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Research article

Length-weight and length-length relationships and condition factor of European pilchard, *Sardina pilchardus* (Walbaum, 1792), in Edremit Bay (North-Aegean Sea, Türkiye)

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Abstract: This research carried out to study the length-weight relationship (LWR) and length-length relationship (LLR) and condition factor (CF) of *Sardina pilchardus* in Edremit Bay. A total of 178 specimens were examined. Total length (TL) of the specimens ranged from 11.0 to 16.2 cm, while the standard length (SL) varied from 9.5 to 15.3 cm. Total weight (TW) ranged from 8.5 to 38.2 g. The calculated *b* value of the LWR indicated isometric growth for overall population. In the LLR analysis, females and the combined sex showed negative allometric growth, whereas males exhibited isometric growth. The mean CF was calculated as 0.80 ± 0.12 for combined sex, there were no significant difference between CF value of males and females. This study offers crucial insights into the growth patterns and health of *S. pilchardus* in Edremit Bay, contributing valuable data for stock assessment and fisheries management. The findings indicate that the population primarily exhibits isometric growth, while the condition factor suggests that Edremit Bay provides a suitable feeding environment for this species.

Keywords: *Sardina pilchardus*, European pilchard, growth, Edremit Bay

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Introduction

Information on fish growth is obtained through growth parameters as length-frequency distribution, length-weight relationship (LWR), length-length relationship (LLR) and condition factor (CF). Length-frequency distribution provides insights into the specific sizes of fish and their corresponding frequencies within a given population. LWR and LLR are valuable tools for fish ecology, resource assessment, and fisheries management (Froese,2006). The LWR is crucial in fishery biology, as it helps estimate growth rates, age structure, and other aspects of fish population dynamics (Sparre et al., 1992; Kolher et al., 1995). Additionally, the LLR is useful for standardizing length types when summarizing data (Froese, 2006) and is also effective for comparative growth studies (Moutopoulos and Stergiou, 2002). Different length measures of fish are utilized depending on the study's focus. Standard length (SL) is often preferred for scientific purposes when total length (TL) is unavailable, such as when the tail is missing. Also, SL is commonly used in

fisheries management to define minimum legal lengths for commercial and recreational fisheries. Consequently, reliable length-length relationships are essential for accurate data conversions (Biole et al., 2020). Condition factor (CF) is also widely used in fisheries and fish biology to study the condition of a fish by calculating the relationship between the length and its weight (Froese, 2006). It also offers insights into the physiological state of fish concerning their welfare, focusing on both reproductive and nutritional aspects (Le Cren, 1951).

European pilchard, *Sardina pilchardus* (Walbaum, 1792), is a pelagic fish species whose distribution extends generally from southern Morocco to British Channel, and from the Azores to the eastern Mediterranean and Black Sea (Parrish et al., 1989). As the mean annual catch of sardines raised up to 17,000 tonnes between 2021 and 2022, it has high commercial importance, being targeted by purse-seine fisheries in Turkish Seas (TUIK, 2023). As to Aegean Sea, the average annual sardine catch rate was stated as 52% (Cihangir & Tıraşin, 1990). With regard to commercial importance of sardine population in Turkish fishery, there are some studies on this species such as biology, population characteristics, growth parameters, diet, mortality rates and biomass (Mater and Bayhan, 1999; Karakayis and Togulga, 2000; Erdoğan et al., 2010; Mustać and Sinovčić, 2010; Tsikliras and Koutrakis, 2013; Şenbahar et al., 2020). While, Whitehead (1985) and Sinovcic et al. (2004) provided reliable data on the length-length relationships (LLR) of *S. pilchardus* in FishBase, the existing literature does not include any studies specifically addressing the LLR.

The aim of this study was to present the length-frequency distribution, LWR, LLR, and condition factor of European pilchard population in Edremit Bay, northern Aegean Sea. This information is intended to support the management and protection of the sardine stock in the region. Furthermore, it is anticipated that our data will serve as a valuable resource for future research.

