Libyan Journal of Ecological & Environmental Sciences and Technology
(LJEEST)
LJEEST
ISSN: 2710-5237
www.srcest.org.ly/jou

DOI: https://doi.org/10.63359/0e19gp41

Morphometry of *Siganus rivulatus* (Siganidae) from the Southern Mediterranean Sea

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ARTICLE INFO

Vol. 7 No. 3 December, 2025

Pages (18- 25)

Article history:
Revised form 30 July 2025
Accepted 05 October 2025

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Keywords:
Siganus rivulatus, morphology, length-weight, condition factor, Mediterranean

ABSTRACT

Siganus rivulatus, a Lessepsian migrant fish species, has successfully colonized the southern Mediterranean Sea. This study aimed to investigate the morphometric characteristics of *S. rivulatus* from Soussa coast, eastern Libya, southern Mediterranean Sea. Twenty specimens were measured individually for fourteen morphometric parameters. The mean length and weight of the fish were 19.52 cm and 109.35 g, respectively. Pairwise correlations among the morphometric parameters were highly significant, ranging from strong to moderate positive relationships. Regression analyses revealed that all parameters increased at different rates with fish length and head length. Fulton's condition factor (K_F) of 1.44 and Clark's condition factor (K_C) of 1.16 indicated that the fish were in good health. The 'b' value of the power regression for the length-weight relationship of 2.93 suggests slightly negative allometric growth.

القياسات المورفومترية لسمكة البطاطا البيضاء *Siganus rivulatus* **(Siganidae)**
من جنوب البحر الأبيض المتوسط

الصادق محمد احمودة، احمد غيث حكيم شعيب، احمد فضل عبد العزيز، رمضان عطية صالح علي، سيد محمد علي

سمكة البطاطا البيضاء من الأسماك المهاجرة عبر قناة السويس (Lessepsian migrant) ، وقد نجحت في استعمار البحر الأبيض المتوسط الجنوبي. هدفت هذه الدراسة إلى دراسة الخصائص المورفومترية لسمكة البطاطا البيضاء من ساحل سوسا، شرق ليبيا. تم قياس 20عينة لأربعة عشر متغيرًا مورفومتريًا لكل سمكة. بلغ متوسط الطول الكلي للسمك 19.52 سم، ومتوسط الوزن 109.35 جم. أظهرت التحليلات الثنائية للارتباط بين المتغيرات المورفومترية علاقات إيجابية عالية الدلالة، تراوحت بين قوية ومتوسطة. أظهرت تحليلات الانحدار أن جميع المتغيرات زادت بمعدلات مختلفة مع زيادة طول السمكة وطول الرأس. أشارت قيم معامل الحالة لفولتن (KF = 1.44) ومعامل كلارك (KC = 1.16) إلى أن الأسماك كانت بصحة جيدة. كما أظهرت علاقة الطول بالوزن (LWR) باستخدام الانحدار القوي (power regression) قيمة2.93 = b ، مما يشير إلى نمو سلبي طفيف غير متناسب.

INTRODUCTION

Fish morphology, the study of the form and structure of fish, is a fundamental aspect of ichthyology that provides critical insights into the biology, ecology, and evolution of fish species. Morphology is typically subdivided into three main categories: morphogenic traits, which pertain to the developmental processes shaping fish form; morphometric traits, which involve quantitative measurements of body dimensions; and meristic traits, which include countable features such as fin rays and scales (Helfman *et al*., 2009). These morphological characteristics are essential for understanding species identification, population dynamics, and adaptive responses to environmental changes. Among the various tools used in fish morphology studies, the length-weight relationship (LWR) and condition factor (CF) are particularly significant. The LWR provides insights into growth patterns, health, and habitat conditions, while the CF serves as an indicator of the overall well-being and nutritional status of fish populations (Froese, 2006; Le Cren, 1951).

The Siganidae family, commonly known as rabbitfishes, comprises herbivorous marine fish species widely distributed in tropical and subtropical regions, particularly in the Indo-Pacific (Woodland, 1990). Among these, *Siganus rivulatus*, a Lessepsian migrant, has garnered attention due to its successful invasion and establishment in the Mediterranean Sea. Lessepsian migration refers to the movement of marine species from the Red Sea to the Mediterranean through the Suez Canal, a phenomenon that has significantly altered the biodiversity of the Mediterranean ecosystem (Por, 1978). *S. rivulatus* has adapted well to its new environment, thriving in the southern Mediterranean and becoming a dominant component of the coastal fish community (Bariche *et al*., 2004). Its proliferation has also led to its incorporation into local fisheries, where it is increasingly harvested for subsistence and commercial purposes, underscoring its dual role as an invasive species and an emerging fishery resource (Bariche *et al*., 2004).

