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Length-Weight Relationships and Metric Characters of the European Pilchard, *Sardina pilchardus* (Walbaum, 1792) (Teleostei: Clupeidae), Caught in Béni-Saf Bay, W-Mediterranean (Algeria)

Khaled RAHMANI[1,*], Zaineb DERRAG[1], Brahim KESBI[2], Farid Bennabi[1]

[1]University of Ain Temouchent, Laboratory of Applied Hydrobiology and Environment, Road to Sidi Bel Abbes - BP 284- 46000, Aïn Témouchent, Algeria

[2]University of Ouargla KASDI Merbah, Laboratory of Saharan Bioressources Preservation and Valorisation, Ouargla, Algeria

[*]**Corresponding Author: khaled.rahmani@univ-temouchent.edu.dz**

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ABSTRACT

The present study examined the morphometric characteristics of the European pilchard, *Sardina pilchardus* (Walbaum, 1792) from Béni-Saf Bay (Algeria), to address the lack of data concerning the exploitation of their stocks in this area. A total of 306 specimens were examined, consisting of 49.35% males, 45.10% females, and 5.56% undetermined individuals. The overall sex ratio was 1.09, slightly favoring males ($\chi 2$ = 0,5848; $P<0.05$). Sixteen measurements were carried out for each specimen; the total length of the observed fish ranged from 6.4 to 22.7 cm. The length-weight relationship for *S. pilchardus* was determined using the regression equation $Wt=aLt^b$. The model parameters for the relationships (LWR) indicated a positive allometric growth for both sexes (t-test, $P<0.05$); the coefficient of determination (R^2) was 0.97 for males and 0.99 for females, indicating a strong correlation between length and weight. The equations of the length-weight relationship were $Wt = 0.0057*Lt^{3.0981}$ for males and $Wt = 0.0066*Lt^{3.0602}$ for females. The results of the model parameters for the relationships $Y=aLt^b$ indicate a strong correlation between all morphological measurements and total length. Regardless of sex, all parameters showed a lower growth allometry (negative allometry), with statistically significant results observed in both sexes (t-test, $P<0.05$). The present study demonstrated that male and female *S. pilchardus* from Béni-Saf Bay (Algeria) showed sexual dimorphism in favor of the females (F-test, $P<0.05$). Females fish have longer fin sizes than males and longer heads than males. Furthermore, females possess a longer upper jaw compared to males.

INTRODUCTION

The European sardine, scientifically known as *Sardina pilchardus* **(Walbaum, 1792)**, holds an ecological significance as a crucial pelagic resource, bridging planktonic production and higher trophic levels. Moreover, it stands as the most abundant fish species in the Algerian fishing lands **(Mustać *et al.*, 2020)**.

In 2003, the oceanographic vessel "Visconde de Eza" conducted a stock assessment. The outcomes of this assessment led the fisheries sector to conclude that the stocks were underexploited, prompting an increase in fishing effort with the expectation of raising annual catches from 30,000 to 220,000 tons. However, a recent research suggests that a majority of the stocks off the Algerian coast are now experiencing overexploitation **(Handjar *et al*., 2019)**.

For biometric traits, the length-weight relationship (LWR) and body condition indices are frequently employed in fisheries research and management. These tools find applications in stock assessment models, biomass estimation and comparisons of fish populations among different regions and seasons **(Mustać *et al*., 2020)**. Moreover, these data are significant in the context of conserving small pelagic fish. This is because their stocks contribute to sustaining predator populations, among larger fish and other marine organisms, thus playing a crucial role in shaping the trophic structure of marine ecosystems **(Mustac & Sinovčić, 2010)**.

Understanding length-weight relationships (LWR) carries a wide significance since it enables the numerical evaluation of fish condition, facilitates comparisons of living conditions within the same species in different regions, aids in calculating biomass using length data, and allows for the conversion of length growth equations into weight growth equations. Each of these applications serves distinct roles in stock assessment and management models **(Şenbahar *et al*., 2020)**. Understanding the LWR of fish species is crucial for the fisheries sustainable management and conservation. This understanding allows estimating fish species distribution, assessing their condition, and making morphological comparisons. All of these contribute to inform decision-making and effective conservation strategies **(Froese & Pauly, 2005; Froese, 2006)**.

The present paper focuses on the growth of the European sardine, *S. pilchardus* (Walbaum, 1792), of the Béni-Saf Bay (North-West Algeria). It particularly highlights the LWR and metric characteristics of the studied population.

To the best of our knowledge, this study represents the first attempt to analyze these aspects of *S. pilchardus* in this region. By examining the metric traits, the study aimed to quantify intraspecific variation within the species and explore the broader ecological and conservation implications of these findings. The research offers valuable insights into the population dynamics of *S. pilchardus* in Béni-Saf Bay, contributing to a deeper understanding of its ecological role and informing conservation strategies in a region where such studies have not been previously conducted.

MATERIALS AND METHODS

A total of 306 specimens of *S. pilchardus* was collected from Béni-Saf trawl fishery (Fig. 1).

Fig. 1. Geographical location of the Beni-Saf Bay (western coast of Algeria)

For each specimen, we recorded 16 measurements (Fig. 2). The different lengths were measured using a caliper to the nearest mm, and the sex was macroscopically determined based on the morphology and the color of gonads **(Rahmani *et al.*, 2021)**.

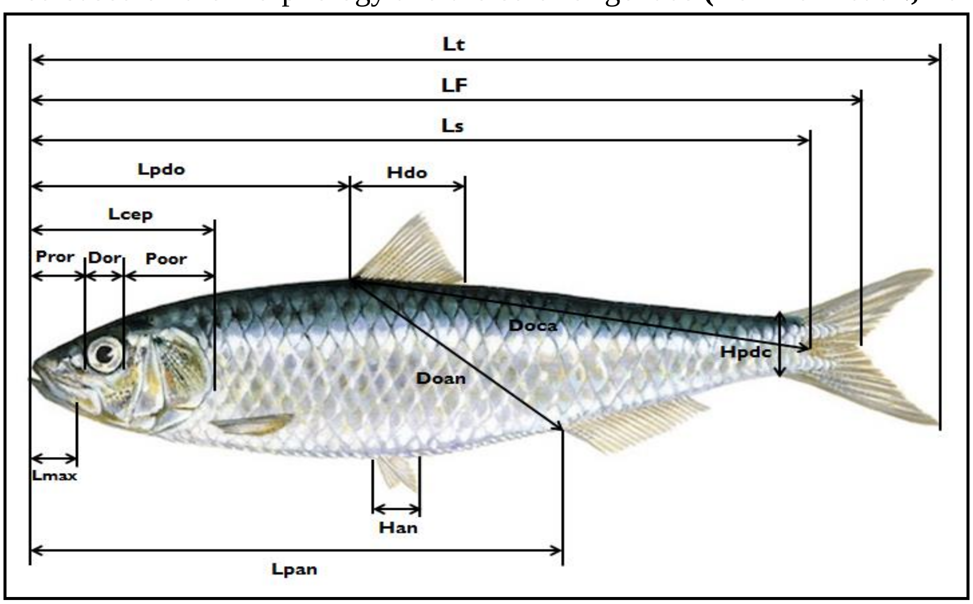


Fig. 2. Morphometric measurements taken for fish (**Lt:** Total length; **LF:** At fork length; **Ls:** Standard length; **Lpdo:** Length pre-dorsal; **Lpan:** Length pre-anal; **Lcep:** Cephalic length; **Doan:** Dorsal / anal distance; **Doca:** Dorsal / caudal distance; **Lmax:** Maxillary length; **Dor:** Diameter orbital; **Pror:** Length pre-orbital; **Poor:** Distance post-orbitaire; **Hdo:** Dorsal height; **Han:** Anal height; **Hpdc:** Peduncle height)

Sex-ratio

The sex ratio is defined as the share of male or female individuals in the total number of individuals. It gives an idea about the sexes balance within the population. It is generally translated as the rate of femininity or masculinity in the population **(Rahmani *et al.*, 2020)**:

$$SR = M/ F$$

F= number of females; **M** = number of males.

