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Age, Growth and mortality of the rabbit fish *Siganus rivulatus* (Forsskål 1775) from the Egyptian Mediterranean coast off Alexandria, Egypt

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ABSTRACT

The present work aimed to provide essential information to assess proper management for the rabbitfish, *Siganus rivulatus* on the Egyptian Mediterranean coast in Alexandria, Egypt. A total of 1116 specimens of rabbit fish were collected from the Egyptian Mediterranean coast off Alexandria during the fishing season of 2021 to study the length-weight relationship, age and growth, mortality rates and exploitation rate. The length-weight relationship showed that the *S. revulatus* growth was nearly isometric (b= 2.935). Age was determined by the otolith-reading technique and its longevity reached five years. The age groups (II+ and I+) were most abundant in the fishing sample. The back-calculation method estimated that the maximum annual increment in length (10.44 cm) was recorded during the first year of life; while the maximum annual increment in weight (23.54 g) was recorded during the fourth year of life. The values of the von Bertalanffy growth parameters were $L\infty$ = 22.8 cm; $W\infty$= 143.53 g; K = 0.341 year^{-1} and t_0 = -1.376 year^{-1}. The mean total mortality "Z" was 1.66 year^{-1}. The natural mortality "M" was estimated as 0.68 year^{-1}, and the fishing mortality rate (F) was 0.95 year^{-1}. The exploitation rate (E) was estimated as 0.59. The length at first catch was 14.56 cm.

INTRODUCTION

Rabbitfish are very small with a short age ranging from 4- 6 years. They belong to the family Siganidae **(Shakman *et al.*, 2008)**. They are distributed across the tropical and subtropical regions. There are four siganid species in the Red Sea: *Siganus argenteus, Siganus luridus*, *Siganus rivulatus*, and *Siganus stellatus*. *Siganus luridus* and *Siganus rivulatus* migrated from the Red Sea and invaded the Mediterranean via the Suez Canal and settled in the eastern Mediterranean (**Ben-Tuvia, 1966**).

Siganus rivulatus is most commonly found in the western Indian Ocean and the Red Sea. It was first discovered in the Mediterranean Sea off Palestine in 1927 and has since spreaded throughout the Eastern Mediterranean, including Cyprus, Syria, Tunisia, Libya, the Aegean Sea, the Ionian Sea, and "Croatia" in the South Adriatic Sea (**Shakman *et al.*, 2008**).

Egypt's Mediterranean coast extend about 1,100 kilometers from El Salam in the west to Rafah in the east and produces about 55,000 tonnes annually (**GAFRD annual reports**). Egypt's Mediterranean coastal fishing grounds are divided into four regions: western, central and eastern. (Alexandria and El Mex, Abu-Qir, Rasheed, El-Maadiya and Mersa Matruh).In 2020, the total production of the Siganidae family on the Mediterranean coast of Egypt is 690 tonnes, supplied to the fresh or frozen commercial markets. Trawls, bottom lines and handlines are commonly used in Siganid fisheries. (**GAFRD, 20٢٠**). This fish is very popular among consumers, is considered excellent seafood and is inexpensive. Despite their importance to Egypt's fisheries, these species have received little attention. Therefore, many past and present studies have addressed different factors of biology, management and population dynamics of the species studied**.** (**El-Gammal, 1988; Mehanna & Abdallah, 2002; Osman *et al*., 2019** and **Saber & Gewida, 2020**).

The present study aimed to address some biological and fisheries aspects of *Siganus rivulatus* collected from Egyptian Mediterranean Sea coast at Alexandria to understand the status of this stock in Egyptian fishery. Also, it aimed to provide essential information to assess a proper management for this species in the Egyptian Mediterranean coast.

MATERIALS AND METHODS

1. Fish sampling:

Fish samples of *Siganus rivulatus* were monthly obtained from Egyptian Mediterranean sea at Alexandria by the artisanal fleet working in this region during the period from January to December 2021 **(Fig. 1)**.

