg is the weight of the gonad, and We are the eviscerated weight of the individual.

Growth function

Von Bertalanffy growth function VBGF

In population dynamics, the model of Von Bertalanffy (1938) is selected to express linear growth analytically. This model is the simplest to incorporate into production equations (Daget *et al*., 1975). This is stated in the following manner:

$$TL_t = L_\infty (1-e^{-k(t-t_0)})$$

Where TL_t is the total length (cm) of fish at time t; $L\infty$ is the asymptotic length, K is the parameter for curvature, and t_0 is theoretical age where L_t=0, $L\infty$ was estimated using LFDA-Version 5.0 Length Frequency Distribution Analysis: A software package for analyzing length-frequency data (Kirkwood and Constable, 2001), t_0: the theoretical age for which the height is zero was calculated using the empirical equation from Pauly (1979, as cited in Sultana *et al*. (2020):

$$Log (-t_0) = - 0.392 - 0.275 \, Log \, L\infty - 1.038K$$

K: the growth coefficient characterising the speed with which the species grows towards its asymptotic size. Fulton's condition factor (K) is typically used to calculate the condition index (Hart and Reynolds, 2002):

$$CF = K = (Wt/Lt^3) \times 100$$

Wt: the weight of an individual fish at time t, Lt: the length of an individual fish at time t

The empirical equation of growth performance (Munro and Pauly, 1983) was applied to compare different estimates of growth parameters as follows:

$$Ø' = \log_{10} k + 2 \log_{10} (L_\infty)$$

Length at 50% sexual maturity

According to the empirical equation developed by Froese and Binohlan (2000), the length at 50% sexual maturity (L50%) was calculated as:

$$Log(L50\%) = 0.8979 \log(L\infty) - 0.0782$$

Mortality

The estimated total mortality, denoted as Z, was determined based on the average size of the catch. When extensive size frequency data are available for a particular fish stock and fishing gear, we estimate Z by considering the relationship:

$$Z = K (L\infty - Lm) / (Lm - L)$$

$L\infty$ and K represent the parameters of Von Bertalanffy's growth equation, Lm stands for the average length of the captured fish, and L corresponds to the smallest size at which all fish in a sample have an equal likelihood of being retained. This formula enables the calculation of Z by taking into account the growth characteristics of the fish population and the size distribution in the catch (Mounir *et al*., 2020).

The natural mortality coefficient (M) was calculated using the Djabali and Mouhoub (1993) method as follows:

$\log_{10} M = 0.0278 - 0.1172 \log_{10} L\infty + 0.5092 \log_{10}$

Fishing mortality (F) was calculated using the simple subtraction formula F = Z – M. The rate of exploitation (E) was estimated using Ricker's (1975, as cited in Gurjar *et al*., 2021) formula: E=F/Z.

Results

During the investigation period, i.e., from December 2018 to February 2020, length and weight measurements were taken from 1576 individuals collected from the Ghazaouet harbour, Algeria. Of those, 1140 were the subject of biological analysis in the lab, allowing us to identify biometric characterisations and biological indexes.

Length-frequency distribution

The length-frequency distribution reveals the demographic appearance of the exploited sardine populations on the Ghazaouet coast. From this finding, the landings over 15 months showed a predominance of sizes between 13.0 and 17.5 cm, with a peak in the [14.0-14.5[cm length class. The modal courses for the global sample, males, and females captured, are [14.0-14.5[, [16.0-16.5[and [16.5-17.0[cm, respectively. For males, the most observed sizes are larger compared to the overall sample, with a maximum catch in the [16.0-16.5[cm class. The most common sizes for females are between 16 and 17 cm. From the results shown in Figure 3, it was clear that the smallest and largest sizes are less exploited.

