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Research Article

Some Biological Aspects of the Common sole, *Solea solea* (Linnaeus, 1758) from the SE Black Sea, Türkiye

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Abstract – This study presents some basic biological parameters of Common sole (*Sole solea*) which was obtained as by-catch from small-scale trammel net fishery along Rize coasts in the SE Black Sea. Fish samples were captured using trammel nets with various mesh sizes from January 2023 to December 2023. A total of 325 individuals (195 females and 130 males) ranging from 12.3 cm to 22.5 cm TL (mean 15.74±0.114 cm) with body weight varying from 13.25g to 109.73 g (mean 36.10±0.971 g) were sampled during the study. The sex ratio was calculated as 1.50:1.00 in favor of females that significantly deviated from the expected ratio of 1:1 (χ^2 test, $p<0.05$). The length-weight relationships (LWRs) were determined as $W=0.005TL^{3.196}$ for females, $W= 0.006TL^{3.153}$ for males, and $W=0.055TL^{3.166}$ for combined sex. The b-values of the LWRs were significantly different from the isometric growth indicating (+) allometric growth across all sexes. The regression analysis revealed that the total length and weight were highly correlated ($r^2>0.9$). Fulton's condition factor (K) values varied from 0.704 to 1.1.145 (mean 0.868± 0.006) in females and from 0.735 to 1.092 (mean 0.879±0.006) in males. The current study will provide a scientific dataset for the fisheries management authority and fisheries scientists for further investigations and comparisons on the species. Furthermore, the reported results will contribute to the conservation and sustainability of this species in the Black Sea.

Keywords – biological parameters, condition factor, growth type, sex and size composition, Sole solea, Black Sea

I. INTRODUCTION

Solea solea (Linnaeus, 1758), also known as the Common sole, is a benthic species of flatfish that is one of the commercially important members of the Soleidea family. It distributes from the Eastern Atlantic to the western Black Sea [1]. This species occurs in the Black Sea, Sea of Marmara, Aegean Sea, and Northeastern Mediterranean coasts in Türkiye [2,3]. This species was also known from the Adriatic Sea, Gulf of Lion, Ligurian Sea, Ionian Sea, Tyrrhenian Sea, and the Aegean Sea [4]. They tend to occur in shallow, sandy, and sandy/muddy habitats from zero to 200 m, but usually in 10-60 m [5].

The Black Sea is the major fishing area in Türkiye since approximately 75% of the total marine fish were landed from there of which 61.5% of this rate comes from the Eastern Black Sea part alone [6]. The global capture production of the common sole was reported as 20,779.43 tons in 2022, while the Common sole landings in the Mediterranean and Black Sea Basin in 2022 amounted to 4,646.92 tons [7]. Total

landings of common sole in Türkiye have dramatically declined in recent years from 1,062 tons in 2010 to 227.7 tons in 2023 [6].

Knowledge of biological characteristics such as size and sex composition, length-weight relationships and condition factor is of great importance for achieving good environmental status and fisheries management strategies. In biological studies, it is essential to determine the growth characteristics related to the length and weight of the fish The length-weight relationships (LWRs) in fish also provide significant insights about the general health, growth pattern, life history, habitat conditions, fish fatness and condition, as well as morphological characteristics of the fish [8, 9, 10, 11, 12].

Since the biological aspects of *S. solea* have been rarely studied in the SE Black Sea, therefore, the main aim of the present study was to provide basic biological data on this species such as size composition, sex ratio, as well as length-weight relationship, and condition factor. The current study will provide a scientific dataset for the fisheries management authority and fisheries scientists for further investigations and comparisons on the species. Furthermore, the reported results will contribute to the conservation and sustainability of this species in the Black Sea.

II. MATERIALS AND METHOD

This research was carried out along the Rize coast (between İyidere and Çayeli) in the south-eastern Black Sea (Fig. 1) from January 2023 to December 2023. Fish samples were monthly collected from small-scale fishermen who are using multifilament trammel nets with various (32-34-36-40 mm in the inner and 100 mm in the outer panel) mesh sizes. During the sampling period, the collected fish samples were put in iceboxes and then transported to the laboratory for further measurements. Each fish specimen was measured in total length (TL) to the nearest 1 mm and weighed to the nearest 0.01 g body weight (W). The sex of the fish samples was determined macroscopically using the morphological differences of the gonads such as structure, shape, and color [11,12].

