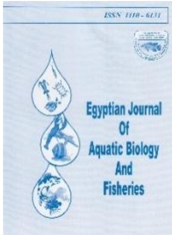
Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 25(2): 437- 455 (2021)
www.ejabf.journals.ekb.eg



Growth, Mortality, Yield Per Recruit and Management of *Siganus rivulatus* Stock from the Suez Canal, Egypt

Elham M. Abdelhak[1,*], Azza A. El Ganainy[2], Fedekar F. Madkour[1], Mohamed A. Abu El-Regal [1,3], Mohamed I. Ahmed[4]

1. Department of Marine Science, Faculty of Science, Port-Said University, Egypt.
2. National Institute of Oceanography and Fisheries, Suez, Egypt.
3. Marine Biology Department, Faculty of Marine Science, King Abdul-Aziz University-80207, Jeddah, Kingdom of Saudi Arabia. (present address)
4. Department of Marine Science, Faculty of Science, Suez Canal University, Egypt.

***Corresponding author: elham.aqua@yahoo.com**

ARTICLE INFO

Article History:
Received: Mar. 13, 2021
Accepted: Mar. 23, 2021
Online: April 15, 2021

Keywords:
Siganus rivulatus,
Suez Canal,
growth, mortality,
exploitation rate,
population dynamic,
management.

ABSTRACT

Siganus rivulatus is considered one of the most successful Lessepsian migrant fish, yet the scarce of studies about its population structure in new habitats of Suez Canal is clearly realized. In the present study, the yield per recruit of *S. rivulatus* was estimated in Suez Canal based on investigation of growth parameters, mortality coefficients and exploitation rate for 581 individuals collected seasonally from Ismailia during the period from autumn 2017 to summer 2018. Otolith was used for aging and estimation of the growth rates. Four years was the maximum attained age. The von Bertalanffy growth parameters were L_∞= 25.356 cm, K= 0.288 y^{-1} and t_0= -0.81 y. Total mortality coefficient (Z) was 1.57 y^{-1}, natural mortality (M)= 0.573 y^{-1} and fishing mortality (F)= 1. 002 y^{-1}. The length at the first capture (L_c= 12.838 cm) was found to be smaller than the lengths of first maturation (L_m= 14.5 and 15.15 cm for male and female, respectively). This may cause a great reduction in the stock due to harvesting small pre-spawning fish. Hence, the exploitation level was estimated recording a value of (E)= 0.636 y^{-1}, which indicated that the stock of *Siganus rivulatus* in Suez Canal is currently overexploited. Therefore, conservation of this stock is a must, which can be achieved by increasing the allowable mesh size to give a chance to each individual to reproduce at least once, and reducing the exploitation rate from 0.636 to 0.355 y^{-1} to maintain a sufficient (50%) of the spawning stock biomass.

INTRODUCTION

Since opening the Suez Canal in 1869, a lot of marine species migrated from the Red Sea to the Mediterranean Sea, that known as the Lessepsian species **(Por, 1978)**. Family Siganidae (rabbitfish) is considered one of the most successful Lessepsian migrant fish. In Egypt, four species of rabbitfish are endemic in Red Sea; *Siganus rivulatus*, *S. luridus*, *S. argenteus* and *S. stellatus* **(Fischer & Bianchi, 1984)**. *S. rivulatus* (Forsskål, 1775) and *S. luridus* (Ruppel, 1828) established a large population in the Mediterranean Sea after migrating through the Suez Canal **(George *et al.*, 1964; Bariche *et al.*, 2004)**. *S. rivulatus* was the most popular with a high economic importance **(Aleem, 1969; Papaconstantinou, 1990)**, and the common in the Egyptian catch of rabbit fish which reached 500 and 828 tons from the Red Sea and the Mediterranean in 2018, respectively **(GAFRD, 2019)**.

To maintain the stock at an equilibrium level (the growth equal to the mortality of recruitment), a simple model must be followed to obtain the biological data such as; age, mean of length and weight at certain age **(Holden & Rait, 1974)**. Growth, mortality parameters of population, length at first capture and first maturation are essential in the assessment and the management of the stock **(Udoh & Ukpatu, 2017)**. Generally, growth can be defined as increasing in length or weight, whereas mortality can be caused by fishing or natural mortality **(Suradi *et al.*, 2017)**. Analysis of length-frequency data can be used to estimate rates of growth, mortality and analytical yield models such as yield per recruitment **(Pauly, 1984)**. Remarkably, high exploitation of fish populations caused a change in its size composition, which is dominated by young or small size **(Ehrhardt & Deleveaux, 2007)** due to the preference of catching large-size fish **(Arreguín-Sánchez, 2000)**. That, in return, would affect significantly the outcome of reproduction, as the small- sized fish has less production. Thus, large-scale of exploitation has led to a change in the structure of population and a shift in age structure.