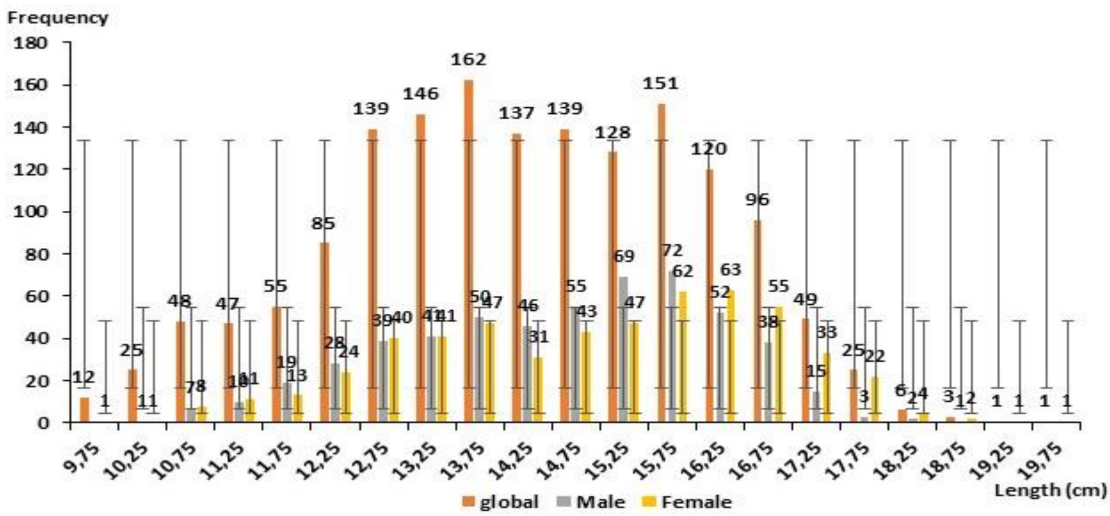

Figure 3: Length frequency distribution of *Sardina pilchardus* samples (global and by sexes).

Length-weight relationship

The length-weight relationship was determined for the overall sample (sex combined) as shown in Figure 4 and for males (Fig. 5) and females (Fig. 6) separately. The result shows a high correlation between the size and weight of the combined sex, males and females of sardines (b~3). On the other hand, the superscript "b" describes the rate of change in weight relative to length to show a difference between the two sexes, and Table 1 represents the results of the length–weight relationship for the overall sample.

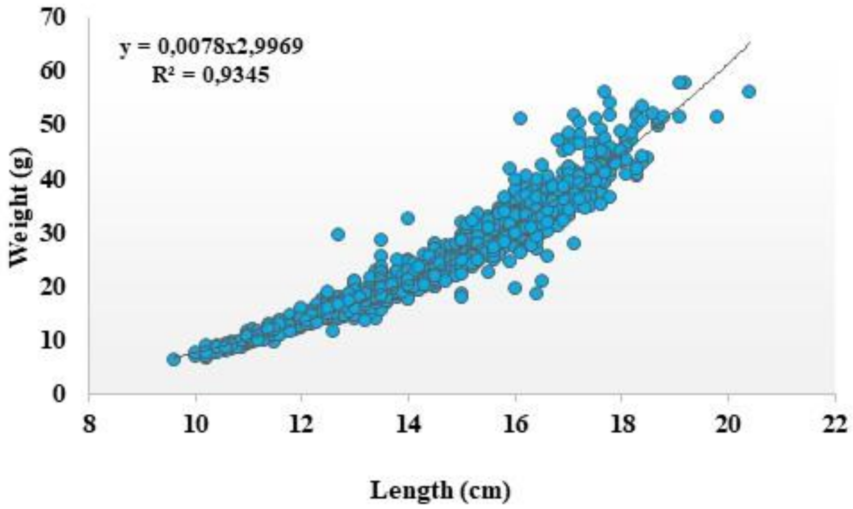

Figure 4: Linear growth regression of *Sardina pilchardus* (both sexes).

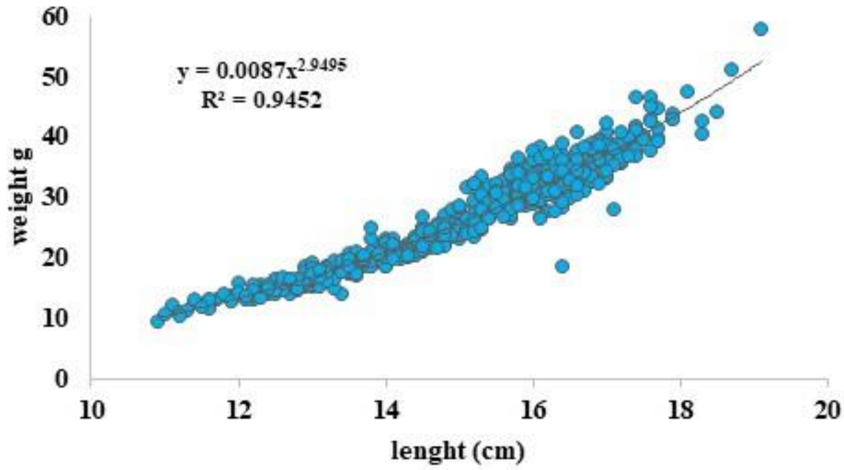

Figure 5: Linear growth regression of *Sardina pilchardus* (males).