The length-weight relationship (LWR)

The LWR was calculated from the equation:

$$Wt = a\ Lt^{b}$$ **(Huxley & Tessier, 1936)**

Where:

Wt is the fish body weight in grams,

Lt: the total fish length in centimeters,

a: an intercept or a constant,

b: the slope or length exponent.

Isometric growth means that an organism's body shape does not change as it grows and that weight increases as the cubic power of length (Lt^3), i.e., the slope (b) is equal to 3. If the value of b is significantly less than 3, this indicates a negative allometric relative growth, which means that fish becomes more slender as it grows longer. Meanwhile, if this value is significantly higher than 3, we have in this case a positive allometric relative growth, which means the fish becomes stouter or deeper-bodied as it increases in body weight. It should be remembered that the coefficient "a" is only a rough indicator of shape when growth is not isometric, or of shape variation when two species or sexes have different allometric parameters. The degree to which one species or sex is considered slender or stouter than another would change with length in the latter case. The value of "a" is directly interpretable as the weight of a fish in g when it is of 1cm in length, as determined in the study of **Riedel *et al*. (2007)**.

Metric characters

To characterize the morphology of *S. pilchardus*, various measured parameters were expressed as a function of the total length using the following regression formula:

$$Y= a\ Lt^{b}$$

Polynomial regression was applied for the examination of morphometric relations compared to the increase in total length **(Kováč *et al.*, 1999)**.

Data treatment and statistical analysis

The likelihood ratio Chi-square test was used to compare sex ratio, significance level was set at P smaller than 0.05.

The growth types were tested using the t-test that investigates whether the slope b was significantly different from the theoretical value 3, with a confidence level of 95%. To detect the presence of sexual dimorphism, an F-test was used to compare the morphological measurements between the sexes, with the significance level set at $P<0.05$.

All statistical analyses were carried out with R version 0.6.5, and IBM Statistics SPSS version 27.

RESULTS

The distribution of the length frequencies of the entire sample is shown in Fig. (3). Male length ranged from 8.5 to 22.7cm with a mean length of 14.25 ± 0.29cm (mean ± SD), while for the female the range was 6.4 to 22.7cm with a mean length of 14.37 ± 0.35cm. For females, the weight ranged between 3.02 to 97.75g, with a mean weight of 27.53 ± 2.13g. For males, the weight ranged from 4.28 to 91.65g, with a mean weight of 24.89 ± 1.62g.

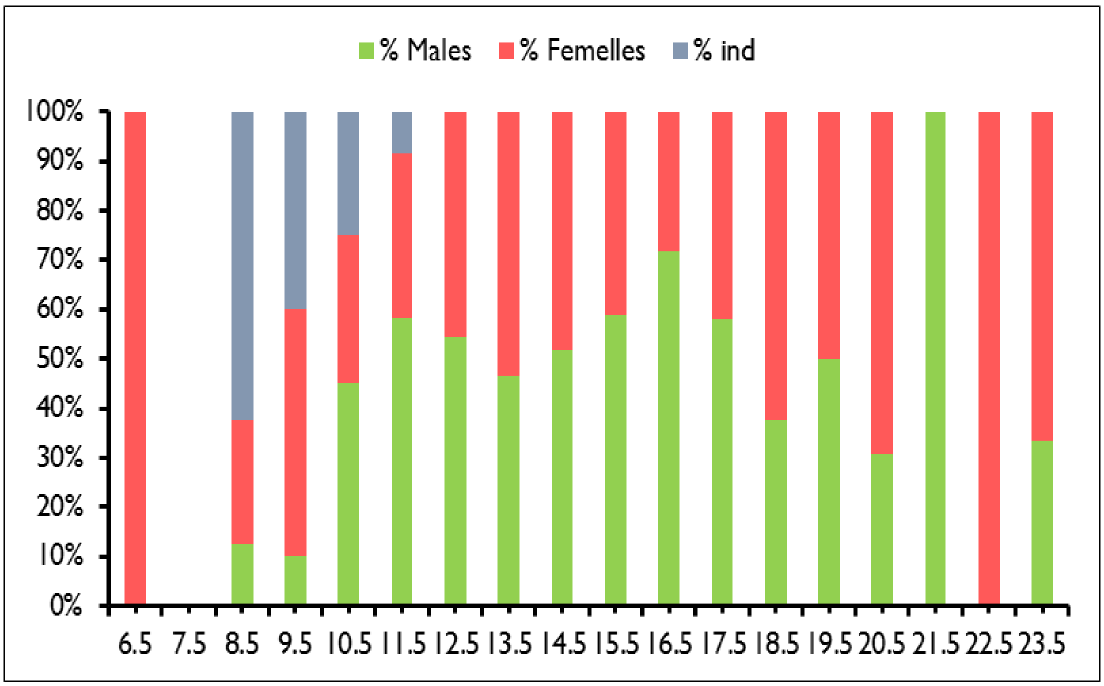


Fig. 3. Length frequency distribution of *S. pilchardus* caught in Béni-Saf Bay

Sex ratio

Among the 306 collected specimens of *S. pilchardus*, 151 were males (49.35%), 138 females (45.10%) and 17 unsexed specimens (5.56%). The sex ratio of the examined individuals was 1.09, indicating that males were significantly more numerous in the sample ($\chi 2 = 0{,}5848$, $P<0.05$).

Monthly and seasonal variations in sex ratio

The sex ratio exhibited seasonal variation. We recorded a higher proportion of females during the winter and summer months, whereas in the spring and autumn, the ratio was skewed in favor of males. Additionally, the sex ratio in the summer and autumn seasons showed statistical significance (χ^2 , $P< 0.05$). The statistical details of sex ratio are provided in Table (1).

Table 1. Seasonal and monthly variations of the sex ratio of *S. pilchardus* in the W-Mediterranean (Algerian coast)

Season /Month	M	F	T	SR	χ^2	P	Significance
Winter	**29**	**30**	**59**	**0,97**	0,0169	0.200472	NS
December	9	10	19	0,90	0,0526	0.14946	NS
January	12	12	24	1,00	0,0000	---	---
February	8	8	16	1,00	0,0000	---	---
Spring	**41**	**38**	**79**	**1,07**	0,1139	0.114751	NS
March	6	20	26	0,30	7,5385	0.000264	S
April	15	7	22	2,14	2,9091	0.005528	S
May	20	11	31	1,82	2,6129	0.006911	S
Summer	**36**	**46**	**82**	**0,78**	1,2195	0.022641	S
June	13	19	32	0,68	1,1250	0.024887	S
July	10	11	21	0,91	0,0476	0.153964	NS
August	13	16	29	0,81	0,3103	0.071315	NS
Autumn	**47**	**24**	**69**	**1,96**	9,7246	0.000071	S
September	11	9	20	1,22	0,2000	0.089961	NS
October	24	5	29	4,80	12,4483	0.000015	S
November	10	10	20	1,00	0,0000	---	---
Overall	**151**	**138**	**289**	**1,09**	**0,5848**	**0.046407**	S

M = number of males, F = number of females, T = total number, SR = sex ratio, χ^2 = value of Chi-square-analysis, P = *p.value* of $\chi2$ test, S = significant difference, NS = not significant difference at risk of 5%.