Fig. (1): Alexandria the Egyptian Mediterranean coast

2. Length-weight relationship

A total of 1116 specimens were collected. For each specimen, the total length (**L**) was measured to the nearest mm and total weight (W) was weighed to the nearest 0.1 g. The relationship between length and weight was described by the following equation:

$$W = a*L^b \qquad \text{(Ricker, 1975)}$$

Where: **W** is the total weight (g), and **L** is the total length (cm), **a** and **b** are constants. The calculated weight at the end of each year was estimated by applying length-weight equation.

3. Age determination

The fish's otoliths were then extracted. All individuals' ages were determined using otolith measurements. Otoliths were readed using transmitted light under a binocular stereoscope with a 25x magnification. An optical micrometer was used to measure the lengths from the otolith focus to the rostrum (maximum radius) and the radius (distance from the otolith focus to the opaque zone border, in the same direction as the maximum radius) of each ring.

4. Back calculation method

The annual growth rings were counted, then the otolith radius and the radius of each annual growth ring were measured under a binocular microscope using ocular micrometer. The log transformation length-otolith radius regression was used to determine back-calculated lengths at the predicted age of individual fish. The back-calculated total length at the end of each year was determined from scale measurements using the equation of **Lea (1910).**

$$Lx = Lp\ (Sx/Sp)$$

Where: **Lx** equals length of fish at age (x), **Lp** equals the fish length at capture, **Sx** equals the scale radius at annulus (x) and **Sp** equals total scale radius. The relationship between scale radius and fish total length for this species was found to be linear and represented by the following equation:

$$L = a + bS$$

Where: **L** is the total body length in cm, **S** is the otolith radius in micrometer division, (**a**) is the intercept on the Y-axis and (**b**) is the slope of the regression line.

Back calculation of fish length at various years of life was determined using the following equation:

$$Ln = [(Sn / S)*(L - a)] + a \qquad \textbf{(Lee, 1920)}$$

Where: **Ln** is the calculated length at the end of n^{th} year of life in cm, **L** is the total length in cm, **Sn** is the otolith radius from the nucleus to the n^{th} annual mark (in micrometer division), **S** is the total otolith radius in micrometer division from the nucleus to the anterior edge of the scale and **a** is the intercept on the Y axis in the length scale relationship.

The obtained formula expressing length weight relationship was used to estimate the back calculated total weights at various years of life for each species under study.

5. Growth parameters:

The von Bertalanffy growth equation was used to describe growth in size:

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

Where: L_t is the length at age **t**, L_∞ the asymptotic length, **K** is the body growth coefficient and t_0 is the hypothetical age at which a fish would have zero length. The values of L_∞ and K were estimated by plotting L_t vs L_{t+1} using the **(Ford, 1933 – Walford, 1946)** plot, while t_0 was estimated by **Gulland & Holt (1959)** plot.

For comparison of the growth parameters with previous studies, the growth performance index was calculated from the following equation:

$$(\Phi') = Ln\ K + 2Ln\ L_\infty \qquad \textbf{(Munro \& Pauly, 1983)}$$

6. Mortality rates

The overall mortality coefficient (Z) was calculated by averaging two separate methods: the linearized catch curve approach of **Pauly (1983b)** and the **Hoenig (1982)** model. The natural mortality coefficient (M) was determined as the geometric mean of three separate methods **(Ursin, 1967; Rikhter & Efanov, 1976** and **Pauly, 1978 & 1980)**. As a result, the fishing mortality coefficient (F) was calculated as follows:

$$F = Z - M$$

7. Exploitation rate

The exploitation ratio (E) was estimated using the formula of **Gulland (1971)** as:

$$E = F / Z$$

8. Length at first capture (Lc)

The length at first capture L_c was estimated by the analysis of catch curve using the method of **Pauly (1984)**.

RESULTS

1. Length – Weight relationship

Siganus rivulatus (1116 specimens) obtained off the Alexandria shore between January and December 2021, they ranged from 7.3 to 22.2 cm in length and weighed between 5 and 145 g. The equation for the length-weight connection is $\mathbf{W = 0.015L^{2.935}}$ (r^2 = 0.9421). There was nearly isometric growth, where b= 2.935 **(Fig. 2)**.