Figure 1. The map of the study area.

The length-weight relationships (LWRs) of the commmon sole, *S. solea* were estimated by using the formula; $W = a \times TL^b$, which was converted to logarithmic form as log W = loga + blogTL, where W is total body weight (g), TL is the total length (cm), a: intercept and b: slope regression coefficients. Then the LWR parameters: the intercept (*a*), slope (*b*), the 95% confidence interval limits (*CI*) of parameters, standard error of b and the coefficient of determination (R^2) were estimated by the linear regression from

the raw dataset using the log-transformed values of this equation [10,13]. Fulton's condition factor (K) was calculated using the following formula: $K = (W/TL^3) \times 100$, where W is total body weight (g) and TL is total length (cm) [14].

Statistical Analysis

ANCOVA was used to determine whether there was a significant difference in slopes (b values) between the sexes. The differences in mean values of TL, W, and Fulton's condition factor across the sexes were tested applying by an independent t-test. Pauly's t-test was performed to compare the slopes to confirm if the b value was different from the isometric growth (b=3) for both sexes and combined using the following formula:

$$t = \frac{Sd_{logTL}}{Sd_{logW}} \times \frac{|b-3|}{\sqrt{1-r^2}} \times \sqrt{n-2}$$

where, Sd_{logTL} is the standard deviation of the *log TL* values, Sd_{logW} is the standard deviation of the *log W* values, r^2 is correlation coefficient, n is the number of specimens used in the calculation. If calculated t value is greater than the table *t* values for n-2 degrees of freedom the value of b is different from the isometric growth (b=3) [15]. All statistical analyses performed using IBM SPSS Statistics (ver.29.0.2.0) software and plots were generated using the Microsoft 365 Excel package.

III. RESULTS

Size composition and length-frequency distribution

A total of 325 common sole individuals ranging from 12.3 cm to 22.5 cm with TL (mean 15.74±0.114 cm) with body weight varying from 13.25g to 109.73 g (mean 36.10±0.971 g) were sampled during the study. Of the common sole specimens collected, the total length and weight of females ranged from 12.3 to 22.5 cm (mean 15.99±0.152) and 13.25-109.73 g (mean 37.79±1.342), while males ranged from 12.3 to 21.9cm (mean 10.51±0.235) and 4.06-42.83 g (mean 33.56±1.332). Females of common sole were slightly heavier and longer than males, however, there were significant differences in mean TL (Independent t-test, t= 2.752, p = 0.006, $p<0.05$) and mean TW values (Independent t-test; t= 2.145, p= 0.033, $p<0.05$) across the sexes. Total length (TL) and weight (TW) characteristics of the Common sole by sexes were presented in Table 1.

Table 1. Total length (TL) and weight (TW) characteristics of the Common sole by sexes

Sex	N	Total Length (cm)		Total Weight (g)	
		Min-Max	Mean±S.E	Min-Max	Mean±S.E
Female	195	12.3-22.5	15.99±0.152	13.25-109.73	37.79±1.342
Male	130	12.3-21.9	15.36±0.165	15.44-96.01	33.56±1.332
Combined	325	12.3-22.5	15.74±0.114	13.25-109.73	36.10±0.971

The total length-frequency distribution of 325 Common sole samples ranging from 12.3 cm to 22.5 TL was plotted based on 1 cm class intervals for both sexes. The length-frequency distribution showed that most of the individuals of females (82.1%, N=160), males (89.2%, N=116), and combined samples (84.9%, N=276) distributed in the length classes between 13 and 17 cm (Figure 2).