The study of *S. rivulatus* morphology in the southern Mediterranean is of particular importance for several reasons. First, understanding its morphometric and meristic traits can shed light on its adaptive strategies and ecological niche in the invaded habitat. Second, monitoring its growth patterns and condition factors provides valuable information on population health and sustainability, crucial for managing ecological impacts and supporting fisheries that now depend on this species. Finally, investigating the LWR and CF of *S. rivulatus* contributes to broader studies on the effects of climate change and habitat alterations on fish populations (Dulčić and Kraljević, 1996). As southern Mediterranean fisheries increasingly exploit this species, data on its morphological traits and condition factors are vital for assessing its viability as a sustainable resource and understanding interactions with native commercial species (Froese, 2006).

This study focuses on the morphometric characteristics of *S. rivulatus* from the Soussa coast in eastern Libya, a region where this species has become well-established. By analyzing 14 morphometric parameters, we aim to provide a comprehensive understanding of its growth patterns, health status, and morphological adaptations in this part of the Mediterranean. The findings will contribute to the growing body of knowledge on Lessepsian migrants and their ecological and economic impacts, while offering insights into sustainable management of invasive species in the Mediterranean Sea.

MATERIALS AND METHODS

Soussa, the fish collection site

The southern Mediterranean coast features numerous brackish-water inlets and small coastal lakes, habitats shaped by limited water exchange with the open sea—a characteristic feature of the Mediterranean's hydrographic conditions. Soussa (often written as "Sousa"), a historic Libyan fishing and commercial harbor, exemplifies this type of coastal environment (Fig. 1). Founded by Greek settlers as Apollonia in the 7th century BCE, Soussa lies at approximately 33°31′N, 23°15′E (33.517°N, 23.250°E) and has been a UNESCO World Heritage Site since 1982 due to its well-preserved archaeological ruins. However, the city faces environmental challenges, including inadequate treatment of municipal wastewater, which frequently discharges untreated into the adjacent marine environment.

Fig. 1. Soussa, from which samples of *S. rivulatus* were collected.

Collection of the fish samples

A total of 20 specimens of *Siganus rivulatus* were randomly collected from the artisanal catch obtained using fishing nets in the Soussa port area (33°31′N, 23°15′E; 33.517°N, 23.250°E). Samples were stored in ice-cooled plastic tanks and transported to the Marine Biology Research Laboratory, Department of Zoology, Faculty of Science, Omar Al-Mukhtar University for analysis.

Morphometric measurements

In the laboratory, the total length (TL, cm) and standard length (SL, cm) of each fish were measured using a digital Vernier caliper. Additionally, 12 other key morphometric parameters (e.g., body depth, head length) were measured to the nearest millimeter (mm) using the same caliper (Table 1). Body weights (BW, g) and eviscerated body weight were recorded to the nearest 0.1 g using a sensitive digital top-loading balance.
Sexes were not distinguished in this study, and no gender-specific analysis was performed.

Table 1. Morphometric parameters (and their codes) of *Siganus rivulatus* Measured in the present study

Morphometric parameters (cm)
Fish Body-Length **(L)**
Fish Weight **(W)**
Standard Length **(SL)**
Body Depth **(BD)**

Head Length **(HL)**
Dorsal Fin Length **(DFL)**
Pre-Dorsal Fin Length **(PREDFL)**
Eye Diameter **(ED)**
Pre-Orbital Length **(PREOR)**
Snout **(SN)**
Pre-Pelvic Fin Length **(PREPL)**
Pre-anal Fin Length **(PREANL)**
Caudal Peduncle Length **(CPL)**
Empty body Weight **(EMP W)**

Establishing the length-weight relationship (LWR)

The length-weight relationship (LWR) of the fish was calculated using the formula proposed by Le Cren (1951), Ricker (1975), and Letourneur *et al*. (1998):

$$W = {}_aL^b,$$

Where:
W = Total fish weight in grams,
L = Total fish Length in centimeters,
"a" and "b" are the constants of the regression line (intercept and the slope, respectively).