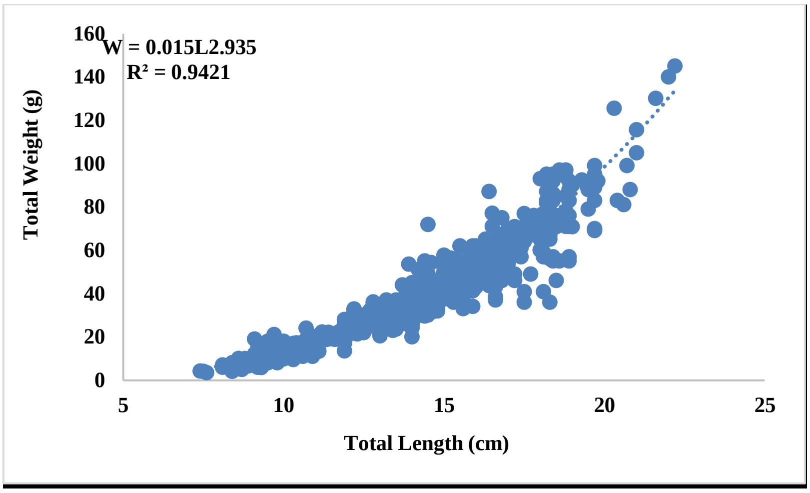

Fig. (2): Length-weight relationship of *Siganus rivulatus* from Alexandria coast

2. Population Structure

2.1. Length frequency distribution

The smallest *Siganus rivulatus* caught was 7.3 cm, while the largest measured 22.2 cm. The majority of fish in this species' capture fall into the 13-13.9 and 14-14.9 cm length categories (**Fig. 3)**.

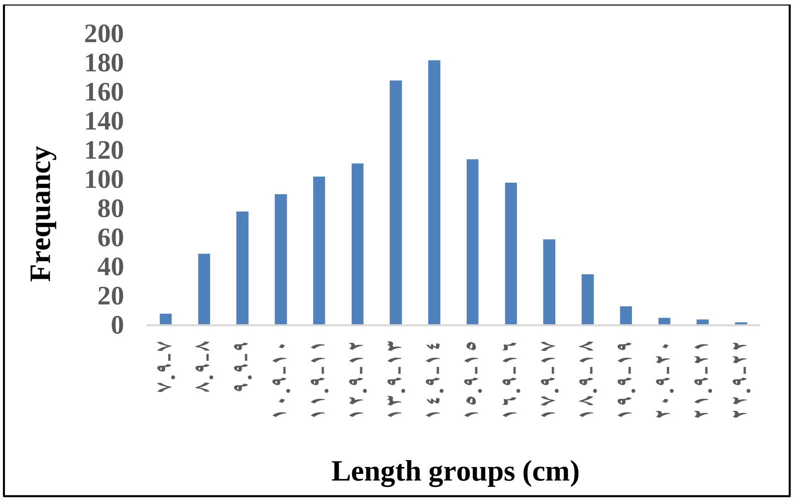

Fig. (3): Frequency distribution of lengths of *Siganus rivulatus* from Alexandria coast

2.2. Age composition

By counting the yearly growth rings on its otolith, *Siganus rivulatus* lived for more than 5 years. The abundance percentage data indicated that age group II^+ fishes are the most numerous (34.07 %), followed by age group I^+ (28.63 %), and age group V^+ has a very low abundance (4.64 %) of the entire catch **(Fig. 4)**.