Materials and Methods

Edremit Bay, in the northern Aegean Sea, is a place where two currents meet and it is rich in plankton because of upwelling. In addition, because the bottoms are suitable for trawl fishing and the area is fed by waters rich in nutrient from erosion through the vicinity of the bay and the Black Sea, there is a rich bottom fish fauna. With these facilities, Edremit Bay has a high potential for sea food, especially fish (Togulga, 1997).

A total of 178 samples were sampled by randomly from commercial fisheries in catch season (between October 2022 and March 2023) in Edremit Bay (Figure 1). After obtaing the samples, specimens were transported in iced styrofoam boxes to Hydrobiology Laboratory at Faculty of Science and Arts of Balikesir University. The samples were identified at species level according to Whitehead (1985). For each fish, TL and SL were measured to the nearest millimeter (mm) and TW was also recorded to the nearest gram (±0.1 g). Sex was determined by macroscopic observation of the gonads in all individuals (Avşar, 2016).

The fish were grouped into different size classes and the percentage frequency and TL were used for the length-frequency distribution. Sex was determined by macroscopic observation of the gonads in all individuals (Avsar, 2016). The chisquare test ($\chi 2$) was used to examine the differences between the observed and the expected ratio of 1:1 (Zar, 1996).

The relationship between TL and TW for almost all fish species was expressed by the following equation (Avsar, 2016);

$W = a \times TL^b$

Where:

W = body weight,

L = total length,

a = the intercept (regression constant)

b = the slope (regression coefficient)

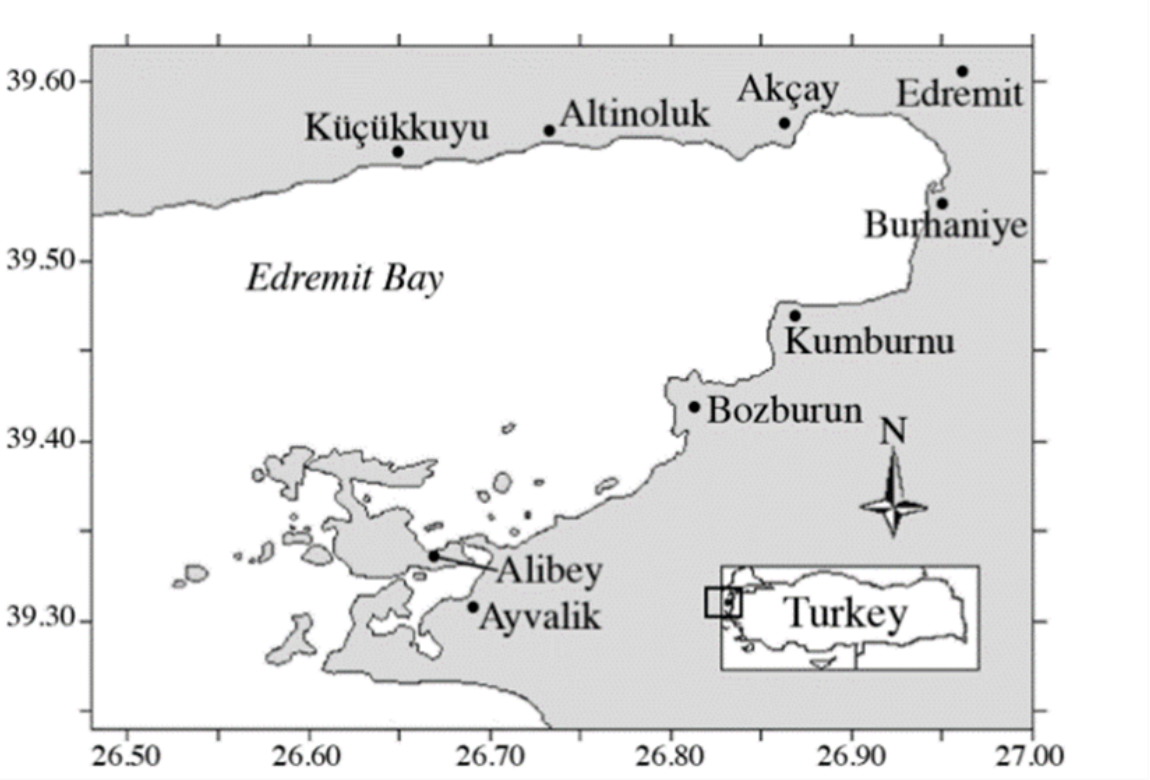

Figure 1. Sampling area in Edremit Bay, in the Northern Aegean Sea (Erdoğan et al., 2010)