The sex ratio exhibited monthly variations. The analysis showed a female-biased ratio in March, June, July, August, and December, while April, May, September, and October displayed a male-biased ratio. In contrast, January and February showed a balanced sex ratio, with equal proportions of males and females. The sex ratio revealed statistically significant differences in the months of March, April, May, June, and October. In contrast, no statistical significance was observed in the other months of the year.

Over the course of the year, the sex ratio showed a distinct male predominance. Furthermore, the annual sex ratio demonstrated statistical significance (SR=1,09; χ^2 = 0.5848; P= 0.046 < 0.05).

The sex ratio shifts with variations in size (Table 2). We recorded a predominance of females at sizes 7.5, 8.5, 13.5, 18.5, 20.5, and 23.5, while a male predominance was noted at sizes 10.5; 11.5; 12.5; 14.5; 15.5; 16.5 and 17.5.

Based on size classification, the sex ratio displayed statistical significance at the following sizes: 6.5; 9.5; 10.5; 11.5; 15.5; 16.5; 17.5; 18.5; 19.5; 20.5; 21.5; and 22.5 (P = < 0.05).

Table 2. Variation of sex ratio as a function of size class for S. *pilchardus* in the W-Mediterranean (Algerian coast)

Class Center	N	M	F	$\bar{X}$	SR	χ^2	P	Sig
6.5	1	1	0	6.4	0.00	1,0000	0,0283	S
7.5	---	---	---	---	---	---	---	---
8.5	3	1	2	8,1333	0,50	0,3333	0,0684	NS
9.5	6	1	5	8,95	0,20	2,6667	0,0066	S
10.5	15	9	6	10,1467	1,50	0,6000	0,0455	S
11.5	33	21	12	11,0606	1,75	2,4545	0,0078	S
12.5	33	18	15	12,1212	1,20	0,2727	0,0767	NS
13.5	43	20	23	13,0093	0,87	0,2093	0,0880	NS
14.5	29	15	14	14,0897	1,07	0,0345	0,1685	NS
15.5	17	10	7	14,9824	1,43	0,5294	0,0501	S
16.5	40	28	13	16,08	2,33	4,9000	0,0014	S
17.5	18	11	7	17,1167	1,57	0,8889	0,0320	S
18.5	16	6	10	18,1312	0,60	1,0000	0,0283	S
19.5	10	5	5	18,96	1,00	0,0000	0	S
20.5	13	4	9	20,1077	0,44	1,9231	0,0120	S
21.5	1	1	0	20.8	0.00	1,0000	0,0283	S
22.5	8	0	8	22,075	---	8,0000	0,00002	S
23.5	3	1	2	22,733	0,50	0,3333	0,0684	NS
Overall	**289**	**151**	**138**	**14,4716**	**1,09**	**0,5848**	**0,0464**	**S**

N= sample size, M = number of males, F = number of females, $\bar{X}$ = mean values, SR = sex ratio, χ^2 = value of Chi-square-analysis, P = *p.value* of $\chi2$ test, S = significant difference, NS = not significant difference at risk of 5%.

The length-weight relationship (LWR)

The model parameters for the LWR Wt=f(Lt) for *S. pilchardus* (Table 3) indicated a positive allometric growth (statistical significance: t-test, $P< 0.05$), with body weight increasing slightly faster than length (Fig. 4 & Fig. 5). The LWR for *S. pilchardus* was determined using the regression equation $Wt=aLt^b$. The coefficient of determination (R^2) was 0.97 for males and 0.99 for females, indicating a strong correlation between length and weight. The obtained b value suggests a positive allometric growth, as it exceeded 3 for both sexes.

Table 3. Descriptive statistics and estimated parameters of LWR for *S. pilchardus* males and females

S. pilchardus	**N**	**Lt (cm)** (min-max)	**Wt (g)** (min-max)	**a**	**b**	**R^2**	**df**	***SE***	**SE(b)**	***t-test***	**P-*value***	**GT**	**Sig**
Males	151	8.5 - 22.7	4.28 - 91.65	0.0057	3.0981	0.9762	580	1.599	0.00569	15.581	0.0001	(+)	S
females	138	6.4 - 22.7	3.02 - 97.75	0.0066	3.0602	0.9909	540	1.704	0.00552	16.035	0.0001	(+)	S

N= sample size; **a=** the intercept of the regression; **b=** the regression slope; **R^2=** the coefficient of determination; **df** = degree of freedom***; SE*** =standard error of difference; **SE(b)=** standard error of slope b**;** t-test = student test; **GT=** Growth ; **(+)=** positive allometric growth; **(-)=** negative allometric growth; **(0)=** Isometric growth; **LWR=** length-weight relationships.

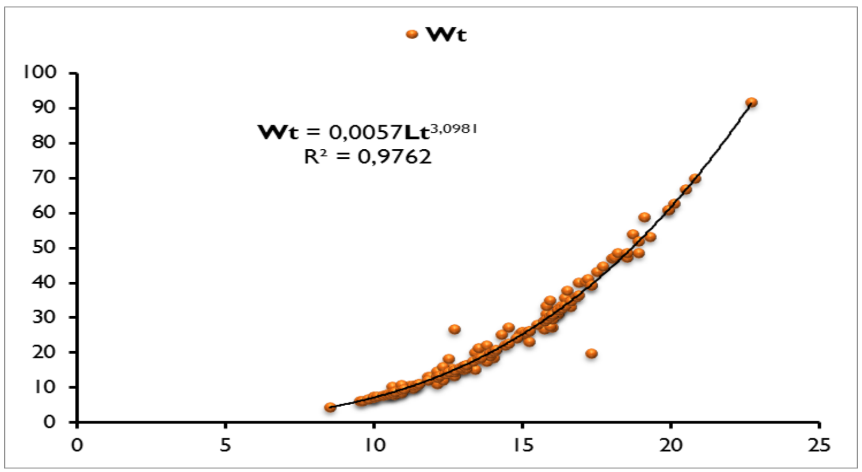


Fig. 4. Weight-length relationships for *S. pilchardus* (Males)

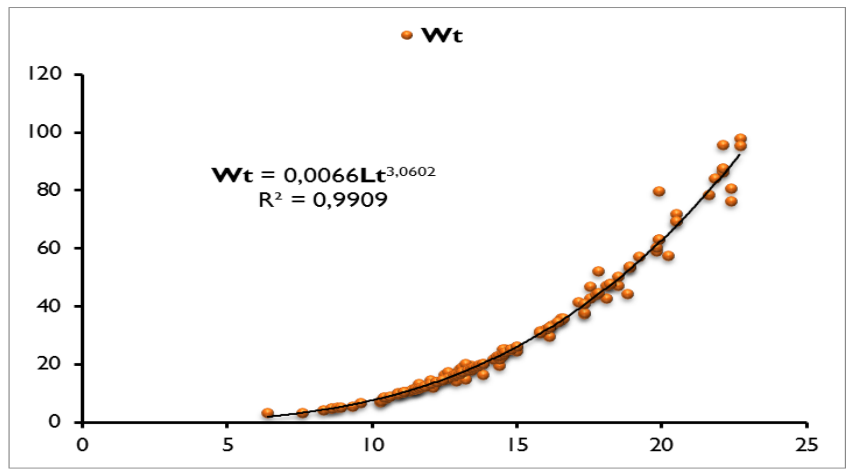


Fig. 5. Weight-length relationships for *S. pilchardus* (Females)

Monthly variations in length-weight relationship

The monthly results indicate a strong correlation between length and weight (Table 4), with the coefficient of determination (R^2) exceeding 0.95 throughout the year for both sexes, except for July in females, where the R^2 value was relatively lower (R^2 = 0.78).