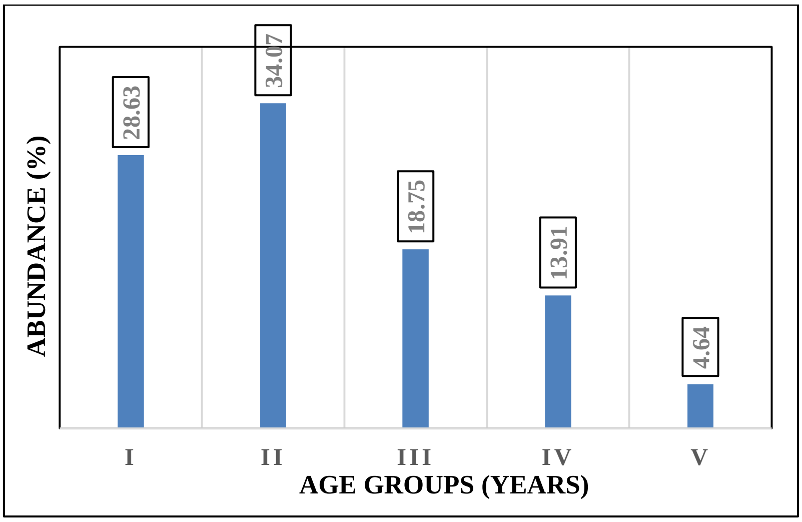

Fig. (4): Age composition of *Siganus rivulatus* from Alexandria coast

3. The back – calculations

Ageing growth study was performed on 573 specimens. The estimated ages varied from 1^+ to 5^+ years. Linking fish length to otolith radius size defines the mean fish length and mean otolith radius per length group **(Fig. 5)**. In the scatterplot, the relationship between total length and otolith showed a linear trend characterized by the following equation:

$$L = 3.845 + 8.3477\ S \text{ and } r^2 = 0.7845$$

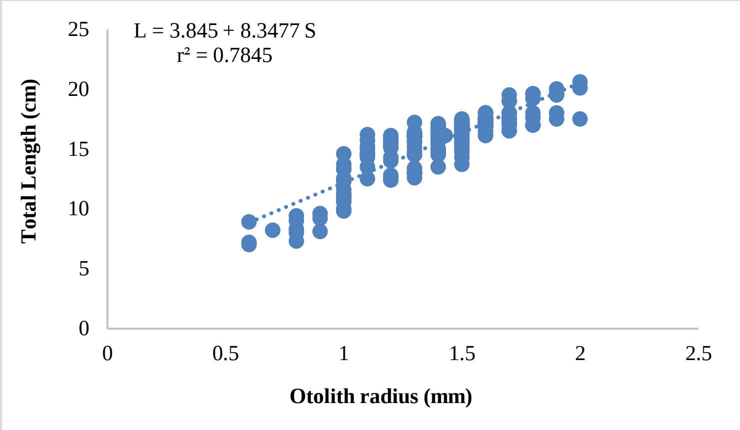

Fig. (5): Relationship between total Length and otolith radius of *S. rivulatus* from Alexandria coast

For the combined sexes, the averages of back - computed length and yearly increment were recorded in **Table (1)** and illustrated in **Fig. (6).** The maximum annual increment was recorded in the first year of life (10.44 cm), with significantly decrease during the next years of life, reaching a minimum value in the fifth year (1.31 cm).

The length - weight connection was used to determine the back - computed weight of *Siganus rivulatus* at the conclusion of each year of life. The maximum annual increment occured in the fourth year of life (23.54 g), while the minimum value of increment (16.87 g) was recorded during the third year of life **(Table, 2** and **Fig. 7)**.

Table (1): Average back-calculated lengths (cm) of *Siganus rivulatus* from Alexandria coast

Age group	Observed length	I	II	III	IV	V
I	11.6	10.19				
II	15.2	11.8	13.6			
III	17.6	10.6	14.5	16.57		
IV	19.0	10.0	14.1	16.5	18.04	
V	20.2	9.6	13.7	16.3	18.2	19.43
Average (cm)		**10.44± 0.842**	**13.98± 0.411**	**16.46± 0.140**	**18.12± 0.113**	**19.43**
Increment (cm)		**10.44**	**3.54**	**2.48**	**1.66**	**1.31**

Table (2): Average calculated weights (g) of *Siganus rivulatus* from Alexandria coast