The values of a and b were estimated by least square regression method using logarithmically transformed length and weight values (Le Cren, 1951; Parson, 1988);

Log W= Log a + b Log L

Additionally, linear regression analysis was conducted using untransformed TL-SL data to recognize the growth type in case of LLR with the equation (Cao et al., 2016)

SL= a+b*TL

Where:

a =the intercept

b = the slope of the linear regression

The 95 % confidence interval (CI) of the b-value was estimated by using the equation (Ahmed et al.,2011);

CI = b ± (1.96 x SE),

Where:

SE = the standard error of b.

In order to check if the value of b was significantly different from isometric value (b= 3.0 for length-weight relationship and b = 1.0 for length-length relationship), the Student's t test was applied as expressed by the following equation Sokal and Rohlf (1987);

ts= (b−3)/SE or ts= (b−1)/SE

Where:

ts = the t-test value,

b = the slope,

SE = the standard error of the slope b.

A t-test was applied to determine significant differences from the isometric value (b= 3.0 for length-weight relationship and b = 1.0 for length-length relationship) (Sokal and Rohlf ,1987). Deviation of the b value from the theoretical isometric value indicates either positive (b > isometric value) or negative (b < isometric value) allometric growth.

The CF value was calculated from the weight (g) and length (cm), and could be used to estimate changes in nutritional condition. The formula most often used is (Ricker, 1975, Pauly 1980);

$CF=100 *W/L^3$

Where:

CF= condition factor, W = body weight, L = total length

Data were analysed using statistical analysis Jamovi 1.6.23 and Microsoft Excel 2013 and past software. Analysis of variance (ANOVA) was used to test whether the calculated regression line was significant (Ogbeibu 2005). All statistical analyses were considered at significant level of 5% ($p < 0.05$).

Results

Length-frequency distribution

Sex, sample size, minimum and maximum TL, SL and weights of *S. pilchardus* are provided in Table 1. According to the t-test, there was a statistically important difference between females and males as regards mean length ($t_{(176)}=4.06$, $p<0.05$) and weight ($t_{(176)}=4.06$, $p<0.05$) values; therefore, the length-frequency distributions were performed separately for females, males, and all individuals. The most dominant TL size classes were estimated as 14.0-14.9 cm for females, 11.5-12.4 cm for males; 12.0-12.4 cm for combined sex (Figure 2).

Sex Ratio

A total of 178 speciemens, including 142 (79.78%) female and 36 (20.22%) males, were examined in this study, the overall sex ratio was significantly different from the expected value of 1:1 (F:M = 3.94:1, $\chi 2$ = 63.12, $p < 0.05$).

Table 1. Sample size (n) along with mean, minimum (min) and maximum (max) values for standard length (SL), total length (TL) and weight (W) for *Sardina pichardus*

Sex	n	Total length (cm) Mean ±S.D. (min-max)	Standart length (cm) Mean ±S.D. (min-max)	Weight (g) Mean ±S.D. (min-max)
F	142	13.49±1.16 (11.00-16.20)	11.90±1.13 (9.50-15.30)	20.29±5.70 (8.54-38.2)
M	36	12.71±0.99 (11.40-15.20)	11.20±1.12 (9.60-14.20)	16.13±4.47 (9.76-28.22)
F+M	178	13.33±1.17 (11.00-16.20)	11.80±1.16 (9.50-15.30)	16.13±4.47 (9.76-28.22)