Table 4. Monthly parameters of the LWR parameters and growth

		N	Lt (min-max)	Wt (min-max)	a	b	R^2	SE(b)	t-*test*	P-*value*	GT	Sig
Males	**J**	12	10.0-17.2	7.15-41.15	0.0052	3.142	0.99	0.00392	4.0604	0.0002	(+)	ES
	F	8	11.4-18.0	10.69-46.86	0.0045	3.199	0.99	0.00261	4.1436	0.0002	(+)	ES
	M	6	11.5-18.1	10.99-47.14	0.0043	3.211	0.99	0.00091	2.1739	0.0426	(+)	S
	A	15	13.0-22.7	15.09-91.65	0.0037	3.248	0.99	0.00344	6.2524	0.0001	(+)	ES
	M	20	8.5-17.5	4.28-43.10	0.0046	3.197	0.99	0.00401	4.9379	0.0001	(+)	ES
	J	13	9.8-19.1	6.67-58.84	0.0040	3.244	0.99	0.00253	5.1420	0.0001	(+)	ES
	J	11	10.6-13.5	8.31-26.66	0.0015	3.664	0.78	0.02117	4.3231	0.0001	(+)	ES
	A	13	10.5-20.8	8.27-69.77	0.0060	3.088	0.99	0.00281	4.7987	0.0001	(+)	ES
	S	11	10.7-17.3	8.78-39.42	0.0074	3.014	0.98	0.00303	4.2495	0.0001	(+)	ES
	O	24	10.7-17.3	8.02-39.27	0.0066	3.028	0.92	0.01127	5.6656	0.0001	(+)	ES
	N	10	10.0-20.1	7.11-62.71	0.0055	3.115	0.99	0.00294	5.6656	0.0001	(+)	ES
	D	9	10.3-19.9	7.79-60.73	0.0043	3.189	0.99	0.00240	3.3473	0.0022	(+)	VS
Females	**J**	12	10.4 - 17.5	8.34 - 42.64	0.0061	3.093	0.99	0.00251	5.5611	0.0001	(+)	ES
	F	8	11.5-17.5	11.49-46.78	0.0036	3.298	0.99	0.00314	3.1626	0.0037	(+)	VS
	M	20	11.1-19.8	10.28-58.87	0.0052	3.150	0.99	0.00595	6.2065	0.0001	(+)	ES
	A	7	8.6-22.1	4.78-87.53	0.0062	3.084	0.99	0.00054	4.1355	0.0003	(+)	ES
	M	11	7.6-17.3	3.13-37.4	0.0059	3.089	0.99	0.00312	2.6064	0.0128	(+)	S
	J	19	6.4-22.7	3.02-97.75	0.0084	2.985	0.98	0.00757	5.9321	0.0001	(0)	ES

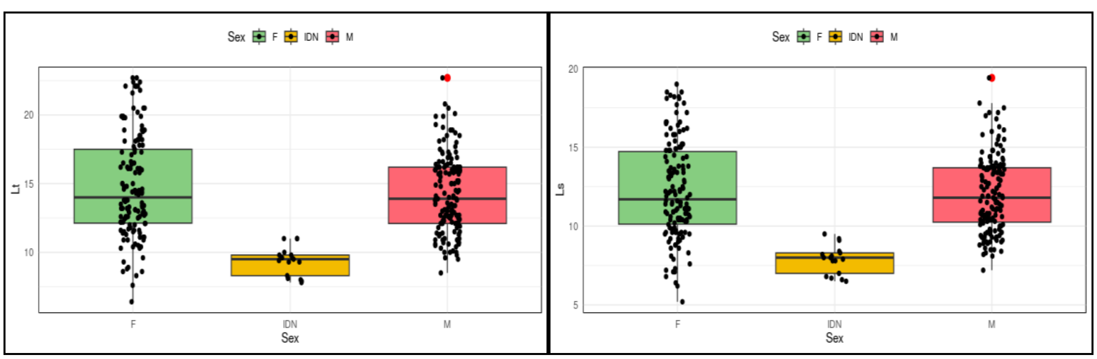
J	11	10.9-13.1	9.65-18.95	0.0045	3.222	0.95	0.01662	2.7743	0.0090	(+)	VS
A	16	9.6-22.4	6.49-86.22	0.0075	3.006	0.99	0.00557	7.0766	0.0001	(0)	ES
S	9	12.6-22.7	15.9-95-16	0.0090	2.962	0.99	0.00209	5.0907	0.0001	(-)	ES
O	5	8.6-16.1	4.61-32.58	0.0075	2.980	0.99	0.00376	2.8718	0.0106	(0)	S
N	10	10.3-21.8	6.78-83.88	0.0041	3.312	0.99	0.00536	5.0095	0.0001	(+)	ES
D	10	11.1-19.8	10.21-60.16	0.0078	2.970	0.98	0.00570	4.2649	0.0001	(-)	ES

N= sample size; **a=** the intercept of the regression; **b=** the regression slope; **SE(b)**= standard error of slope b**; T=** student t-test; **R^2=** the coefficient of determination; **GT=** Growth ; **(+)=** positive allometric growth; **(-)=** negative allometric growth; **(0)=** Isometric growth; **VS**= very statistically significant; **ES**= extremely statistically significant; **S**= statistically significant.

Analysis of the monthly model parameters for the relationships Wt=f(Lt) revealed a positive allometric growth between height and weight in males. This trend was similarly observed in females, except for the months of June and August, where the relationship between height and weight was neutral. In addition, in December, a negative relationship between height and weight was noted. The association between height and weight demonstrates statistical significance across all months of the year for both males and females (t-test, $P < 0.05$).

Metric characters

The studied morphological measurements are illustrated in Figs. (6, 7) (Box-whiskers plots). In addition, an overall distribution of all measured parameters, including the total weight can be seen in Figs. (6, 7).