Age group	Observed weight	I	II	III	IV	V
I	21.00	18.11				
II	47.65	18.73	34.10			
III	71.34	19.03	38.13	59.22		
IV	82.39	14.17	39.62	38.13	81.11	
V	103.21	17.09	40.99	67.89	76.12	96.35
Average		**17.43± 1.966**	**38.21± 2.979**	**55.08± 15.306**	**78.62± 3.528**	**96.35**
Increment		**17.43**	**20.78**	**16.87**	**23.54**	**17.74**

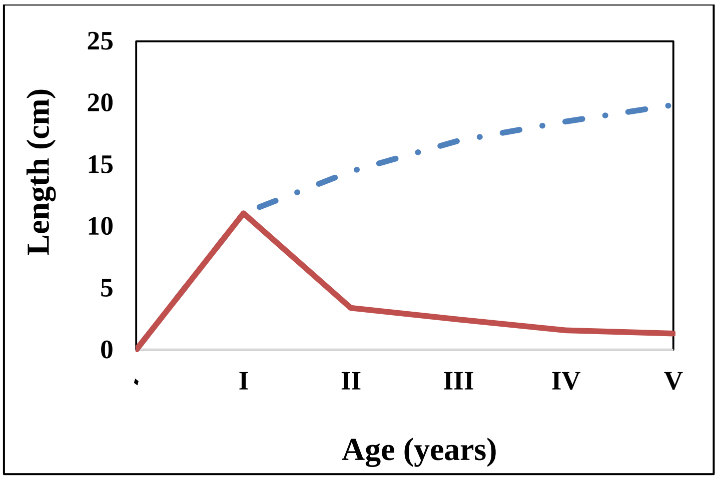

Fig. (6): Growth in length and increments at end of each life year of *S. rivulatus* from Alexandria coast

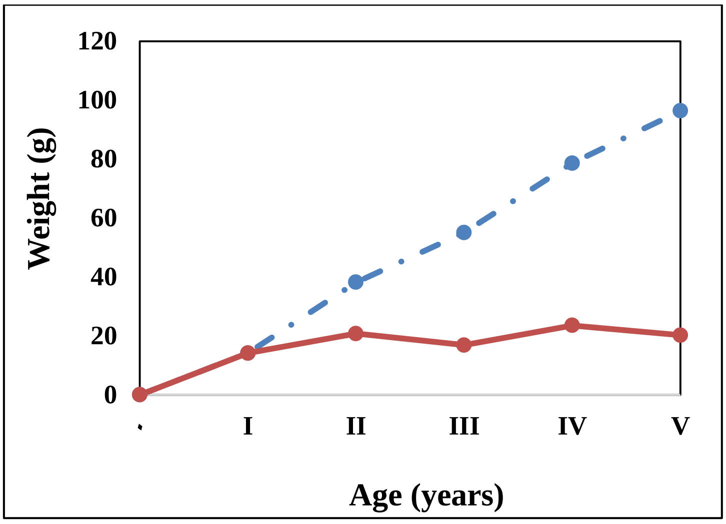

Fig. (7): Growth in weight and increments at end of each life year of *S. rivulatus* from Alexandria coast

4. Growth parameters:

The results of applying the von Bertalanffy method showed that the growth parameters of *S. revulatus* were found to be: $L\infty$= 22.8 cm; $W\infty$= 143.53 g; K = 0.341 year^{-1} and t_0 = -1.376 year^{-1}. The growth performance index (Φ') was determined to be 2.25.

5. Mortalities and exploitation rates

Total mortality (Z) from length-converted catch curves for *Siganus rivulatus* was estimated as 1.66 yr^{-1} **(Fig. 8)**, while natural mortality (M) was estimated as 0.68 yr^{-1}, and the fishing mortality rate (F) was 0.95 year^{-1}.

According to **Gulland (1971)**, the optimal exploitation rate for any fish population is around 0.5 when F=M, and the current exploitation rate (E) is 0.59 based on these data. More recently, **Pauly (1987)** advocated a lower ideal F of 0.4. According to **Patterson (1992)**, an exploitation rate of roughly 0.4 is safe for the stock.

6. Length at first capture (L_c)

The length at first catch (the length at which 50% of fishes kept by the gear is the mean selection length, L_c) was 14.56 cm; 25% of all fish were taken with 12.84 cm, and 75% had 15.87 cm. **(Fig. 9)**.