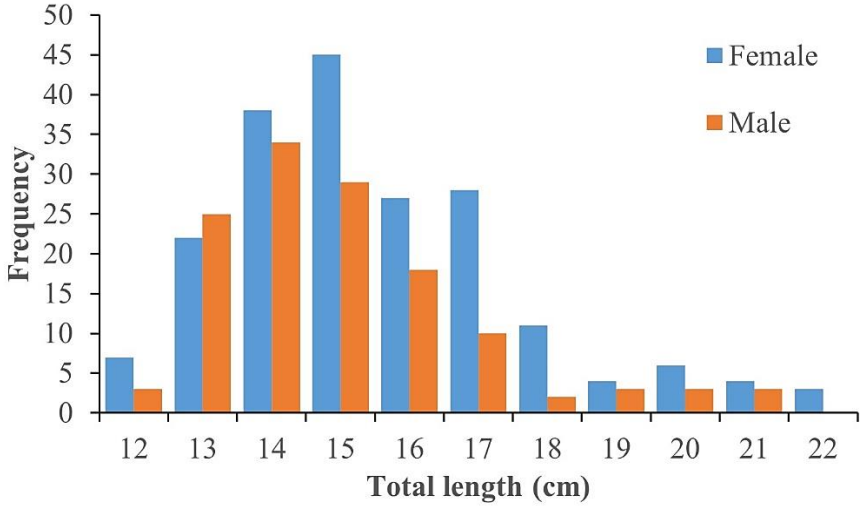

Figure 2. The total length - frequency distribution of the Common sole, *Solea solea* by sexes.

Sex composition

Of the total obtained 325 Common sole specimens, 60.0 % (N= 195) were females and 40.0% (N=130) were males. Accordingly, the sex ratio (F: M) was calculated as 1.50:1.00 in favor of females, which significantly deviated from the expected ratio of 1:1 (χ^2 = 13.00, $p<0.001$).

The length-weight relationships (LWRs)

The length-weight relationships (LWRs) of the Common sole were estimated using total length and weight by each sex and combined data. The b-values of the LWRs that indicate the fish growth type pointed out that the growth pattern of males, females, and combined individuals was positive allometric (A+) growth (b>3) deviating statistically significant from the isometric growth with a 95% confidence interval for the b-value of 3.196 (3.081-3.310) for females, of 3.153 (3.034-3.271) for males, and of 3.166 (3.082-3.249) for combined sex of the Common sole (Paulys' t-test, t_{female} = 3.372, t_{male} = 2.553, $t_{sexes\ combined}$ = 3.917, p<0.05). The length-weight relationships (LWR) for Common sole by sexes were presented in Figure 3. The correlation coefficient (R^2) for regression analysis revealed that the Common sole has a high correlation (R^2>0.9) between the total length and weight for both sexes and combined data. Descriptive statistics and estimated parameters of the LWRs of Common sole by sexes were presented in Table 2.

Table 2. Descriptive statistics and estimated parameters of the LWRs for Common sole, *Solea solea* by sexes.

Sex	**N**	**Parameters of LWRs**						
		a	**b**	**S.E. (b)**	**95% CI of b**	**R^2**	**Growth type**	**Pauly's t-test**
Female	195	0.005	3.196	0.058	3.081-3.310	0.954	A+	$p<0.05$
Male	130	0.006	3.153	0.060	3.034-3.271	0.972	A+	$p<0.05$
Combined	325	0.055	3.166	0.042	3.082-3.249	0.960	A+	$p<0.05$

(N: Sample size, a: Intercept of the relationship, b: Slope; S.E.(b): Standard Error of b, R^2: Coefficient of determination, C.I.: Confidence Intervals)