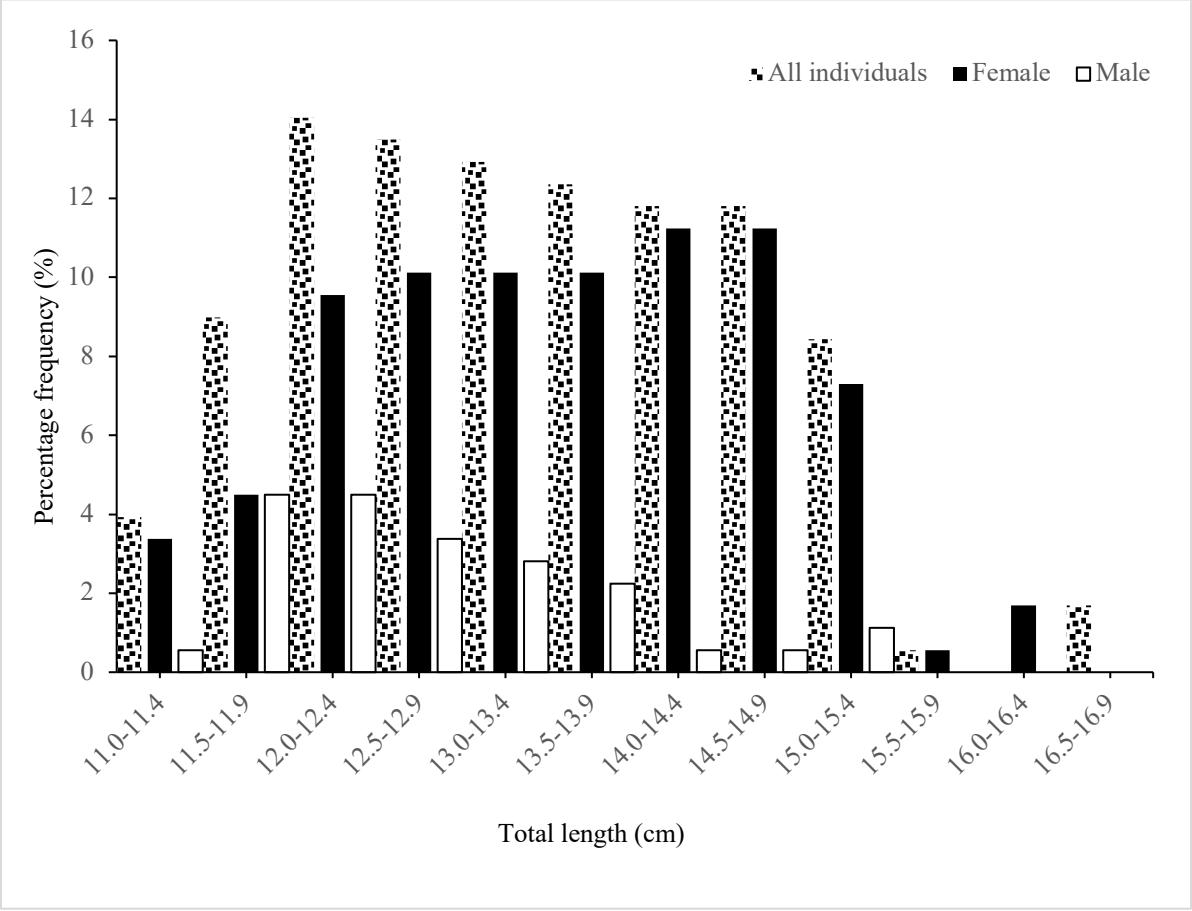

Figure 2. Total length frequency distribution of *Sardine pilchardus*

Length-weight Relationship (LWR) and Length-length Relationship (LLR)

LWR were calculated for female, male and combined sex as $W=0.009L^{2.95}$ ($R^2=0.76$), $W=0.006L^{3.12}$ ($R^2=0.83$), $W=0.007L^{3.04}$ ($R^2=0.78$), respectively. The *b* coefficients were not significantly ($p>0.05$) different from 3 for sardine population, showing isometric growth. The LLR were estimated for female, male and combined sex as SL=0.04+0.88TL ($R^2=0.83$), SL= -1.89+1.03TL ($R^2=0.85$), SL= -0.22+0.90TL ($R^2=0.84$) and TL=0.10+0.89SL ($R^2=0.72$),
TL= 1.90+1.03SL ($R^2=0.85$), TL= -0.11+0.89SL ($R^2=0.72$), respectively.