Some studies were conducted on population dynamic of *S. rivulatus* in the Red sea **(El-Gammal, 1988; El Ganainy & Ahmed, 2002; Gabr *et al.*, 2018; Cerim *et al.*, 2020)**, and in the Mediterranean **(El-Okda, 1998; El-Far, 2008)**. On the other hand**, s**ome authors compared between the two populations **(Golani, 1990; Mohammed, 1991; Hassan *et al.*, 2003)**. Nevertheless, the data about the population structure of *S. rivulatus* is very limited in Suez Canal, spotting one study that was conducted in Bitter Lakes **(El-Drawany, 2015)**. The scarce of those studies reveals the limited information about population dynamic and structure of *S. rivulatus* in new habitats of Suez Canal. Hence, the present work was organized to assess this required basic information about population by determining their age, growth dynamics, mortality rates and exploitation rate, in order to protect this valuable resource and implement the best plan of fishing and manage its sustainability.

MATERIALS AND METHODS

- **Sampling and study area**

A total of 581 specimens of *Siganus rivulatus* were collected seasonally from Ismailia (Fig. 1) from autumn 2017 to summer 2018. Samples were transported by ice box immediately to the laboratory for further analysis. Total length (TL) of each fish was recorded to the nearest 0.1 cm, and the total weight (TW) was measured to nearest 0.1 g. Samples were separately grouped with 1 cm interval into a 14 length-classes. Length frequency distribution was graphically illustrated seasonally in a bar chart.

Fig (1) Location of the studied site; Suez Canal (Ismailia).

- Age determination

The age of 133 fish from Suez Canal (about 10 specimens for each length-class), each of which was determined by examining the annual growth rings on its otolith. Xylol was used to treat the otoliths under microscope at 25X with reflected light against a dark background, then otoliths were moistened with chamomile oil to count visible annual growth rings **(Bariche, 2005)**. The count was performed without checking the fish length.

- Fish length-radius relationship

The relationship between the otolith radius (R) and the total body length (TL) was represented according to **Whitney and Cohen (1956)** by the following equation:

$$TL = a + b\,(R)$$

Where; (R) is the total otolith radius from nucleus to edge of otolith in micrometer division.

(a) is the intercept on the Y-axis, and (b) is the slope of the linear regression.

- Back-calculated length and weight

The value of intercept (a) obtained from length-radius relationship was used as a correction factor for back-calculation lengths and weight at the end of each year of life from otolith measurements by **Lee (1920)** equation as following:

$$L_t = (TL - a)\, S_t / S + a$$

Where; L_t is the calculated length at the end of (t) years (cm).

S_t is the otolith radius to the *t* annulus (micrometer division).

S is the total otolith radius (micrometer division).

- Estimation of von Bertalanffy growth model (1938) constants

- **The constants (L_∞ and K)** were estimated by three methods, following those of **Ford (1933)**, **Walford (1946)**, **Gulland-Holt (1959)** and **Chapman (1961).**
- **The constant "t_0"** was estimated from the following von Bertalanffy equation:

$$-\ln\,[1 - (L_t/L_\infty)] = -k{*}t_0 + k{*}t \qquad \textbf{(Pauly, 1984)}$$

The straight-line equation relates the age (t) with ($-\ln$ (1- (L_t/L_∞)), having a slope (b) equals to (k) and an intercept (a) equals to ($-k{*}t_0$) then: $t_0 = -a/b$.

- Theoretical Growth estimation

The von Bertalanffy equation was used to describe the theoretical growth in length (L_∞). Then, length-weight relationship equations ($W = a\,L^b$) were applied to calculate the theoretical growth in weight (W_∞). The von Bertalanffy growth equations can be written as:

$$L_t = L_\infty\ [1-e^{-k\,(t-to)}]\ \text{(Growth in length).}$$

$$W_t = W_\infty\ [1-e^{-k\,(t-to)}]^b\ \text{(Growth in weight).}$$

Where, L_t is total mean length (cm) & W_t is total mean weight (g) of the fish at age t.