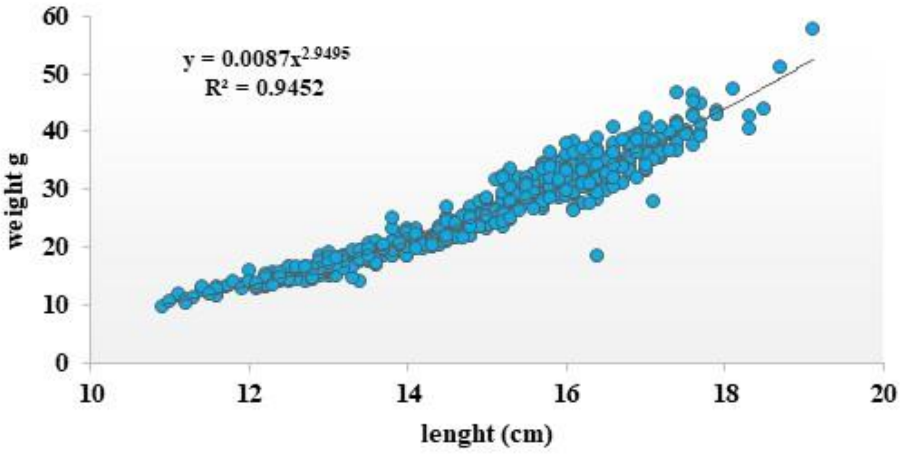

Figure 6: Linear growth regression of females of *Sardina pilchardus*.

Table 1: a, b, LWR for both and separated sexes in *Sardina pilchardus*.

	Combined	Males	Females
a	0.0078	0.0087	0.0073
b	2.997	2.950	3.021

$W=0.0078L^{2.997}$ (Combined) $W=0.0087L^{2.950}$ (males) $W=0.0073L^{3.021}$ (females)

Based on the analysis of variance findings outlined in Table 5, the derived p-value was markedly below the designated significance threshold (α=0.05). Consequently, the null hypothesis (H0) was dismissed, while the alternative hypothesis (H1) was upheld.

Sex-ratio

Figure 7 displays the monthly sex ratio variation, revealing a dominance of males in December (year) and females in January (year). In the other months, the sex ratio is more or less equitable for both sexes, meaning that males and females are present in the samples in roughly equal proportions.

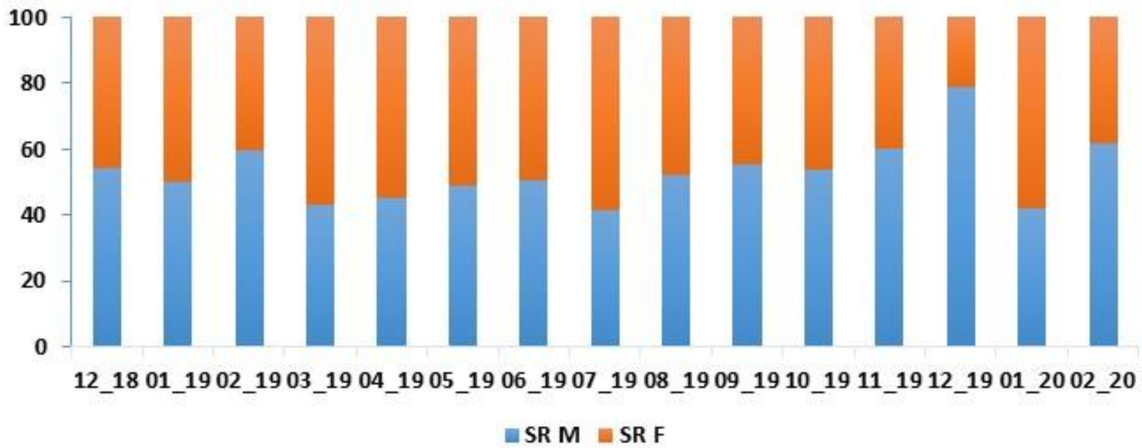

Figure 7: variation of the sex ratio of *Sardina pilchardus* by month and by sex.