The condition factor

Fulton's condition factor (K_F) was calculated according to Fulton (1904) using the formula:
$K_F = 100 \times TW / L^3$

Where TW is the total body weight in grams, and L is the total body length in centimeters.

Clark's condition factor (K_C) was calculated according to Clark *et al*. (1983) as:

$$K_C = 100 \times EW / L^3$$

Where EW is the eviscerated body weight in grams and L is total body length in centimeters.

RESULTS AND DISCUSSION

Morphometric traits of *S. rivulatus* from the Soussa coast

Length and weight of *S. rivulatus*

In this study, the length of *S. rivulatus* ranged from 15.90 to 21.70 cm (Table 2), with a mean length of 19.52 cm (±0.36 SE). The weight ranged from 66.20 to 162.10 g, with a mean weight of 109.35 g (±6.08 SE). The other morphometric parameters are presented in the table.

Table 2. The morphometric parameters (Mor. Par.) of *S. rivulatus*, n = 20.

Mor. par.	Minim	Maxim	Mean	Std. Err
Length (cm)	15.90	21.70	19.52	0.36
Weight (gm)	66.20	162.10	109.35	6.08
Body depth (mm)	49.68	67.73	58.04	1.03
Head length (mm)	31.84	42.24	37.65	0.61
Snout (mm)	11.75	18.70	15.88	0.34
Pre orbital (mm)	11.15	18.42	14.81	0.43
Eye diameter (mm)	8.14	11.23	9.54	0.19
Pre pelvic fin (mm)	41.10	64.76	51.55	1.13
Pre anal fin (mm)	74.53	104.26	89.97	1.66
Dorsal fin (mm)	91.74	130.67	110.06	2.39
Pre Dorsal fin (mm)	34.75	52.31	45.05	1.06
Caudal peduncle (mm)	9.09	13.75	11.10	0.26
Empty weight (mm)	53.90	121.6	87.71	4.52
Standard Length (mm)	13.50	18.30	16.19	0.29

Length-weight relationship:

The linear, logarithmic, and power regressions of *S. rivulatus* weight versus its length (Table 3 and Fig. 2a) showed strong coefficients of determination (R^2) with similar values, indicating that all three models describe the relationship effectively. The "b" value of the power regression, calculated as 2.93, suggests slightly negative allometric growth. A similar conclusion was drawn for the relationship between fish length and weight (Table 3 and Fig. 2b).

Table 3. Length-weight relationship of *S.rivulatus* from the Soussa coast. n = 20.

Parameter	Regressions	a	b	R^2	P
TW Vs TL	**Li**	-202.9	15.9	0.92	0.00
	Log	-787.6	302.8	0.91	0.00
	Po	.017	2.9	0.94	0.00
TL Vs TW	**Li**	13.2	0.05	0.92	0.00
	Log	-9.08	6.13	0.94	0.00
	Po	4.35	0.32	0.94	0.00

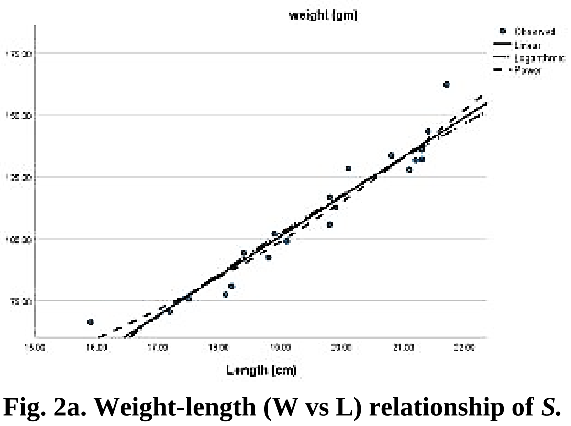

Fig. 2a. Weight-length (W vs L) relationship of *S. rivulatus* from the Soussa coast