L_∞ & W_∞ are the expected theoretical maximum total length and total weight.

K is the coefficient of growth that determines the rate at which L_∞ is attained.

t is the age of fish at length L_t. - t_0 is the theoretical age at length zero.

b is the slope of length–weight relationship.

- **Growth performance index (*Φ*)**

To compare the growth performance of the species with that of the same species in other areas, the growth performance index (*Φ*) was estimated by using von Bertalanffy parameters (K and L_∞) according to the formula:

$$\Phi = \log_{10} K + 2 \log_{10} L_\infty \quad \textbf{(Pauly \& Munro, 1984)}$$

- **Mortality estimation**
  - **Total mortality coefficient (Z)**

The rate of total mortality (Z) was estimated by Fi-SAT II program using length frequency distribution; based on length converted catch curve method developed by **Pauly (1983)** and the slope of the descending right limb. To construct the catch curve, length would converse to age by using the growth parameters of the von Bertalanffy growth equation. The value of "Z" was estimated through the following relationship:

$$Ln\ (n\ /\Delta t)\ =\ a\ +\ bt$$

Where: (n) is the frequency of length groups. (a) and (b) are constants

(Δt) is the time needed to grow from (t_1) to (t_2) of a given length group.

(T) is the relative age corresponding to the midpoint of the length group.

This is a linear relationship, where $Y = Ln\ (n\ /\Delta t)$, $X= (t_1 + t_2)/2$ and the slope b= -Z.

  - **Natural mortality coefficient (M)**

The natural mortality was calculated by using the empirical equation of **Then *et al.* (2014)** based on the estimated maximum age (t_{max}) and the growth coefficient (K) (t_{max} = 3/K)

$$M= 4.899t_{max}^{-0.916}$$

  - **Fishing mortality coefficient (F)**

The fishing mortality could be calculated by simple subtraction:

$$F\ =\ Z - M.$$

- **Rate of exploitation (E)**

Exploitation rate is the ratio of the fishing mortality (F) to the total mortality (Z), it was estimated by the following relationship:

$$E\ =\ F\ /\ (F +\ M)\ =\ F\ /\ Z\ \textbf{(Pauly, 1984)}$$

- **Length and age at first capture (L_c and t_c)**

Length at first capture (L_C) is the length at which 50% of the fish are vulnerable to fishing gear. It was computed from the equation of **Beverton and Holt (1956)**, which applies the growth constants of von Bertalanffy:

$$L_c = L^{-} - K\,(L_\infty - L^{-})\,/\,Z$$

The corresponding age at first capture (t_c) was calculated by the following equation:

$$t_c = (-1 / K) (Ln (1- L_c / L_\infty)) + t_0$$ **(Beverton & Holt, 1957)**

Where: L_c is the length at first capture. - $L^{\bar{}}$ is the mean length of the catch.

Z is the instantaneous total mortality coefficient.

K, L_∞ and t_0 are the constants of von Bertalanffy.

- **Relative Yield per Recruit (Y'/R)**

The model of **Beverton and Holt (1957),** modified by **Pauly and Soriano (1986)**, was applied to estimate the relative yield per recruit. This model allows a relative prediction of the catch weights and stock biomass under different exploitation rates as incorporated in Fi-SAT software **(Gayanilo *et al.*, 1997)**.

$$Y'/R = E*U^{(M/K)} * [1 - (3U/1+m) + (3U^2/1+2m) - (U^3/1+3m)]$$

Where: m = (1-E)/ (M/K) = (K/Z). - U = 1 - (L_c/ L_∞).

E is the the exploitation rate. - L_c: the length at first capture.

- **Relative biomass per recruit (B'/R)**

Relative biomass per recruit (B'/R) was calculated according to **Ricker (1975)** using above estimated relative yield per recruit (Y'/R) and the fishing mortality (F) as:

$$B'/R = (Y'/R) / F.$$

RESULTS

- **Length-frequency distribution**

Length frequency distribution of *S. rivulatus* was estimated for 581 specimens. The TL fluctuated from 8 to 22 cm. Seasonal length frequency distribution showed closed percentage of individuals in four length classes during autumn (Fig. 2); 14-14.5 cm (22.83%), 15-15.9 cm (20.65%), followed by 11-11.9 and 13-13.9 cm with the same percentage of 17.39%. A class of 10-10.9 cm was the most frequented (43.3%) and (25.41%), followed by 9-9.9 cm (26.79%) and (20%) in winter and spring, respectively. During summer, the highest percentage was 18.75% for 17-17.9 cm.