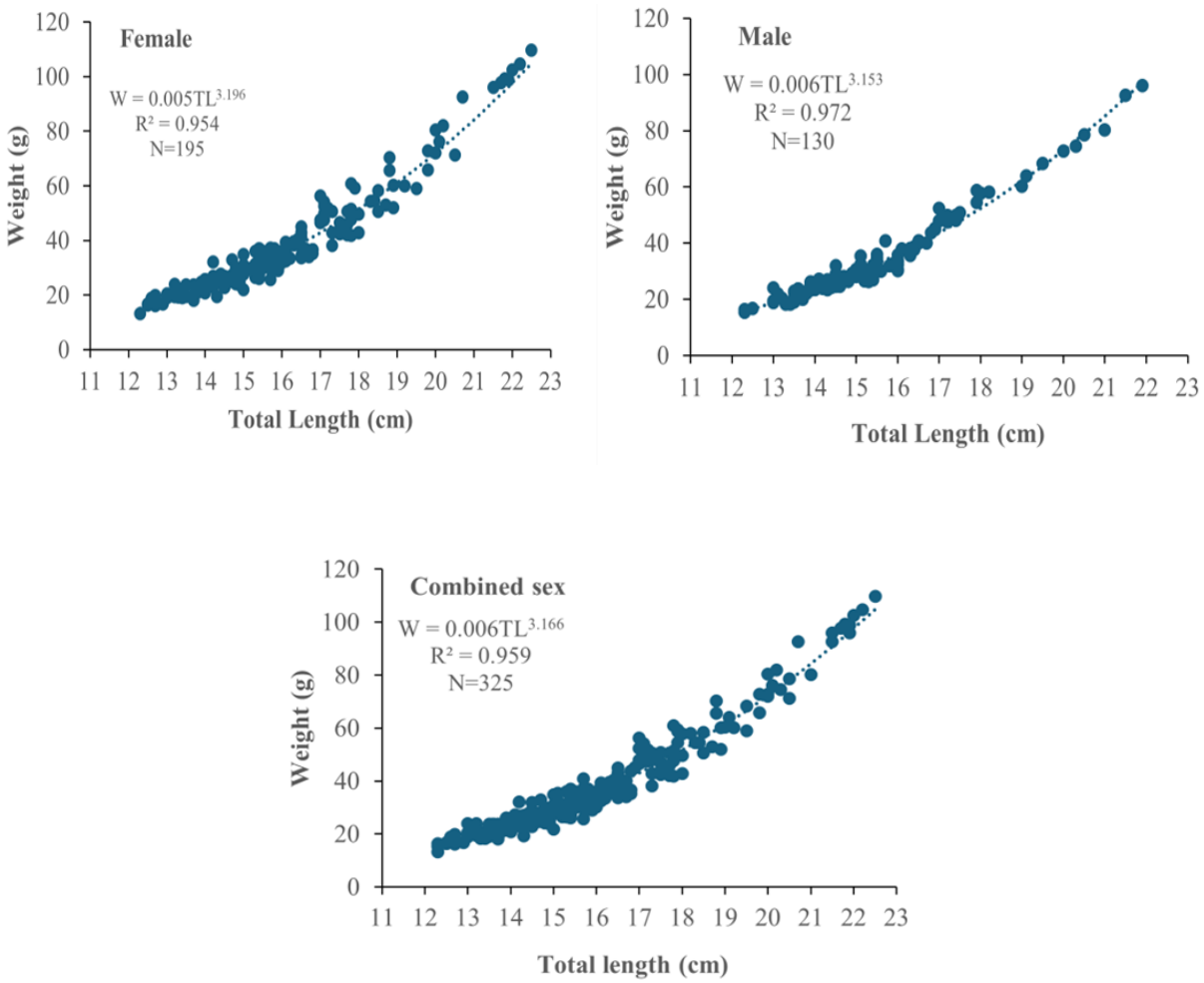

Figure 3. The length-weight relationships (LWRs) for the Common sole, *Solea solea* across sexes and combined sexes.

Fulton's condition factor (K)

Fulton's condition factor (K) values ranged from 0.704 to 1.145 in females and from 0.735 to 1.092 in males. There were no significant differences in mean K values between females and males (Independent t-test, t= -1.102, p=0.271; $p>0.05$) (Table 3).

Table 3. Fulton's condition factor (K) values of the Common sole, *S. solea* by sexes.

Sex	N	K range	Kmean±S.E.	t-test
Female	195	0.704-1.145	0.868± 0.006	$p>0.05$
Male	130	0.735-1.092	0.879±0.006	$p>0.05$

IV. DISCUSSION

The biological aspects of *S. solea* have been rarely studied in the SE Black Sea, therefore, the main aim of the present study was to provide basic biological data on this species in terms of size composition, sex ratio, as well as length-weight relationship and condition.

The length-weight relationship (LWR) is an important tool in fisheries biology. By understanding how fish weight correlates with length, scientists can make better predictions about fish populations and manage fisheries more effectively [11,12]. This relationship varies by species and environmental factors, so it's crucial to gather specific data for each fish species to ensure accurate assessments. In fish populations,

sex ratio and size structure provide basic valuable information to assess reproductive potential and estimate stock size [16]. Size composition also plays an important role in maintaining the reproductive potential and stability of a fish population. Therefore, investigating the variation of size structure can provide insight into how resilient a fish population can be [17].