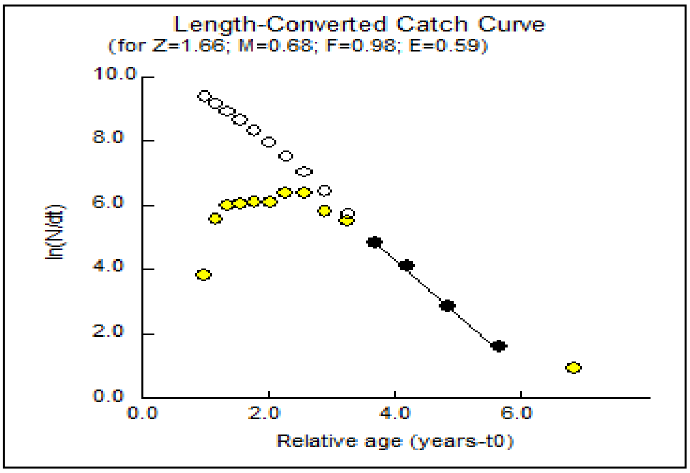

Fig. (8): Length-converted catch curve of *Siganus rivulatus* from Alexandria coast

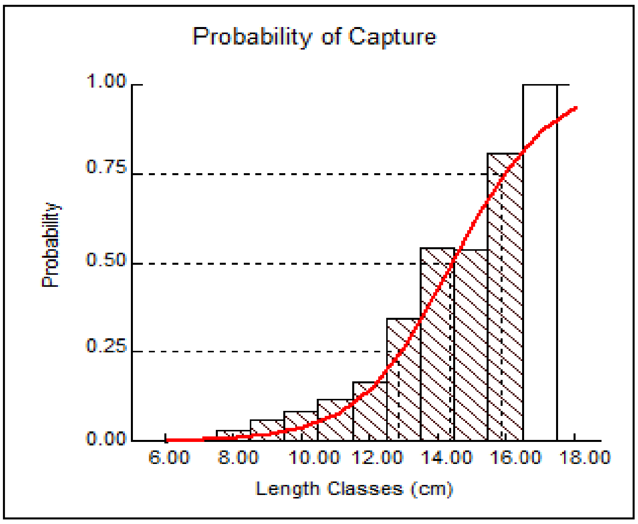

Fig. (9): Analysis of capture probability of *Siganus rivulatus* from Alexandria coast

DISCUSSION

Length-weight relationships are used to convert length data to weights and vice versa. The length-weight connection parameters [a and b] are important in fisheries science in a variety of ways, including estimating individual weight based on length, calculating health indicators and compare life histories and population morphology from different regions **(Petrakis & Stergiou, 1995).** Most studies on fish growth have used the function: $W= aL^b$. The values of (b) can be used to compare the condition of the fish **(El-Sedfy, 1971)**. The exponent (b) tends to have a value of around (3). $W=aL^3$ represents a condition in an ideal fish, where the fish maintenance, constant shape **(Allen, 1938)**. The value of (b) lying between 1.34 and 3.68 for the different fish stock **(Hile, 1936)** and ranged between 2.5 and 4 **(Hunt & Jones, 1972)**. Any difference between the observed and expected weights will indicate the well-being, fattening capacity or gonadal development of the fish (**Le Cren, 1951**).

The data for the length-weight connection of *Siganus rivulatus* taken off the coast of Alexandria indicated modest negative allometry (less than "3"), indicative of that the fish grows lighter for its equivalent length. However, several published results of the length-weight connection for *S. rivulatus* in the Mediterranean and Red Sea are presented; the parameters of these relationships are presented in **Table (3).** Estimates of 'b' index for the Red Sea population ranged from 2.841 to 3.071 and it ranges from 2.783 to 3.232 for Mediterranean Sea populations. Variation in b-value from length to weight can be attributed to a variety of factors, including season, geography, water temperature, sex, food availability, and sample length range used in the regression analysis.