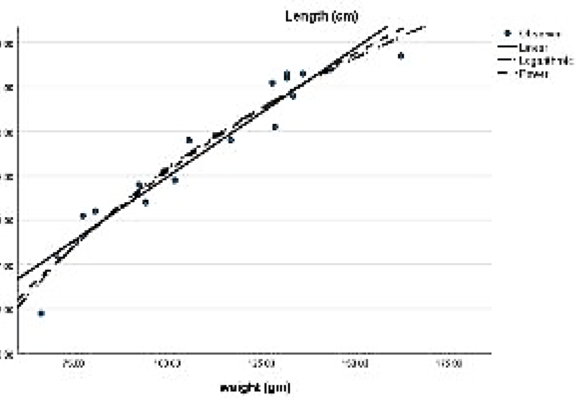

Fig. 2b. Length-weight (L vs W) relationship of *S. rivulatus* from the Soussa coast

Condition factor

The mean Fulton's condition factor (K_F) was 1.44, and Clark's condition factor (K_C) was 1.16.

Binary Correlations of Morphometric Measurements

Pearson's binary correlations of *Siganus rivulatus* total length (TL), weight (TW), and other morphometric parameters (Table 4) showed moderate to strong correlation coefficients. All correlations were positive and highly significant ($p < 0.01$), indicating that these parameters increase proportionally during fish growth. The analyses were performed on a sample size of n = 20. TL and standard length (SL) are expressed in centimeters, while all other morphometric parameters are in millimeters.

Table 4. Pearson's binary correlations of morphometric parameters of *Siganus rivulatus* from the Soussa coast (n = 20)

	TL	TW	BD	HL	SN	PRE ORL	ED	PREPL	PREA NA	DFL	PREDFL	CPL	EMP W
TW	.952**												
BD	.899**	.917**											
HL	.855**	.800**	.830**										
SN	.812**	.792**	.755**	.781**									
PREORL	.623**	.631**	.671**	.813**	.737**								
ED	.659**	.678**	.690**	.712**	.761**	.609**							
PREPL	.710**	.722**	.697**	.665**	.546*	.547*	.537*						
PREANA	.854**	.800**	.830**	.824**	.738**	.672**	.554**	.833**					
DFL	.855**	.805**	.833**	.762**	.740**	.538*	.652**	.520*	.720**				
PREDFL	.728**	.690**	.630**	.582**	.620**	.540*	.523*	.659**	.815**	.551**			
CPL	.623**	.710**	.689**	.682**	.647**	.658**	.621**	.617**	.628**	.632**	.619**		
EMP W	.971**	.988**	.912**	.854**	.807**	.575**	.682**	.685**	.874**	.876**	.685**	.691**	
SL	.951**	.982**	.854**	.882**	.798**	.672**	.714**	.721**	.888**	.864**	.733**	.687**	.928**

Relationship Between Morphometric Parameters and Fish Size

Morphometric parameters within the head region of the fish were analyzed in relation to head length using regression equations (Table 5 and Figs. 3–5). All regressions exhibited positive slopes ("b values") and were highly significant, indicating that these parameters increased as head length increased during fish growth. The coefficients of determination (R^2) for the regressions ranged from moderate to semi-strong, and all regressions were highly significant ($P < 0.001$).

Table 5. Morphometric parameters within the head region of *Siganus rivulatus* related to head length (HL) by linear (Li), logarithmic (Log), and power (Po) regressions (n = 20).

Parameters	Regressions	a	b	SE (b)	R^2	P
SN vs HL	Li	-.82	0.44	0.04	0.61	.00
	Log	-44	16.4	1.1	0.61	.00
	Po	0.32	1.07	0.07	0.59	.00
PREOR vs HL	Li	-6.6	0.57	0.05	0.64	.00
	Log	-61	21.0	1.2	0.63	.00
	Po	0.08	1.42	0.08	0.62	.00
ED vs HL	Li	0.79	0.23	0.03	0.50	.00
	Log	-22	8.65	1.0	0.51	.00
	Po	0.33	0.91	0.06	0.55	.00

Note: *a* and *b* are regression constants, R^2 is the coefficient of determination, P is the significance level, SE(b) is the standard error of the slope.