In the current study, the sex ratio for the Common sole, *S. solea* of female to male was calculated as 1.50:1.00 which significantly deviated from the expected ratio of 1:1. The sex ratios of females to males reported from different locations were given in Table 4. Knowledge of the sex composition in fishes is the most important for the reproduction of the population. In many species, the sex composition (female: male ratio) is close to 1:1. However, there may be deviations from this ratio in some species or some age groups in fish species [11,12, 18]. The sex ratio in fishes can generally differ from species to species, between different populations of the same species, and from year to year in the same population as well [19].

There have been very few studies that report condition factor values (K) of the Common sole in Turkish marine waters. The K values of the Common sole from the Sea of Marmara were found between 0.36 and 2.96 (mean 0.79) [20], while in another study which was conducted in Izmir Bay in the Aegean Sea, the mean K values were reported as 0.89±0.13, 0.88±0.12 and 0.89±0.12 for females, males, and combined sex, respectively [21]. The condition (K) values mainly vary depending on the age, sex, season, and habitat of the fish [22], so are difficult to compare. However, the reported K results from different regions were similar to the present study. The condition factor (K) gives basic and important information regarding the feeding and especially spawning activity and/or reproduction time of a fish species. For a fish species or population throughout their life span in different periods the condition factor is not constant and can be influenced by both biotic and abiotic factors [11,12]. Differences in several biotic factors (e.g. predation rate on species, disease-prone environment, availability of food) and abiotic factors (e.g. pH, pollution level, and water temperature) of the study area are known to affect the K value of fishes [21] and these factors cause the condition value to deviate from the theoretical value of 1 [14]. Higher K values ($K \geq 1$) indicate the suitability of a specific aquatic habitat for growth as well as a good level of feeding and appropriate environmental conditions in favor of fish whereas the K value lower than 1 ($K \leq 1$) is an indicator of the reverse conditions [11,12,14,24,25]. Although at present there is no detailed data on the biotic and abiotic factors of the study area, and these are not the focus of this study.

The values of the coefficient b of the LWRs for the Common sole, *S. solea* in this study were 3.196, 3.153, and 3.166 for females, males, and combined sexes, respectively within the expected range of 2.5-3.5 [10,13]. However, the b value of LWR can range between 2 and 4 [26]. The growth pattern was positive allometric growth (A+ growth) for Common sole across the sexes. The value of $b>3$ indicates that the fish become plump as they increase in length [27]. Descriptive statistics and estimated parameters of the LWRs of Common sole, *S. solea* by sexes from different localities were given in Table 4. It was seen that there are strong relationships between the lengths and weights of the fish ($R^2>0.9$, $p<0.05$). The reported b values of the LWRs for the common sole varied from 2.40 in Izmir Bay, Aegean Sea [21] to 3.423 in Sinop (Middle Black Sea) [28]. However, most of the b values were similar to those in this study. The b value in fishes generally varies between 2 and 4 [26]. The values of the parameter b which represents the growth type of the fish in reported studies were generally within the expected range of 2.5 - 3.5 [10,13].

The result of the present study and some of the previous results of LWR parameters estimated in different localities for Common sole, *S. solea*, were also presented in Table 4 for comparison of the results. The results of this study are consistent with those of the previous studies carried out in the Black Sea with some differences that can be mainly attributed to the ecological characteristics of the studied areas. Besides, the LWR in fish is influenced by many factors such as the presence of food, feeding ratio, gonad development, spawning period, season, sex, and habitat [28]. The LWRS may also be influenced by geographical location and environmental conditions in a given year [11,12, 29]. Differences in fishing gears used in sampling, locality, bio-ecological factors, fishing pressure, and stock status also can cause these differences.