As to each LLR, the *b* coefficient was significantly ($p<0.05$) less than 1 for females and all individuals, showing negative allometry, while the *b* coefficient was not significantly ($p>0.05$) different from 1 for males, with isometric growth. In the present study, the parameters of the LWRs and LLRs (*a* and *b*), the coefficient of determination (R^2), the 95 % confidence interval (CI) for *b* value, and the growth type are represented, as shown in Table 2.

Table 2. Parameters for LWRs and LLRs and related statistics for *Sardina pilchardus*

			$W=a*TL^b$		
Sex	a	b	S.E. of b 95%Cl of b	r^2	GT
F	0.009	2.95	0.14 (2.67-3.22)	0.76	I
M	0.006	3.13	0.27 (2.59-3.67)	0.83	I
F+M	0.007	3.04	0.12 (2.80-3.31)	0.79	I
			*SL=a+b*TL		
F	0.04	0.88	0.03 (0.81-0.93)	0.83	-
M	-1.89	1.03	0.08 (0.83-1.18)	0.85	
F+M	-0.22	0.90	0.03 (0.84-0.95)	0.84	-
			*TL=a+b*SL		
F	0.10	0.89	0.17 (-0.95-1.33)	0.72	-
M	1.90	1.03	0.33 (-1.09-0.82)	0.85	
F+M	0.11	0.89	0.20 (-3.37-0.39)	0.72	-

*Unknown length

Condition Factor (CF)

The mean condition factor of population was calculated as 0.80 ± 0.12. The mean condition factor for female (0.81±0.13) was similar to that of male (0.77±0.10) and the differences between sexes were not significant ($p> 0.05$).

Discussion

A total of 178 specimens were examined and the length distributions for female and male were observed 11.0-16.20 cm and 11.4-15.2 cm, respectively (Table 1). The findings were in a harmony with those by Petrakis and Stergio (1995) and Karadurmuş and Aydın (2023) (Table 3). Tsikliras and Koutrakis (2013) stated that the different growth rates often observed between males and females of the same fish species may result to varying mean and maximum population lengths, as well as different length frequency distributions between sexes. The same authors indicated that clupeoid fishes are known for growth differences between sexes [*S. pilchardus*: Akyol et al. (1996)], and for that reason the length-frequency distributions were performed separately for females, males, and all individuals in this study. Otherwise, this variation may be due to different stages in ontogenetic development, as well as differences in condition, length, age, sex, gear selectivity, gonadal development, and geographical variations (Ricker, 1975).

In this study, females longer than males and there was a significant difference between two genders. This is similar to the data which was estimated in Aegean Coast of Türkiye by Karakayış and Toğulga (1977). Sex ratio studies provide information on the proportion of male to female fish in a population and are expected to be 1:1 in nature. This may vary from species to species, differing from one population to another of the same species, and may vary year after year within the same population (Nıkolsky, 1980). The fact that the females are dominance in *S. pilchardus* population may be attributed to an easier catch of one sex, spawning period and ground, various fishing methods and equipments.

LWR and LLR parameters, (*a* and *b*) and the coefficient of determination (R^2) are represented in Table 2. The *b* coefficients for LWRs were not significantly ($p>0.05$) different from 3 and growth patterns of *S. pilchardus* for females, males and combined sex were isometric. However, it was also reported as negative and positive allometric growth patterns in the previous studies and *b* values varied from a minimum of 2.37 to a maximum of 3.60 (Table

3). Although the ideal *b* value for fish is determined 3 or close to 3 (Wooten, 1998; Froese, 2006) proposed that the ideal b value should range from 2.5 to 3.5. If fish grow isometrically than it retains its body shape and its specific gravity will also remain unchanged during the life time, therefore, in such cases, its *b* value must be equal to 3.0. In addition, the difference in *b* values can be attributed to the combination of one or more factors such as the number of specimens examined, area / seasonal effect, habitat, water condition, degree of stomach fullness, gonadal maturity, sex, health and general fish condition, preservation technique, and differences in the observed length ranges of the specimens caught (Wooton, 1998).