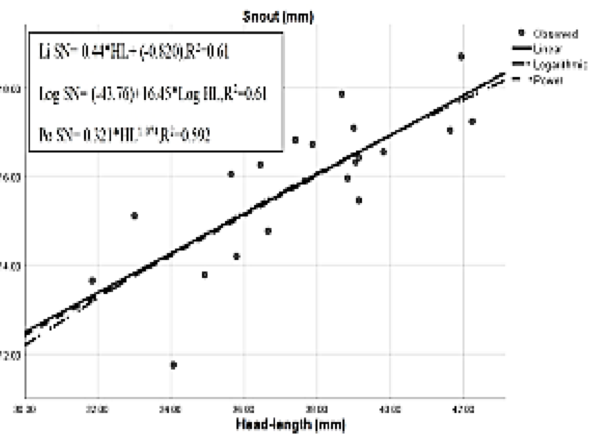

Fig. 3. Snout (SN)-head length (HL) relationship of *S. rivulatus* from the soussa coast, n = 20.

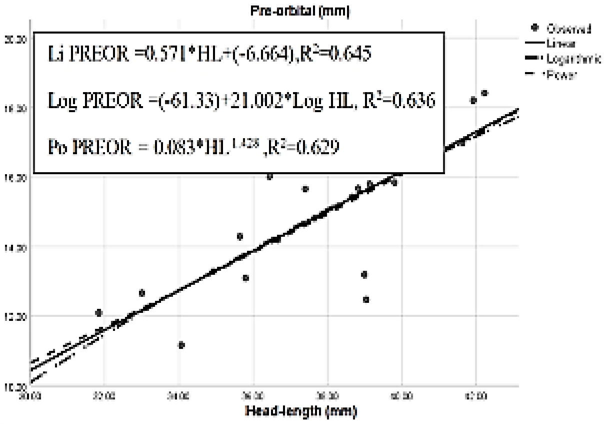

Fig. 4. Pre-orbital length (PREOR)-head length (HL) relationship of *S. rivulatus* from the Soussa coast, n = 20.

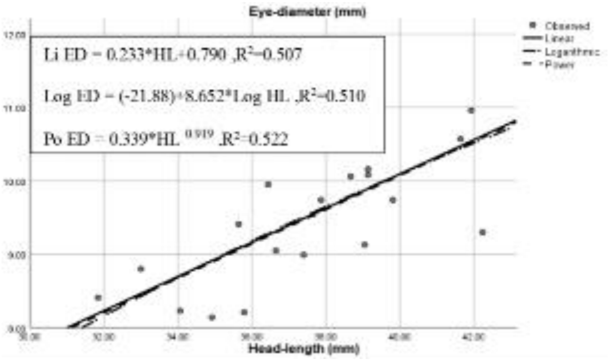

Fig. 5. Eye diameter (ED)-head length (HL) relationship of *S. rivulatus* from the soussa coast, n = 20.

Morphometric parameters outside the head region of *Siganus rivulatus* were analyzed in relation to total length (TL) using linear (Li), logarithmic (Log), and power (Po) regression models (Table 6, Figs. 6–14). All regressions exhibited positive slopes (b-values), indicating that these morphological features increased proportionally with fish size.

The coefficients of determination (R^2) were mostly strong (≥ 0.70), and all regressions were highly significant ($P < 0.001$), demonstrating robust relationships between TL and the examined morphometric traits.

Table 6. Morphometric parameters outside the head region of *Siganus rivulatus* related to fish total length (TL) by linear (Li), logarithmic (Log), and power (Po) regressions (n = 20).

Parameters	Regressions	a	b	SE (b)	R²	P
BD vs TL	Li	5.86	2.67	0.08	0.80	.00
	Log	-92.6	50.75	1.5	0.80	.00
	Po	4.13	0.88	0.05	0.82	.00
HL vs TL	Li	8.04	1.51	0.07	0.74	.00
	Log	-48.5	29.03	1.3	0.75	.00
	Po	3.57	0.79	0.04	0.77	.00
PREPL vs TL	Li	6.55	2.30	0.10	0.50	.00
	Log	-80.2	44.38	1.6	0.51	.00
	Po	3.70	0.88	0.06	0.53	.00
PREANL vs TL	Li	7.26	4.23	0.15	0.78	.00
	Log	-150	80.98	2.1	0.78	.00
	Po	5.71	0.92	0.07	0.79	.00
DFL vs TL	Li	-6.16	5.95	0.14	0.75	.00
	Log	-222	111.9	2.0	0.73	.00
	Po	5.30	1.02	0.06	0.73	.00
PREDFL vs TL	Li	1.55	2.22	0.12	0.52	.00
	Log	-82.4	42.92	1.8	0.54	.00
	Po	2.28	1.00	0.05	0.55	.00
CPL vs TL	Li	-1.95	0.34	0.09	0.41	.00
	Log	-12.8	5.88	0.8	0.41	.00
	Po	0.06	1.49	0.04	0.37	.00
EMP W vs TL	Li	-159	12.62	0.20	0.94	.00
	Log	-619	238.2	2.5	0.92	.00
	Po	0.01	2.87	0.07	0.95	.00
SL vs TL	Li	1.04	0.77	0.06	0.90	.00
	Log	-27.6	14.76	1.0	0.90	.00
	Po	1.01	0.93	0.05	0.91	.00