Table 4. Some study results of the LWRs for the Common sole, *S. solea* in different areas

N	Sex	TL range (cm)	W range (g)	a	b	R^2	G. T.	Locality	Reference
550	F	10.5-28.2	10.3-183.0	0.0091	3.077	0.960	I	İskenderun Bay	[30]
533	M	8.8-25.0	8.0-115.3	0.0117	2.998	0.973	I		
55	C	6.9-16.0	2.28-31.50	0.0043	3.171	0.928	I	Sea of Marmara	[31]
406	C	15.0-45.0	15.0-45.0	0.1130	2.960	0.932	A-	French Catalan coast	[32]
53	C	20.0-33.2	25.0-930.0	0.0060	3.055	0.853	I	Sea of Marmara	[33]
183	F	12.2-22.2	13.25-104.71	0.0055	3.154	0.913	A +	Eastern Black Sea	[34]
117	M	11.7-19.0	14.44-60.31	0.0105	2.909	0.840	I		
309	C	11.7-22.2	13.25-104.71	0.0062	3.111	0.901	I		
528	C	11.0-27.6	10.70-263.20	0.0028	3.423	0.961	A +	Middle Black Sea, Sinop	[35]
150	C	11.80-32.3	8.95-356.70	0.0091	2.944	0.966	I	Sea of Marmara	[20]
80	C	9.0-32.0	7.56-319.62	0.0082	3.010	0.960	I	Sea of Marmara	[36]
607	F	7.1-31.1	-	0.0079	3.064	0.987	A +	Southern Aegean Sea, Güllük Bay	[37]
529	M	3.9-28.7	-	0.0088	3.024	0.993	I		
1136	C	3.9-31.1	0.24-458.67	0.0079	3.064	0.992	A +		
248	F	12.6–29.5	-	0.0349	2.554	0.903	A-	Sea of Marmara	[38]
294	M	11.8–27.8	-	0.0253	2.624	0.934	A-		
94	F	-	-	0.085	3.010	0.700	I	Aegean Sea, Izmir Bay	[21]
19	M	-	-	0.0547	2.400	0.460	A-		
122	C	-	-	0.0107	2.930	0.660	I		
478	C	11.0-39.0	11.50-670.0	0.0066	3.092	0.910	A+	Mediterranean Sea, Egypt	[39]
133	C	6.7-16.9	2.80-46.10	0.0065	3.143	0.998	A+	North Aegean Sea, Çandarlı Bay	[40]
32	C	10.7-25.1	1.42-172.51	0.0066	3.124	0.972	A+	Köyceğiz Lagoon	[41]
103	C	8.5–15.5	5.0–36.3	0.005	3.248	0.998	A+	Gediz Estuary, İzmir Bay, Central Aegean Sea	[42]
195	F	12.3-22.5	13.25-109.73	0.005	3.196	0.954	A+	Eastern Black Sea, Rize Coasts	Present study
130	M	12.3-21.9	15.44-96.01	0.006	3.153	0.972	A+		
325	C	12.3- 22.5	13.25-109.73	0.055	3.166	0.960	A+		

(F: Female, M: Male, C: Combined sex, I: Isometric, A+:Positive Allometric, A-: Negative Allometric, G.T: Growth type)

V. CONCLUSION

In conclusion, future studies need to focus on the bio-ecological and population dynamics, also exploitation status of *S. solea,* and the impact of fishing pressure on its stocks. In the SE Black Sea, the common sole is primarily caught by trammel nets, because bottom trawling has been completely banned in this region for a long time. However, further comprehensive investigations including trammel net by-catch and selectivity studies are necessary for determining the optimum mesh size for targeting demersal species to reduce the number and amount of non-target species and regulations for trammel nets that are intensively used in small-scale fisheries will provide important contributions to the conservation of demersal fishes and the management of their stocks for sustainable fisheries in the Black Sea. By addressing these concerns through targeted research and regulation, the conservation of demersal fish species and the management of their stocks in the Black Sea can be significantly improved, ensuring that fisheries remain viable, and ecosystems are preserved. These issues highlight an important concern in the management and conservation of demersal fish species, specifically with the use of trammel nets in small-scale fisheries in the Black Sea. Trammel nets, often used for capturing demersal species are known to have significant by-catch, which includes non-target species. The need for further comprehensive studies and the establishment of regulations on mesh size and by-catch management is crucial for sustainable fishery management and conservation of fish stocks in the Black Sea.

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