Table 3. Parameters of length-weight relationships (a and b), and CF of *Sardina pilchardus* in this and previous studies. – indicates absence of data.

Literature	Locality	Sex	n	L	Lenght cm)	W (g)	a	b	R^2	CF
Sinovcic (1991)	Adriatic	F+M	1516	TL	7.5-20.3	2.3-56.6	0.0033	3.2764		
Petrakis and Stergiou (1995)	South Euboikos Gulf	F+M	82	FL	11.8-17.2		0.000033	2.754	0.82	
Voulgaridou and Stergiou (1999)	Ionian Sea	F+M	2500	TL			0.006876	3.05	0.85	
Mater and Bayhan (1999)	Aegean Sea	F+M	364	TL	9.6-14.9	8.79-39.3	0.0045	3.3591	0.83	1.00-1.22
Karakayis and Togulga (2000)	Aegean Sea	F+M	332		9.3-14.3	6.89-36.8	0.0062	3.214	0.92	0.99-1.11
Voulgaridou and Stergiou (2003)	Mediterranean	F+M	51246	TL			0.0050	3.153	0.894	
Mendes et al. (2004)	Portuguese	F+M	304	TL	16.9-23.7	38.0- 150	0.0092	2.980	0.76	
Sinovčić et al. (2004)	Adriatic Sea	F+M	4441	TL	5.5.-19.3	1.77-45.2	0.0038	3.230	0.98	
Özaydin and Taskavak (2006)	Aegean Sea	F+M	388				0.0076	3.190	0.89	
Pešić et al. (2006)	Boka Kotorska Bay	F+M	2489				0.0047	3.167	0.99	
Tarkan et al. (2006)	Marmara Sea	F+M	11				0.0021	3.540	0.98	
Mustac and Sinovčić (2007)	Adriatic Sea	F+M	1292	TL	13.0-19.0	16.7-51.5	0.0261	2.5538	0.69	
Sinovčić et al. (2008)	Krka River, (Crotia)	F+M	1125	TL	4.9-12.5	1.01-11.2	0.007	2.9587	0.96	
Karachle et al. (2008),	North Aegean Sea	F+M	752		7.7-16.7		0.0053	3.144	0.90	
Sinovčić et al. (2009)	Off Dugi Otok		105	TL	13.5-17.5		0.004	3.214	0.92	
Sinovčić et al. (2009)	Zrmanja River		194	TL	7.5-19.5		0.003	3.319	0.91	
Veiga et al. (2009)	Southern Portugal	F+M	752				0.0053	3.144		
Mustac et al. (2010)	Middle Adriatic Sea	F	541				0.0342	2.465	0.73	
Mustac et al. (2010)	Middle Adriatic Sea	M	668				0.0425	2.371	0.58	
Torres et al. (2012)	Gulf of Cadiz	F+M	1656		10.5-22.4	9.3-96.2	0.0082	3.016	0.87	
Acarli et al. (2014)	Izmir Bay	F+M	77		6.0-12.5	1.68-15.9	0.0070	3.053	0.99	
Senbahar et al. (2020)	Aegean Sea	F+M	567	TL	9.5-15.3	9.1-21.3	0.0077	2.7981	0.93	
Karadurmuş and Aydın (2023)	Black Sea		276	TL	12.8-17.2	12.7-46.2	0.0234	2.5643	0.71	
This study	Edremit Bay	F	142	TL	11.0-16.2	8.54-38.2	0.009	2.95	0.76	0.81
This study	Edremit Bay	M	36	TL	11.4-15.2	9.8-28.2	0.006	3.13	0.83	0.77
This study	Edremit Bay	F+M	178	TL	11.0-16.2	8.5-38.2	0.007	3.04	0.79	0.80