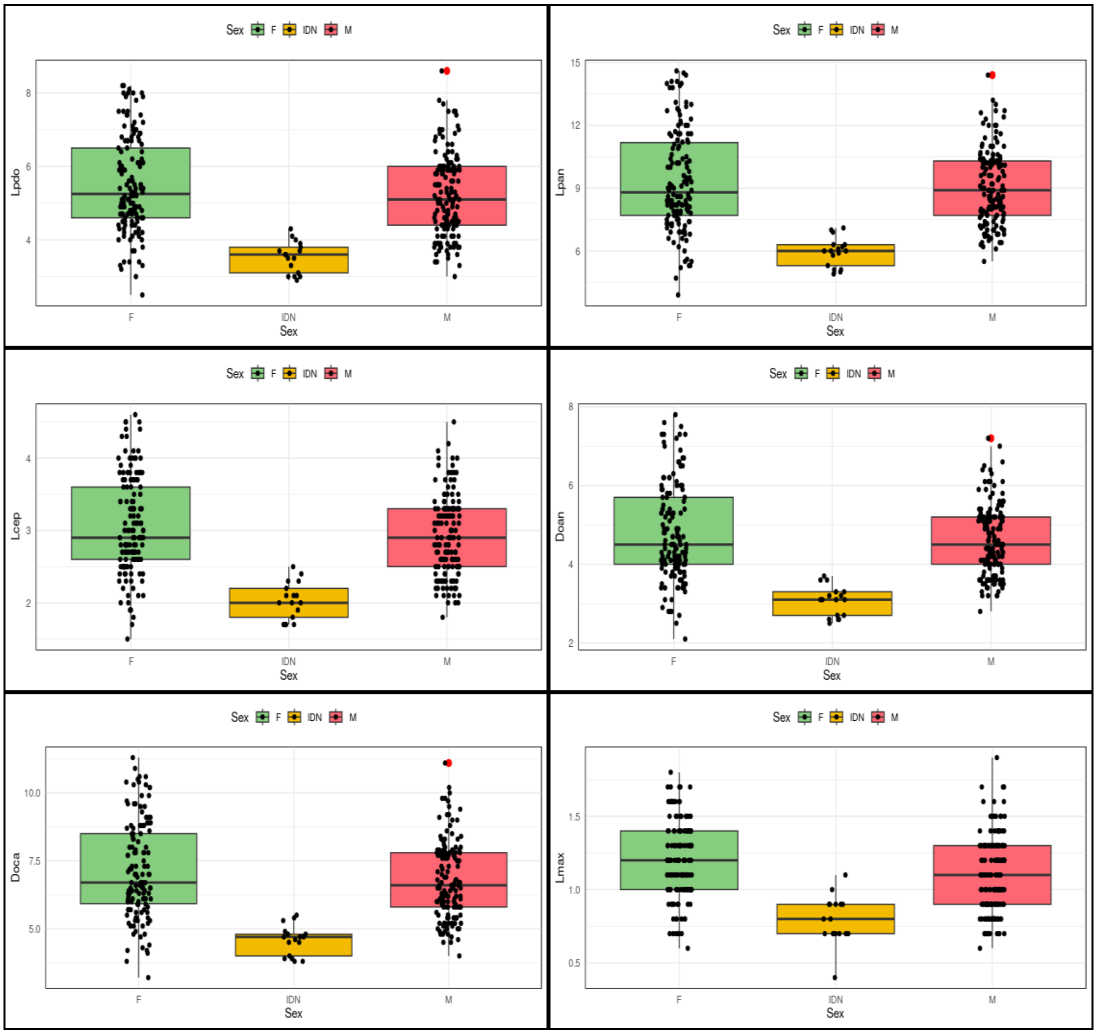
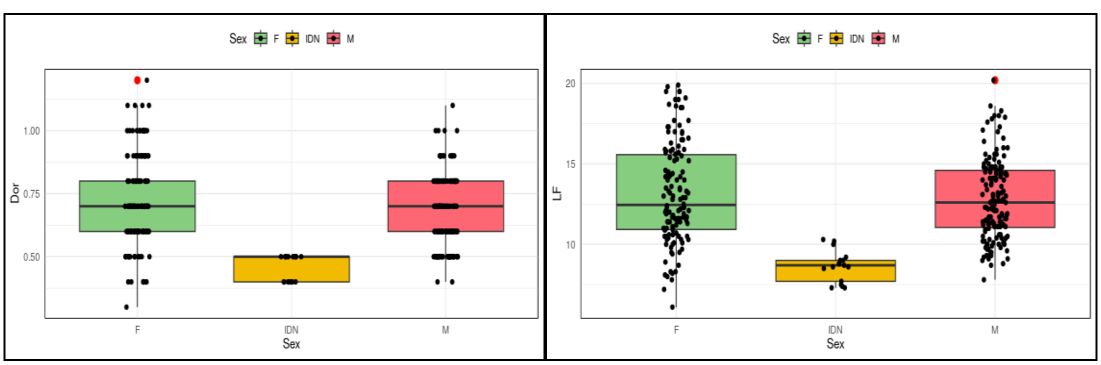


Fig. 6. Box-whiskers plots of 8 (Lt, Ls, Lpdo, Lpan, Lcep, Doan, Doca, Lmax) for males females and undetermined individuals. The central box covers 50% of data values, the vertical line indicates the range of the values, and the horizontal line represents the median



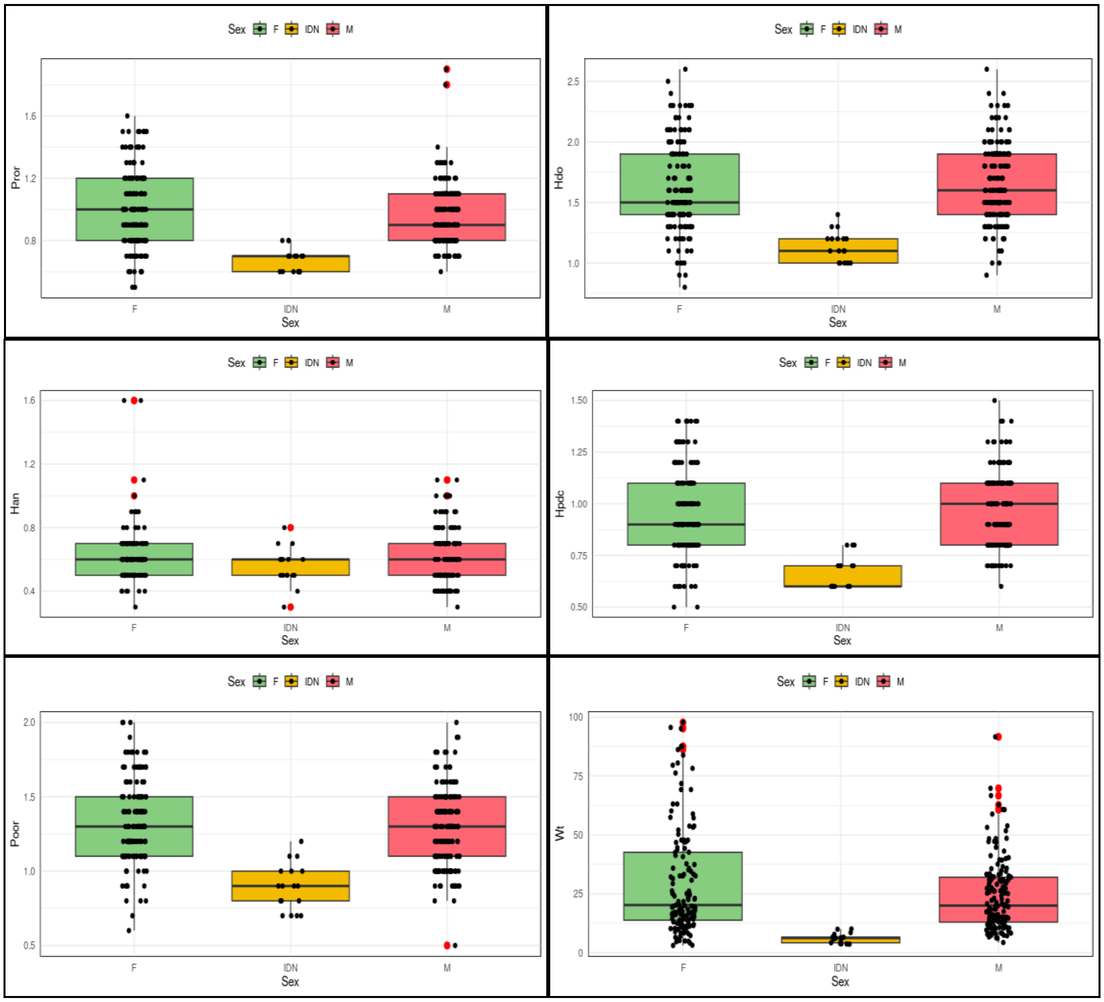


Fig. 7. Box-whiskers plots of Dor, LF, Pror, Hdo, Han, Hpdc, Poor, Wt for males females and undetermined individuals. The central box covers 50% of data values, the vertical line indicates the range of the values, and the horizontal line represents the median