Note: TL and SL are expressed in cm; all other morphometric parameters are in mm. *a* and *b* are regression constants, R^2 is the coefficient of determination, P is the significance level, SE(b) is the standard error of the slope, and df is degrees of freedom.

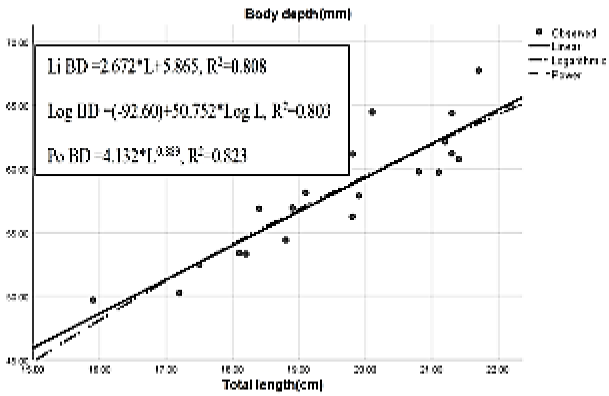

Fig. 6. Body depth (BD)-fish length (L) relationship of *S. rivulatus*, n = 20.

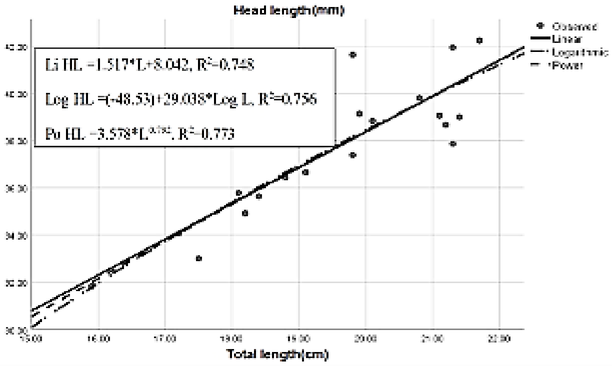

Fig. 7. Head length (HL)-fish length (L) relationship of *S. rivulatus*, n = 20.

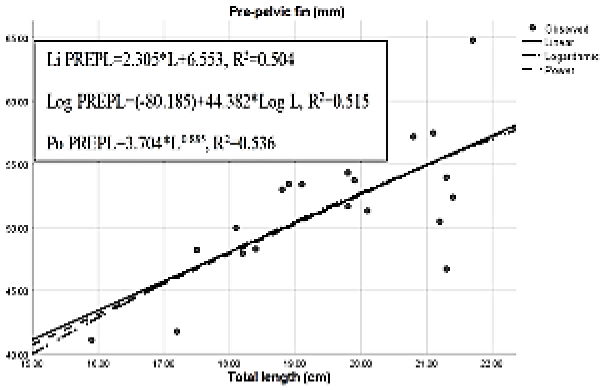

Fig. 8. Pre-Pelvic fin length (PREPL)-fish length (L) relationship of *S. rivulatus*, n = 20.

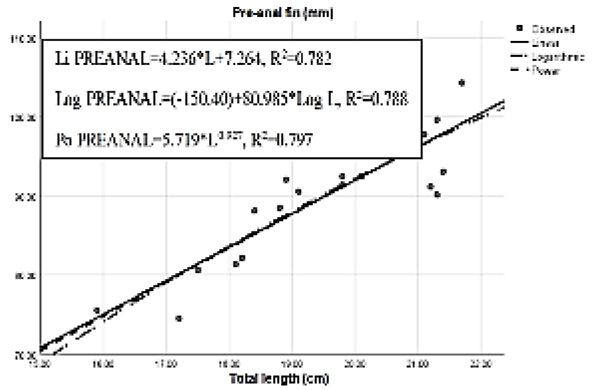

Fig. 9. Pre-anal fin length (PREANL)-fish length (L) relationship of *S. rivulatus*, n = 20.