The values obtained from the LWR of *S. pilchardus* from the Edremit Bay showed significant correlation ($p<0.001$) between the TL and TW. This means that as the length of fish increases the weight increases in the same proportion. Our data agrees with previous studies on different populations from various water bodies, except for those in Adriatic Seas (Mustac and Sinovcic, 2007; Karachle and Stergiou, 2008) (Table 3). LLR among various length measurements are used for size converting between various body measurements when one of the body parts are damaged during sampling procedures (Frose, 2006). The present study inferred that value of *b* for LLR is less than 1 which indicates negative allometric growth for female and all individuals while the b coefficient was not significantly ($p>0.05$) different from 1 for males, with isometric growth. When the literature is examined, studies on the length- length relationships of *S. pilchardus* are very limited. *b* values in LLR are in a harmony with the relevant literature in FishBase (Table 4). In addition, all LLR were correlated ($p<0.001$), and the most of the coefficients of determination values were calculated ≥0.72 as lower than the other studies. These differences may be atributed to between geographic regions, sample size or environmental conditions (Bagenal & Tesch, 1978).

Table 4. Parameters of lenght-lenght relationships *S**ardina** pilchardus* in this and previous studies. – indicates absence of date

						SL=a+bTL			T = a + bSL		
Literature	Locality	Sex	n	Standart Lenght (cm)	Total lenght (cm)	a	b	R^2	a	b	R^2
Whitehead (1985)	Adriatic Sea	-	-	-		0.000	0.810	-	-	-	-
FishBase (2024)	-	-	-	-	26.0-26.0	0.000	0.846	-	-	-	-
Karachle et al. (2008)	North Aegean Sea	F+M	752	-	7.6-16.7	-0.19	0.85	0.99	-	-	-
Sinovčić et al (2004)	Adriatic Sea	F	1343	-	7.3-19.3	-0.136	0.860	0.99	-	-	-
Sinovčić et al (2004)	Adriatic Sea	M	1590	-	7.5-18.4	-0.129	0.860	0.99	-	-	-
Sinovčić et al (2004)	Adriatic Sea	F+M	4441	-	5.5-19.3	-0.150	0.860	0.99	-	-	-
FishBase (2024)	-	-	-	-					0.000	1.186	-
The study	Edremit Bay	F	142	9.50-15.30	11.00-16.20	0.04	0.88	0.83	0.10	0.89	0.72
The Study	Edremit Bay	M	136	9.60-14.20	11.40-15.20	-1.89	1.03	0.85	1.90	1.03	0.85
The Study	Edremit Bay	F+M	278	9.50-1530	11.00-16.20	-0.22	0.90	0.84	0.11	0.89	0.72

The CF of *S. pilchardus* calculated during this study was found to be different from the values obtained by Mater and Bayhan (1999) and Karakayış and Toğulga (2000). This could be attributed to the study season, food availability, feeding rate, gonad development and spawning period (Petrakis and Stergiou, 1995; Bagenal and Tesch, 1978; Koutrakis and Tsikliras, 2003). Besides, as sampling was carried out in spawning period which was occured between September and May in Edremit Bay (Erdoğan et al., 2010), food reserves of sardines might be used for gonadal devolepment.

Conclusion

Growth studies provide the important scientific data for the management and conservation of fisheries. The LWR and LLR and CF in fish show variations depending on several factors such as feeding, gonad development, sampling size, reproductive periods, geographic and environmental conditions. Therefore, periodic monitoring of natural fish stocks is crucial for sustainability. Our research aims to provide comprehensive references on the length-weight and length-length relationships of this fish species in Turkish coastal waters for future studies.

Ethical Approval

The study was conducted by collecting the fish samples in dead conditions. An ethical approval is not required for the period during which the study was conducted.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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The authors don't declare any fund.

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