Gonado-somatic index (GSI)

The evolution of the gonado-somatic index allows monitoring of the reproductive period of *S. pilchardus*. For males, Figure 8 shows that the GSI reaches its maximum between December and February, with values above 6% and a peak in February 2020 (+9%). For females, a reproductive period between December and February is noted by GSI values that ranged between 5 and 24%; the peak of GSI was observed in December 2019 at 24%, according to the monthly variations (Fig. 9).

Growth parameters: Von Bertalanffy Growth Function (VBGF)

The current study conducted on the Algerian coast's western Mediterranean found a value for the asymptotic length ($L\infty$) parameter of 21.26 cm and a value for the growth coefficient (K) of 0.77 $year^{-1}$ (Table 2). However, the value for the theoretical age for which the height is zero (t_0) parameter is -0.17 $year^{-1}$, while the value for the von Bertalanffy growth function (Ø') is 2.54 years. The L50% value was 13 cm.

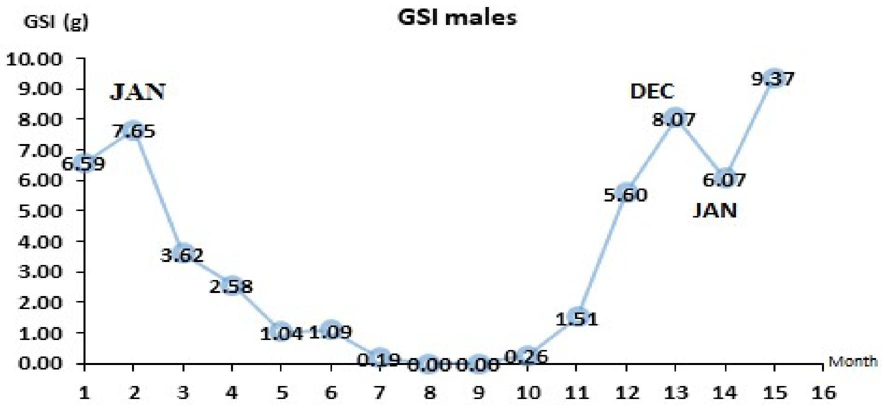

Figure 8: Variation of GSI (males) during 15 months of assessment in *Sardina pilchardus.*

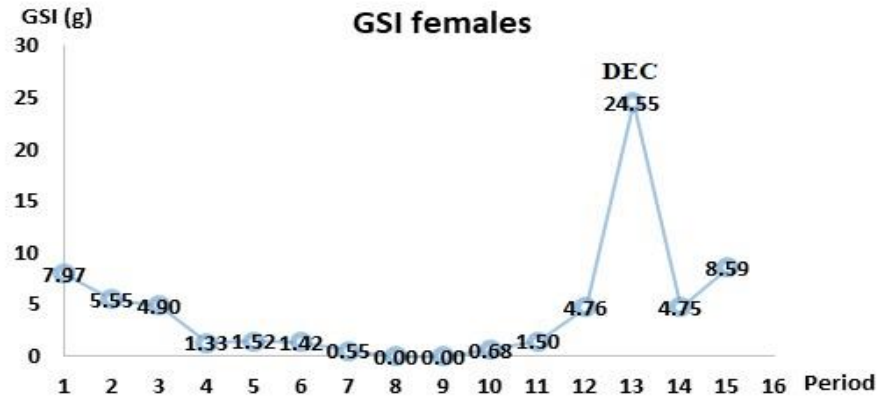

Figure 9: Variation of GSI (females) during 15 months of assessment in *Sardina pilchardus.*

Table 2: VBGF parameters for Combined and separated sexes of *Sardina pilchardus* from the West coast of Algeria.

Parameter	Males	Females	Combined
Asymptotic Length L_∞	20.21	21.26	21.26
K (Fulton's) year $^{-1}$	0.76	0.77	0.77
t_o year $^{-1}$	-0.17	-0.17	-0.17
Φ'	2.49	2.54	2.54

Mortality

Total mortality (Z) and natural mortality (M) rates

Table 3 shows the mortality rates and exploitation ratio of *S. pilchardus* on the West Coast of Algeria. The total mortality 'Z' for males, females, and combined sexes was 1.57, 2.01, and 1.79 year^{-1}, respectively. The natural mortality 'M' was 0.65 year^{-1} for both sexes and combined.

3.6.2 Fishing mortality (F) and exploitation (E) rates.

The fishing mortality rate was 0.92 year^{-1} with E = 58.60% year^{-1} for males, 1.36 year^{-1} With E = 67.66% year^{-1} for females, and 1.14 year^{-1} with E = 63.69% year^{-1} for combined sex. The ratio F/M>1 for the males (1.42), females (2.09), and the combined sex (1.75) year-^{1}.