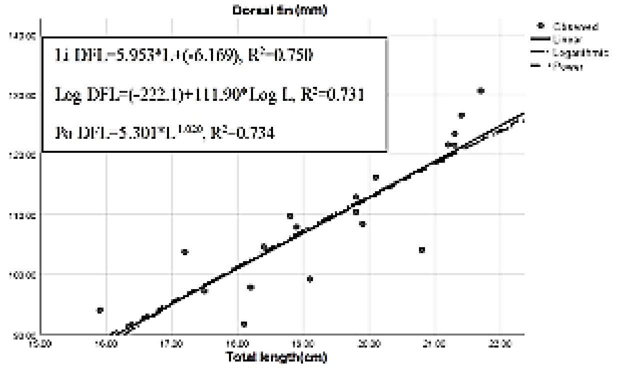

Fig. 10. Dorsal fin length (DFL)-fish length (L) relationship of *S. rivulatus*, n = 20.

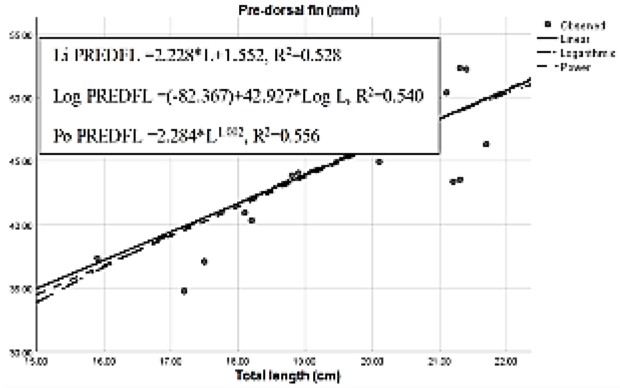

Fig. 11. Pre-dorsal fin (PREDFL)-fish length (L) relationship of *S. rivulatus*, n = 20.

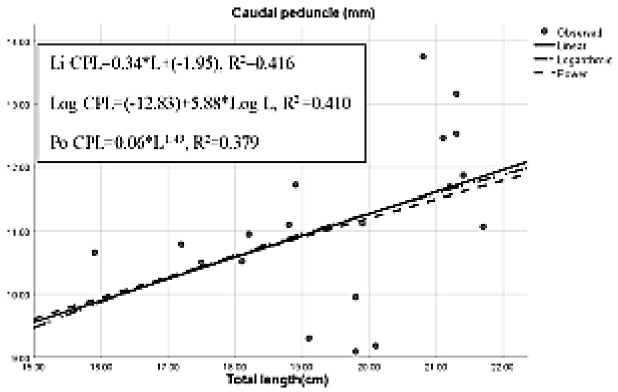

Fig. 12. Caudal peduncle length (CPL)-fish length (L) relationship of *S. rivulatus*, n = 20.

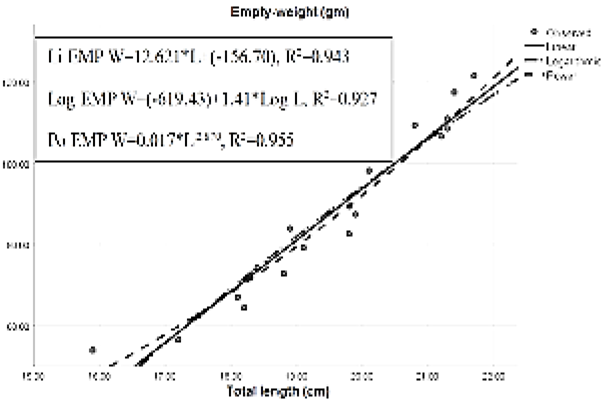

Fig. 13. Empty weight (EMP W)-fish length (L) relationship of *S. rivulatus*, n = 20.