For both sexes, the results of the model parameters for the relationships $Y=aLt^b$ indicate a strong correlation between all morphological measurements and total length, with the coefficient of determination (R^2) exceeding 0.78. The exception was the morphological measurement "Han" in females, where the R^2 value was relatively low ($R^2 = 0.46$). The regression equations of observed values of all metric characters (for males and females) and descriptive statistics are presented in Tables (5, 6).

Table 6. Correlation coefficients and regression equations of the various parameters measured as a function of the total length (Sex females, n = 138)

Y=f(Lt)	Range	Equation	R^2	Growth Type	SE	CI	*t*-test	*p*-value	Sig
Ls=f(Lt)	$5.2 \leq Ls \leq 19.0$	$Ls = 0.8042Lt^{1.0117}$	0.9755	Allometric (-)	0.452	0.64 to 2.41	3.3711	0.0008	ES
Lpdo=f(Lt)	$2.5 \leq Lpdo \leq 8.2$	$Lpdo = 0.4383Lt^{0.9397}$	0.9909	Allometric (-)	0.377	4.15 to 5.63	12.974	0.0001	ES
Lpan=f(Lt)	$3.9 \leq Lpan \leq 14.6$	$Lpan = 0.5898Lt^{1.0254}$	0.9969	Allometric (-)	0.379	5.13 to 6.62	7.1226	0.0001	ES
Lcep=f(Lt)	$1.5 \leq Lcep \leq 4.6$	$Lcep= 0.3003Lt^{0.8639}$	0.9521	Allometric (-)	0.379	5.13 to 6.62	15.499	0.0001	ES
Doan=f(Lt)	$2.1 \leq Doan \leq 7.8$	$Doan = 0.3141Lt^{1.0137}$	0.9927	Allometric (-)	0.373	4.47 to 5.94	13.9701	0.0001	ES
Doca=f(Lt)	$3.2 \leq Doca \leq 11.3$	$Doca= 0.5247Lt^{0.9712}$	0.9919	Allometric (-)	0.382	3.36 to 4.86	10.755	0.0001	ES
Lmax=f(Lt)	$0.6 \leq Lmax \leq 1.8$	$Lmax = 0.134Lt^{0.8157}$	0.8747	Allometric (-)	0.375	6.82 to 8.29	20.144	0.0001	ES
Dor=f(Lt)	$0.3 \leq Dor \leq 1.2$	$Dor = 0.0569Lt^{0.9432}$	0.9698	Allometric (-)	0.407	5.82 to 7.42	16.275	0.0001	ES
LF=f(Lt)	$6.1 \leq LF \leq 19.9$	$LF = 1.0811Lt^{0.9286}$	0.9940	Allometric (-)	0.466	0.08 to 1.91	2.132	0.0335	S
Pror=f(Lt)	$0.5 \leq Pror \leq 1.6$	$Pror = 0.0738Lt^{0.9743}$	0.9743	Allometric (-)	0.398	6.26 to 7.82	17.698	0.0001	ES
Hdo=f(Lt)	$0.8 \leq Hdo \leq 2.6$	$Hdo = 0.179Lt^{0.82}$	0.8559	Allometric (-)	0.377	6.23 to 7.71	18.496	0.0001	ES
Han=f(Lt)	$0.3 \leq Han \leq 1.6$	$Han = 0.1268Lt^{0.5879}$	0.4687	Allometric (-)	0.395	5.95 to 7.50	17.047	0.0001	ES
Hpdc=f(Lt)	$0.5 \leq Hpdc \leq 1.4$	$Hpdc = 0.0851Lt^{0.9007}$	0.9746	Allometric (-)	0.405	6.10 to 7.69	17.029	0.0001	ES
Poor=f(Lt)	$0.6 \leq Poor \leq 2$	$Poor = 0.154Lt^{0.7975}$	0.8758	Allometric (-)	0.374	6.66 to 8.13	19.776	0.0001	ES

R^2= the coefficient of determination; **(+)**= positive allometric growth; **(-)**= negative allometric growth; **(0)**= Isometric growth; ***SE** = standard error;* **CI=** Confidence interval; ***t*-test =** Student test; **ES =** extremely statistically significant; **S =** statistically significant.

Table 6. Correlation coefficients and regression equations of the various parameters measured as a function of the total length (Sex males, n = 151)

Y=f(Lt)	Range	Equation	R^2	Growth Type	SE	CI	*t*-test	*p*-value	Sig
Ls=f(Lt)	$7.2 \leq Ls \leq 19.4$	$Ls = 0.8653Lt^{0.9931}$	0.9938	Allometric (-)	0.392	0.69 to 2.23	3.7133	0.0002	ES
Lpdo=f(Lt)	$3.0 \leq Lpdo \leq 8.6$	$Lpdo = 0.2989Lt^{1.0767}$	0.9861	Allometric (-)	0.328	4.21 to 5.50	14.783	0.0001	ES
Lpan=f(Lt)	$5.5 \leq Lpan \leq 14.4$	$Lpan = 0.658Lt^{09877}$	0.9958	Allometric (-)	0.360	2.69 to 4.11	9.4436	0.0001	ES
Lcep=f(Lt)	$1.8 \leq Lcep \leq 4.5$	$Lcep= 0.2325Lt^{0.2529}$	0.9878	Allometric (-)	0.323	5.72 to 6.99	19.689	0.0001	ES
Doan=f(Lt)	$2.8 \leq Doan \leq 7.2$	$Doan = 0.3645Lt^{0.9566}$	0.9861	Allometric (-)	0.321	5.01 to 6.27	17.596	0.0001	ES
Doca=f(Lt)	$4.0 \leq Doca \leq 11.1$	$Doca= 0.4355Lt^{1.0368}$	0.9941	Allometric (-)	0.333	3.54 to 4.85	12.623	0.0001	ES
Lmax=f(Lt)	$0.6 \leq Lmax \leq 1.9$	$Lmax = 0.0511Lt^{1.1542}$	0.9194	Allometric (-)	0.345	6.50 to 7.86	20.802	0.0001	ES
Dor=f(Lt)	$0.4 \leq Dor \leq 1.1$	$Dor = 0.0468Lt^{1.006}$	0.9746	Allometric (-)	0.361	5.76 to 7.18	17.913	0.0001	ES
LF=f(Lt)	$7.8 \leq LF \leq 20.2$	$LF = 1.0106Lt^{0.9579}$	0.9871	Allometric (-)	0.415	0.37 to 2.01	2.8625	0.0044	VS
Pror=f(Lt)	$0.6 \leq Pror \leq 1.9$	$Pror = 0.088Lt^{0.8998}$	0.8672	Allometric (-)	0.364	6.22 to 7.65	19.047	0.0001	ES
Hdo=f(Lt)	$0.9 \leq Hdo \leq 2.6$	$Hdo = 0.1406Lt^{0.9317}$	0.8409	Allometric (-)	0.341	5.98 to 7.32	19.499	0.0001	ES
Han=f(Lt)	$0.3 \leq Han \leq 1.1$	$Han = 0.0219Lt^{1.2425}$	0.8804	Allometric (-)	0.349	6.21 to 7.58	19.752	0.0001	ES
Hpdc=f(Lt)	$0.6 \leq Hpdc \leq 1.5$	$Hpdc = 0.0855Lt^{0.918}$	0.9797	Allometric (-)	0.357	6.45 to 7.85	20.027	0.0001	ES
Poor=f(Lt)	$0.5 \leq Poor \leq 2$	$Poor = 0.1023Lt^{0.9501}$	0.7848	Allometric (-)	0.328	6.84 to 8.13	22.827	0.0001	ES