Table 3: Mortality and exploitation parameters for combined and separated sexes of *Sardina pilchardus.*

Parameter	Males	Females	Combined sex
Z	1.57	2.01	1.79
M	0.65	0.65	0.65
F	0.92	1.36	1.14
E	0.59	0.68	0.63
F/M	1.42	2.09	1.75

Discussion

This study conducted on the west-east coast of Algeria, i.e., Ghazaouet, between December 2018 and February 2020 on the stock *S. pilcahrdus*, the most fished and consumed aquatic organism in the country (MFFP, 2021) revealed that much pressure is imposed on the species stock. Over a 15-month period, the landings recorded consistently revealed a pronounced prevalence of fish within the size range of 13.0 cm to 17.5 cm. The size classes exhibiting the highest frequency in the entire dataset, as well as for male and female specimens, were [14.0-14.5[, [16.0-16.5[, and [16.5-17.0[cm, respectively. This size distribution offers valuable insights into the composition of sizes within the catch, facilitating a comprehensive analysis of the population's demographic structure. In the period from January to December 2019, Keznine *et al*. (2020) found that the size composition of the sardine captured ranged from 7.5 to 20 cm with a bimodal size frequency of 13.5 and 11 cm. In the period before, from June 2017 to May 2018, Znari and Mounir (2021) found domination by medium size classes [15.0-17.0[and [14.0-19.0[, the smaller and larger size classes are underrepresented, which is very close to our findings. This prominent pattern provides compelling evidence of the heightened catchability of larger fish across various age groups, concurrently indicating the preservation of smaller individuals.

Most fish have an allometric relationship between fish size and weight (Beverton and Holt, 1957). In the present study, the sardine shows a nearly isometric growth (b~3) where the weight increases in proportion with the size; this implies a statistically significant impact of S. *pilchardus* length on weight within the western sector of the Algerian coastline, with negligible risk of misjudgment. (coefficient of determination r^2 =0.91, Regression statistics and ANOVA in Table 5). Overall, the sardine increases in all dimensions at the same rate and for both sexes, which reflects a good growth condition. Some authors who worked in the same area found that *S. pilchardus* has isometric growth (Handjar *et al*., 2019). Conversely, some studies, like Sinovčić *et al*. (2008), found positive allometric growth in the eastern part of the Mediterranean Sea. This controversy over the results might be related to the study area, which represents a difference in physical-chemical conditions and other phenomena, such as upwellings.

The sex ratio of the sardines landed in our study period presented a balance between males and females, with both sexes having the same spatial distribution. The same results were documented by Véron *et al*. (2020) in the Bay of Biscay, while Sinovčić *et al*. (2008) declared that there is no significant deviation from the hypothetical distribution of 1:1, so in general, there is no difference in the distribution between males and females.

Table 4: Average values of von Bertalanffy's parameters recorded for *Sardina pilchardus* in the Mediterranean Sea and adjacent waters M=Males F=Females.

Location	Parameters					Reference
	L∞	K	t_0	Ø'	L50%	
Western Mediterranean, Algeria	21.26	0.77	-0.17	2.54	12.996	This study
	M 20.21	0.76	-0.17	2.49	12.418	
	F 21.26	0.77	-0.17	2.54	12.996	
Agadir bay, Atlantic	22.64	0.311			13.133	Mounir *et al.* (2020)
Western Mediterranean, Morocco	20.21	0.47	-1.93		13.29	Keznine *et al.*, (2020)
Atlantic, Morocco					11.5	Mounir *et al.* (2022)
Eastern Algerian basin	22.56	0.31				Bedairia and Djebar, (2009)
Northeastern Mediterranean	F 17.21	0.53	-1.28		11.65	Tsikliras and Koutrakis, (2013)
	M 16.59	0.65	-1.22		11.37	

Table 5: Regression statistics and ANOVA analysis.

Regression statistics	
Multiple R	0.957512935
R Square	0.916831021
Adjusted R square	0.916778148
Standard Error	2.762368548
Observations	1575

ANOVA	df	SS	MS	F	Significance F
Regression	1	132318.2933	132318.2933	17340.3017	0
Residual	1573	12003.05963	7.630679995		
Total	1574	144321.3529			

These outcomes might be explained by the fact that males and females share the same spatial-temporal distribution and the same behavior toward the fishing gear.