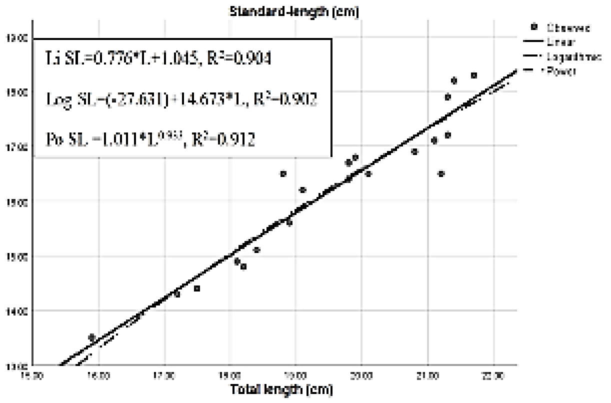

Fig. 14. Standard length (SL)-fish length (L) relationship of *S. rivulatus*, n = 20.

The present study demonstrates that the morphometric relationships of *Siganus rivulatus* from the Soussa coast, Libya, show significant positive correlations among total length and various body parameters. These findings are consistent with previous studies on *S. rivulatus* in Libya (Shakman *et al*., 2008) and align with research on other rabbitfish species in similar environments (Nehemia *et al*., 2012). The length-weight relationship (LWR) serves as a crucial tool in fisheries science, as it provides insights into growth patterns, fishery yield potential, and stock assessments (Froese, 2006). The LWR in this study revealed a b value of 2.93, indicating slightly negative allometric growth, suggesting that the fish allocate slightly more energy to increasing length than weight (Ricker, 1975).

The length-weight relationship is often used as a measure of robustness, general well-being, and to facilitate geographical comparisons among populations (Beyer, 1987). Generally, a *b* value close to 3 suggests isometric growth, where length and weight increase proportionally, whereas values significantly above or below 3 indicate positive or negative allometric growth, respectively (King, 1996). The b value of 2.93 further confirms slightly negative allometric growth, indicating that *S. rivulatus* individuals grow marginally more in length than in weight, a pattern commonly observed in populations exposed to fluctuating environmental conditions (Dulčić & Kraljević, 1996).

The observed differences in *b* values among populations of *S. rivulatus* may be attributed to variations in environmental conditions, food availability, and seasonal factors (Froese, 2006). Temperature, habitat quality, and food resource distribution have been shown to affect growth patterns in marine fish (Jenjan, 2011). Moreover, the strong correlations found between body weight and other morphometric parameters suggest that *S. rivulatus* exhibits a relatively uniform growth pattern within the Soussa coast population. The high correlation coefficients ($p < 0.05$) indicate a predictable relationship between length and weight, supporting the use of LWR in monitoring fish population dynamics (Nehemia *et al*., 2012).

Condition factors such as Fulton's condition factor (K_F) and Clark's condition factor (K_C) provide valuable insights into fish health, metabolic status, and ecological adaptability (Le Cren, 1951). In this study, the mean K_F of 1.44 and K_C of 1.16 indicate that *S. rivulatus* is in good condition in the Soussa coastal region. These values are comparable to those reported by Ibrahim *et al*. (2022) in Benghazi, where a K value of 1.69 was found, suggesting a similarly favorable environment. According to Ndimele *et al*. (2010), condition factors exceeding 1.0 generally indicate a healthy fish population with adequate food availability.

Environmental factors, including temperature fluctuations and habitat changes, influence the condition factor of fish species. Imam et al. (2010) emphasized the role of the condition factor in assessing fish welfare, particularly in fisheries management and aquaculture. Since *S. rivulatus* is an herbivorous species, its condition factor may be affected by seasonal variations in algal abundance, a critical food source (Bariche *et al*., 2004). Additionally, anthropogenic factors such as pollution and overfishing can impact fish health, warranting further research on the ecological dynamics of *S. rivulatus* populations in the Mediterranean.

CONCLUSION

The findings of this study indicate that *Siganus rivulatus* from the Soussa coast exhibits slightly negative allometric growth, with a b value of 2.93. This implies that the fish increase marginally more in length than in weight, a trend consistent with populations of *S. rivulatus* exposed to fluctuating environmental conditions.

The Fulton's (KF = 1.44) and Clark's (KC = 1.16) condition factor values suggest that the species is in generally good health, reflecting favorable environmental conditions along the Soussa coast.

These results provide a solid baseline for further research on the population dynamics, growth patterns, and stock assessments of *S. rivulatus* in the region. They emphasize the need for continuous monitoring to evaluate the impacts of environmental changes, fishing pressures, and potential anthropogenic influences on this species.

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