R^2= Coefficient of determination; **(+)**= Positive allometric growth; **(-)**= Negative allometric growth; **(0)**= Isometric growth; ***SE*** **=** Standard error; **CI=** Confidence interval; ***t*-test =** Student test; **ES =** Extremely statistically significant; ; **VS =** Very statistically significant; **S =** Statistically significant.

The high values of the correlation coefficient of all measurements with total length confirm the close coincidence between them. Whatever was the sex, all parameters showed a lower growth allometry (negative allometry).

The regression equations obtained for each of the different morphometric measurements indicated a strong relationship with the total length of the fish, with statistical significance observed for both sexes (*t*-test, *P*-value<0.05).

Sexual dimorphism

To investigate potential sexual dimorphism in sardines, a comparison was made of all lengths and total weights for both sexes (Table 7).

Table 7. Statistics relations of morphometric characters between the two sexes (Sexual Dimorphism)

Metric parameter	n		SD		CI	F-test	*P*-value	sig
	F	M	F	M				
Lt [(F)/(M)]	267	282	5.74	5.16	0.79 - 1.27	1.2376	0.07809	NS
Ls [(F)/(M)]	272	296	4.71	4.24	0.79 - 1.26	1.234	0.07708	NS
Lpdo [(F)/(M)]	267	295	4.89	4.94	0.79 - 1.26	0.9907	0.9397	NS
Lpan [(F)/(M)]	266	298	3.42	3.37	0.79 - 1.26	1.0308	0.7981	NS
Lcep [(F)/(M)]	299	268	2.05	2.35	0.89 - 1.12	0.759	0.02053	**S**
Doan [(F)/(M)]	271	298	2.13	1.94	0.89 - 1.12	1.2116	0.1061	NS
Doca [(F)/(M)]	274	299	2.60	2.46	0.79 - 1.26	1.1173	0.3486	NS
Lmax [(F)/(M)]	275	301	2.35	2.94	0.89 - 1.12	0.6397	0.0001786	**S**
Dor [(F)/(M)]	272	301	3.44	3.44	0.89 - 1.12	1.0005	0.9951	NS
LF [(F)/(M)]	269	292	5.03	5.79	0.79 - 1.26	1.1042	0.4069	NS
Pror [(F)/(M)]	274	297	3.18	3.47	0.89 - 1.12	0.8361	0.1329	NS
Hdo [(F)/(M)]	272	296	2.36	2.72	0.89 - 1.12	0.7485	0.01545	**S**
Han [(F)/(M)]	275	300	3.09	3.05	0.89 - 1.12	1.0266	0.8228	NS
Hpdc [(F)/(M)]	272	298	3.37	3.28	0.89 - 1.12	1.0554	0.649	NS
Poor [(F)/(M)]	276	301	2.32	2.31	0.89 - 1.12	1.0104	0.9288	NS
Wt [(F)/(M)]	276	301	27.32	26.37	0.89 - 1.12	1.073	0.5497	NS

M = Number of males; F = Number of females; n=Sample size; SD= Standard deviation; CI= Confidence interval; F-test =Ficher test; P = *P-value* of F-test; S = Significant difference, NS = Not significant difference at risk of 5%.

Morphological comparisons between male and female sardines revealed a significant variation in three measurements (Lcep, Lmax and Hdo), with strong statistical significance recorded (F-test, *P*-value<0.05).

The present study demonstrated that male and female *S. pilchardus* from Béni-Saf Bay (Algeria) can be distinguished by their fins, heads, and maxillary length. Females fish have longer fin sizes than males, also have longer heads than males. Furthermore, females possess a longer upper jaw compared to males.

DISCUSSION

The sex ratio is slightly in favor of the males (SR=1,09; χ^2=0,58 ; P= 0.046). The evolution of this index does not have regularity. Males dominate in April, May, september and October period, whereas females dominate in March, June, July, August and December. Based on previous studies on the reproduction of sardines in the Mediterranean Sea, particularly the findings of **Keznine *et al.* (2020)**, **Basilone *et al.* (2021)** and **Znari *et al.* (2021)**, it has been observed that sex ratios tend to equalize during the spawning period while differing outside this period. This observation helps explain the results of our study. The variation in sex ratios can also be attributed to the living habits of sardines, which are pelagic fish that form dense schools. In certain populations, either males or females may predominate. Factors such as species behavior, mortality rates, sampling procedures, and the aggregation of individuals of the same sex all contribute to these observed changes in sex ratio, complicating their interpretation.

The present study shows that values of the parameter b remain higher than 3 (*t*-test, P< 0.05), regardless of sex. The small differences indicating that the weight increases slightly faster than the length. The LWR of *S. pilchardus* shows a positive allometric growth for both females and males. The values of the coefficient of determination (R^2) is close to 1, which confirms a strong correlation between the two variables (Lt, Wt) (Males: SE_b = 0.00569 ; Females : SE_b = 0.00552).

Compared to previous researches (Table 8), we found out that our results are close to the findings of **Mouhoub (1986)** in Bou-Ismail Bay (Alegria), **Torres *et al.* (2012)** in Gulf of Cadiz , **Acarli *et al.* (2014)** in Izmir Bay, **Bouhali (2016)** in Algerian East coast, **Kara *et al.* (2018)** in central Aegean Sea and **Mustać *et al.* (2020)** in the eastern Adriatic Sea.

While our findings are relatively superior to those recorded by **Petrakis and Stergiou (1995)** in South Euboikos Gulf , **Mendes *et al.* (2004)** in Portuguese west coast, **Mustac and Sinovčić (2010)** in the middle Adriatic Sea, **Erdogan *et al.* (2010)** in northern Aegean Sea and **Şenbahar *et al.* (2020)** in Aegean Sea- Izmir Bay.

On the other hand, our results do not agree with those cited by **Bouchereau (1981)** in Oran Bay (Alegria), **Sinovčić *et al.* (2004)** in Adriatic Sea, **Tarkan *et al.* (2006)** in Marmara (Turkey), **Itchir and Merine (2018)** in the Algerian Basin, **Falsone *et al.* (2022)** in South of Sicily and **Dahel *et al*. (2024)** in the Algerian East coast.

The LWR parameters can vary between stocks and even between areas as mentioned by **Andrade and Campos (2002)**. The differences in the "b" values can be attributed to the combination of one or more of the following factors: a) differences in the number of examined specimens, b) area/season effect, and c) differences in the observed length ranges of the caught specimens. **Dulčić and Kraljević (1998)** stated that temperature, food quantity, size, sex and stage of maturity are responsible for the differences in parameters of relationship. In addition, **Froese (2006)** stated that small specimens have a different LWR relationship than larger ones.