Table (3): Summarized the values of (a) and (b) for *Siganus rivulatus* in various regions.

Regions	Length-weight relationship	Authors
Red Sea (Saudi Arabia)	$W = 0.021\ L^{3.071}$	**Hashem, 1983**
Red sea (Egypt)	$W = 0.011328\ L^{2.841}$	**El-Gammal, 1988**
Med. (Egypt)	$W = 0.012\ L^{2.934}$	**Mohammed, 1991**
Med. (Egypt)	$W = 0.016\ L^{2.872}$	**EL Okda,1998**
Med. (Turkey)	$W = 0.047\ L^{3.203}$	**Taskavak & Bilecenoglu, 2001**
Med. (Turkey)	$W = 0.0713\ L^{3.179}$	**Bilecenoglu & Kaya, 2002**
Red sea (Egypt)	$W = 0.0122\ L^{3.01835}$	**Mehanna & Abedallah, 2002**
Med. (Lebanon)	$W = 0.010\ L^{3.037}$	**Bariche, 2005**
Alexandria (Egypt)	$W = 0.0233\ L^{2.7831}$	**EL.Far, 2008**
Libyan coast	$W = 0.0101\ L^{3.232}$	**Shakman, 2008**
Bardawil lagoon (Egypt)	$W = 0.0163L^{2.8971}$	**Ali, 2015**
Bitter Lakes in (Egypt)	$W = 0.0104\ L^{3.010}$	**EL Drawany, 2015**
Red Sea (Saudia Arabia)	$W = 0.011\ L^{3.061}$	**Gabr *et al.*, 2018**
Red sea (Egypt)	$W = 0.0124\ L^{3.0097}$	**Saber & Gewida, 2020**
Alexandria (Egypt)	$W = 0.015L^{2.935}$	**The present study**

Because otoliths develop early in childhood, they are a more convenient and satisfying way to determine age than scales **(Williams & Bedford, 1974)**. The age of *Siganus rivulatus* in Alexandria coast fisheries was determined using the counting and interpretation of growth zones generated on the sagittal pair of otoliths. For combined sexes, five age groups were allocated, with total lengths ranging from 7.3 to 22.2 cm. However, many authors from the Red Sea and the Mediterranean have agreed on the use of otoliths to determine the age of *Siganus rivulatus* **(Hashem, 1983; El - Gammal, 1988; El Okda, 1998; Mehanna & Abdallah, 2002)**.

The relationship between otolith radius (R) and total fish length (cm) for *Siganus rivulatus* in Alexandria coast fisheries was found to be linear in the present study, and the recalculated lengths for each age group can therefore be approximated. The findings of growth in length and yearly increment for combined sexes of *Siganus rivulatus* at different years of life are compared with years of life from different localities **(Table, 4)**.

Comparison of the estimates by different authors at different locations in the Mediterranean Sea and the Red Sea showed that there are differences in the number of age groups and the calculated annual increments in length for age groups, which may be related to differences in sample size ranges, age of determination methods and components, and measurements **(Bariche, 2002)**.

Mean lengths for *Siganus rivulatus* calculated retroactively at the end of each year were converted to corresponding weights using the appropriate length–weight formula for pooled data. In contrast to growth in length, weight gain is slow during the first year of life (18.11 g). Based on the length recalculation and the length weight relationship parameters, it is possible to deduce that the weight growth rate for *Siganus rivulatus* at the various sites is the same

Table (4): The annual increment in length (L) for different years of life of *Siganus rivulatus* in different marine regions