Reproduction takes place in winter, particularly between December and February (peak >9% for males and >24% for females); when we distinguish the peak of reproduction for males and females, the egg-laying period mainly takes place from December to February. On the other hand, the GSI reaches its minimum value during the summer season, particularly in July and August. Our findings are comparable to those of Andreu and Pinto (1957) and Mouhoub (1986) along the coast of Algeria. This is in accordance with works from Keznine *et al.* (2020), while on the eastern coast of Algeria, it started in November (Hani *et al.*, 2016). It is noteworthy that *S. pilchardus*, like most pelagic species, attained sexual maturity during the winter season. Therefore, the maximum weight of gonads can be seen during this period as a result of nutrient reserves.

In this study, growth parameters L∞=21.26 cm, K=0.77 year $^{-1}$, t_0 = - 0.17 year $^{-1}$ are compared to the growth parameters of *S. pilchardus* from various studies conducted in the Mediterranean Sea and nearby waters Table 4. The results show some regional differences in the von Bertalanffy growth parameters of *S. pilchardus* populations in the

Mediterranean Sea; specifically, the values of von Bertalanffy's parameters were higher in the Western region compared to Eastern populations. Nevertheless, the results of Moroccan investigations (Keznine *et al*., 2020) in the Mediterranean part are pretty similar to those obtained from our research. It can be explained by the proximity of the sampling area (Alboran Sea) to the same physicochemical parameters that provided the fish with the same growth parameters. And the heterogeneity of the methods used, such as the direct reading of otoliths or scales, back calculation, size frequency analysis, individual cohorts, or synthetic cohorts. The environmental conditions (temperature, salinity, etc.) and productivity of the region, on the other hand, could account for the differences observed. In addition, the extension of the continental plateau in the area could also contribute to its richness, which could explain why these parameter values are higher here. It could also be because the oldest sardines are in the southwestern Mediterranean. Overall, the findings of this study contribute to the existing knowledge of the population dynamics of *S. pilchardus* in the Western Mediterranean (Handjar *et al*., 2019).

For both sexes, natural mortality was similar M=0.65 year $^{-1}$. The reason for such similarity can be explained by the fact that males and females share the same ecosystem and, therefore, the same natural mortality factors (predation, diseases, etc.). In contrast to fishing mortality, it is evident that males exhibit lower vulnerability compared to females. This phenomenon can be attributed to the spatio-temporal distribution patterns and the potential for females to attain greater weight than males. These observations present intriguing avenues for further exploration in subsequent studies. The rates of exploitation for males, females, and both sexes indicated an overfishing situation E=0.63 year^{-1}. Compared to other studies, almost all of them show the same situation of overfishing in the S.pilchardus stock, like all the small pelagic stocks, which are vulnerable to environmental conditions and recruitment, as declared by Almeida *et al*. (2014), Baldé *et al*. (2022) and Handjar *et al*. (2019).

Through analysis of length-frequency data, we determined the Von Bertalanffy growth function (VBGF) parameters (L∞, K, and t0) for S. pilchardus on the west coast of Algeria, providing valuable insights into its population dynamics. By modeling growth, we elucidated current length ranges and projected asymptotic lengths under specified conditions. These growth metrics facilitated the calculation of total mortality (Z), integrating both natural and fishing mortalities. The subsequent estimation of the exploitation rate (E) from total mortality (Z) allowed us to gauge the impact of fishing activities on the population. Our findings delineate the proportion of mortality attributed to natural causes (M) versus fishing pressures (F), thereby informing sustainability considerations. Comparison of the exploitation rate (E) to recommended thresholds offers critical assessments of current harvest levels vis-à-vis the population's growth and mortality patterns, contributing to informed management strategies for *S. pilchardus* stocks in this region.

Conclusions

In summary, applying established growth models to available sardine data from Algeria's west coast has facilitated an assessment of stock status for this commercially important fish population. The findings of this study indicate that the Algerian western stock of sardine is overfished and provides an objective basis to guide management decisions regarding sustainable harvest levels. In general, fisheries managers need to implement strategies to ensure the preservation and responsible use of fisheries resources. The implementation of conservation and management measures should be based on robust scientific evidence and prioritize the long-term sustainability of fishery resources. These policies should also strive to maximize the exploitation of these resources and secure their availability for present and future generations.

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Conflicts of interest

The authors have no conflicts of interest to disclose.

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