Table. 8. Parameters of the length-weight relationship and weight in *S. pilchardus* obtained by various authors

Author (year)	Region	Sex	a	b	Growth
Bouchereau, 1981	Oran Bay (Alegria)	♂ ♀	0.00161	3.370	+ allometric
Mouhoub, 1986	Bou-Ismail Bay (Alegria)	♂ ♀	0.07 0.08	2.959 3.012	- allometric + allometric
Petrakis & Stergiou, 1995	South Euboikos Gulf	♂ ♀	0.00003	2.754	- allometric
Sinovčić *et al.*, 2004	Adriatic Sea	♂ ♀	0.0038	3.230	+ allometric
Mendes *et al.*, 2004	Portuguese west coast	♂ ♀	0.0017	2.772	- allometric
Tarkan *et al.*, 2006	Marmara (Turkey)	♂ ♀	0.0021	3.540	+ allometric
Pešić *et al.*, 2006	Boka Kotorska Bay	♂ ♀	-0.0047	3.167	+ allometric
Özaydin & Taskavak, 2006	Aegean Sea- Izmir Bay	♂ ♀	0.0076	3.190	+ allometric
Karachle *et al.*, 2008	North Aegean Sea	♂ ♀	0.0053	3.144	+ allometric
Veiga *et al.*, 2009	Southern Portugal	♂ ♀	0.0051	3.140	+ allometric
Mustac & Sinovčić, 2010	Middle Adriatic Sea	♂ ♀	0.0425 0.0342	2.371 2.465	- allometric - allometric
Erdogan *et al.*, 2010	Northern Aegean Sea (Turkey)	♂ ♀	0.0435 0.0274	2.455 2.642	- allometric - allometric
Torres *et al.*, 2012	Gulf of Cadiz	♂ ♀	0.0082	3.016	0 allometric
Acarli *et al.*, 2014	Izmir Bay – Homa Lagoon	♂ ♀	0.0070	3.053	+ allometric
Bouhali, 2016	Algerian East coast	♂ ♀	0.0053	3.100	+ allometric
Kara et *al.*, 2018	Central Aegean Sea (Turkey)	♂ ♀	0.0069	3.065	+ allometric

Itchir & Merine, 2018	Algerian Basin	♂♀	0.003	3.330	+ allometric
Mustać *et al*., 2020	Eastern Adriatic Sea	♂♀	0.0057	3.069	+ allometric
Şenbahar *et al*., 2020	Aegean Sea- Izmir Bay	♂♀	0.0059	2.7930	- allometric
Bayhan & Aydın, 2022	Izmir Bay (Turkey)	♂♀	0.0054	3.137	
Falsone *et al*., 2022	South of Sicily	♂♀	0.0032	3.306	+ allometric
Rodríguez-García *et al*., 2023	Gulf of Cadiz	♂♀	0.0071	3.0259	0 allometric
Dahel *et al*., 2024	Algerian East Coast	♂♀	0.0039	3.236	+ allometric
Present study 2024	BÉNI-SAF BAY	♂ ♀	0.0057 0.0066	3.0981 3.0602	+ allometric + allometric

a= Intercept; **b**= Length exponent; **(+)**= Positive allometric growth; **(-)**= Negative allometric growth; **(0)**= Isometric growth.

All the metric characters studied (16 parameters) exhibit slower growth compared to the total length of the fish, indicating a minor evolutionary change. Furthermore, certain metric parameters develop differently in the two sexes, consistent with the findings of **Geldenhuys (1973)**, **Borges *et al.* (1977, 1991)** and **Macer (1977))**. Among the 16 measurements, only a few suggest a slight degree of sexual dimorphism (F-test, *P*-value< 0.05). Specifically, three characters demonstrate sexual dimorphism in favor of females: Lcep, Lmax, and Hdo.

CONCLUSION

This research aimed to enhance the understanding of shifts in *Sardina pilchardus* populations in the western region of Algeria, specifically in Béni-Saf Bay. We assert that the relationship between fish weight and length provides valuable insights into the biology and ecology of fish populations. Our findings indicate that the "b" parameter in the length-weight relationship can serve as a meaningful indicator of maturity and reproductive biology. Furthermore, it has significant predictive capability, offering essential insights for fishery and ecosystem resource managers. This approach can contribute to a better understanding of marine environmental variations and their impacts on the dynamics of small pelagic stocks. The study of metric characters in *Sardina pilchardus* provides a comprehensive overview of the species' morphological and ecological traits. The observed variations in these characters reflect the species' health and ecological adaptations. These findings are critical for guiding conservation and management strategies, particularly in habitat protection and sustainable fisheries management. Additionally, the study of sexual dimorphism in *S. pilchardus* from Béni-Saf Bay (Algeria) can serve as a foundation for future taxonomic and biological discussions, especially in conservation efforts and the potential domestication of this species as a commodity for fish markets.

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ملخص

تهدف هذه الدراسة إلى وصف الخصائص المورفومترية لسمك السردين ، *Sardina pilchardus* (Walbaum1792)، في خليج بني صاف (الجزائر)، وذلك لتعويض نقص البيانات حول استغلال مخزون هذا النوع في المنطقة. تم تحليل 306 عينة، حيث كانت نسبة الذكور 49.35% والإناث 45.10%، بينما بلغت نسبة الأفراد غير المحددين جنسياً 5.56%. أظهرت النتائج أن نسبة الجنس العامة تميل قليلاً لصالح الذكور بنسبة 1.09 (χ^2 = 0.5848, P<0.05).

تم إجراء ستة عشر قياسًا لكل عينة، حيث تراوحت الأطوال الكلية للأسماك المرصودة بين 6.4 و22.7 سم. تم تحديد علاقة الطول بالوزن باستخدام معادلة الانحدار $Wt=aLt^b$ حيث أظهرت معلمات نموذج علاقة الطول بالوزن (LWR) نموًا متزايدًا إيجابيًا لكلا الجنسين (اختبار t، p<0.05) مع معامل تحديد (R^2) بلغ 0.97 للذكور و0.99 للإناث، مما يشير إلى ارتباط قوي بين الطول والوزن.

أظهرت نتائج معلمات النموذج للعلاقات $Y=aLt^b$ ارتباطًا قويًا لجميع القياسات المورفولوجية والطول الكلي. و بغض النظر عن الجنس، تُظهر جميع المعلمات نموًا أقل (نمو سالب)، مع وجود دلالة إحصائية لكلا الجنسين (اختبار t ، p<0.05)

بينت المقارنات المورفولوجية بين الذكور والإناث اختلافًا كبيرًا في ثلاثة قياسات (Lcep و Lmax وHdo) مع تسجيل دلالة إحصائية قوية (اختبار F، p <0.05) حيث تمتلك إناث الأسماك أحجام زعانف أكبر من الذكور، كما أن لديهن رؤوس أطول. علاوة على ذلك، تمتلك الإناث فكًا علويًا طويل مقارنة بالذكور.

الكلمات المفتاحية : *Sardina pilchardus* ، علاقة الطول بالوزن، الخصائص المترية، الازدواج الشكلي الجنسي، خليج بني صاف، الجزائر.

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Consent to participate: No live animals used in this study. Not applicable.

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