Regions	Age groups						Authors
	I	II	III	IV	V	VI	
Red Sea (Saudi Arabia)	8.00	7.00	5.00	4.5	3.00	2.00	**Hashem (1983)**
Red Sea (Egypt)	13.24	7.50	4.08	3.04	2.81	-	**El-Gammal (1988)**
Mediterranean (Libya)	12.99	6.22	4.74	4.26	2.61	1.28	**Shiekh-Eldin (1988)**
Red Sea (Egypt)	13.86	7.44	6.54	3.14	2.32	-	**Mehanna & Abedallah (2002)**
Red Sea (Egypt)	15.8	3.5	3.0	1.7	-	-	**El-Ganainy & Ahmed (2002)**
Mediterranean (Egypt)	10.47	4.09	2.18	2.41	1.94	-	**EL- Far (2008)**
Bardawil Lagoon (Egypt)	10.11	4.14	2.31	1.97	1.50	-	**Ali (2015)**
Red Sea (Saudi Arabia)	10.70	6.60	4.70	4.90	2.12	-	**Gabr *et al.*, (2018)**
Alexandria (Egypt)	**10.44**	**3.54**	**2.48**	**1.66**	**1.31**	**-**	**The present study**

In the present work, the von Bertalanffy growth parameters were determined using the **Ford (1933)** and **Walford (1946)** methods, and the von Bertalanffy growth equation for the theoretical description of *Siganus rivulatus* growth in length and weight in Alexandria coast fisheries may be expressed as follows:

$$L_t = 22.8\ [1\text{-}e^{-0.341(t+1.376)}] \qquad W_t = 143.526\ [1\text{-}e^{-0.341(t+1.376)}]^{2.9351}$$

Based on values of the estimated growth parameters, the growth performance index for *Siganus rivulatus* (Ǿ) was estimated to be:

$$\acute{\O} = \text{Log } 0.275 + 2 \text{ Log } 38.06 = 2.25$$

Table (5): Von Bertalanffy's growth parameters (L∞, K, t_o and W∞) for *Siganus rivulatus* for various authors and in different locations.

Author	Location	L_∞ (cm)	W_∞ (g.)	K (yr^{-1})	t_o (yr^{-1})
Mouneimne (1978)	Med. (Lebanon)	27.8	240.80	0.040	-2.661
Mehanna & Abdalla (2002)	Red Sea (Egypt)	37.1	665.69	0.397	-0.186
Bilecenoglu & Kaya (2002)	Med. (Turkey)	22.3	137.87	0.279	-0.503
Bariche (2005)	Med. (Lebanon)	31.9	318.20	0.225	-1.307
EL-Far (2008)	Med. (Egypt)	29.3	280.37	0.257	-0.838
Ali (2015)	Bardawil lagoon	22.54	133.7	0.3798	-0.633
Gabr *et al.*, (2018)	Red Sea (Saudi Arabia)	38.1٠	784.65	0.275	-0.240
Saber & Gewida (2020)	Red Sea (Egypt)	٢٨.٣١	٢٩٠.٦١	٠.٢٢	-٠.٣٢١
The present study	Alexandria (Egypt)	**22.8**	**143.53**	**0.341**	**-1.376**

The total mortality coefficient 'Z' of *Siganus rivulatus* in Alexandria coast fisheries was estimated to be 1.66 $year^{-1}$ using the linearized length converted catch curve graphically represented in Figure (8), the natural mortality coefficient 'M' was 0.68 $year^{-1}$, and the fishing mortality coefficient 'F' was 0.98 $year^{-1}$, which is the difference between the total 'Z' and natural 'M' mortality coefficients. As a result, the *Siganus rivulatus* exploitation rate was calculated to be E = 0.59 $year^{-1}$. This finding agreed with **Ali (2015)** in Bardawil lagoon (E = 0.56 year $^{-1}$) and **EL-Ganainy & Ahmed (2002)** in Red Sea, Egypt (E= 0.55 year $^{-1}$) and it disagreed with **Mehanna & Abdallah (2002)** in Red Sea, Egypt (E= 0.80 $year^{-1}$) and **EL-Far (2008)** in Mediterranean Sea, Egypt (E= 0.80 year $^{-1}$).

The frequency distribution of the cumulative and first capture length of *Siganus rivulatus* caught in the coastal fishing areas of Alexandria was 14.56 cm. The estimated length at first catch in the current research is less than that determined for the same species in the Egyptian sector of the Red Sea by **Mehanna & Abdallah (2002)** Lc =17.04 cm, and that recorded in the Mediterranean Sea by **El- Far (2008)** Lc =15.6 cm.

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