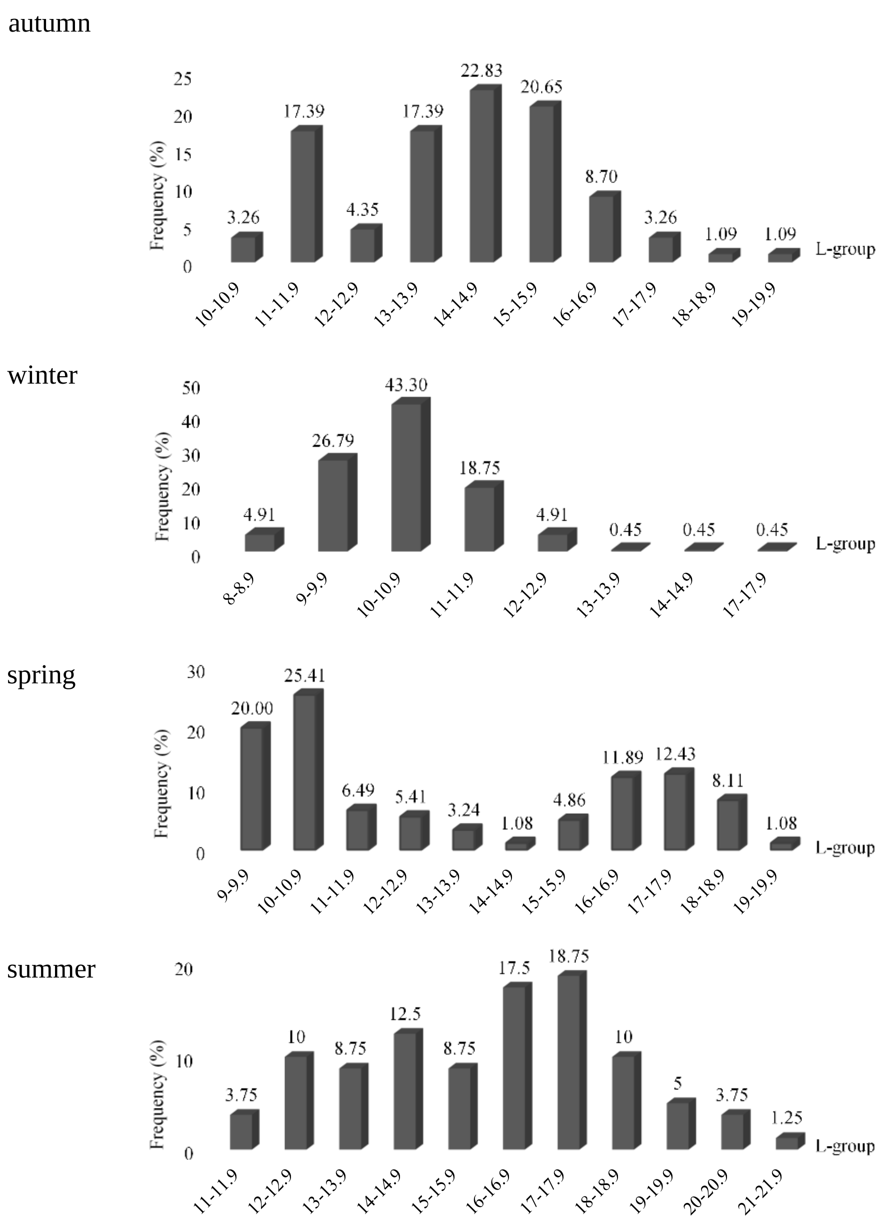


Fig. 2 Seasonal length frequency distribution of *S. rivulatus* collected from Suez Canal.

- **Otolith examination**
  - **Age determination by otolith**

The otoliths of *S. rivulatus* was laterally compressed structure, longer than wide and wider than thick (Fig. 3). The mean observed lengths of *S. rivulatus* in Suez Canal were 10.93, 14.8, 17.58 and 19.75 cm at age I, II, III and IV, respectively.

Fig. 3 Otolith of 3 years old *S. rivulatus* (TL=16.8cm) collected from the Suez Canal.

- **Total length-radius relationship**

The relationship between total length of the body and the otolith radius of *S. rivulatus* in Suez Canal was expressed by the linear regression equations (Fig. 4) showing correlation of:

$$L = 5.888 + 0.459R \text{ - } (r^2{=}0.7248).$$

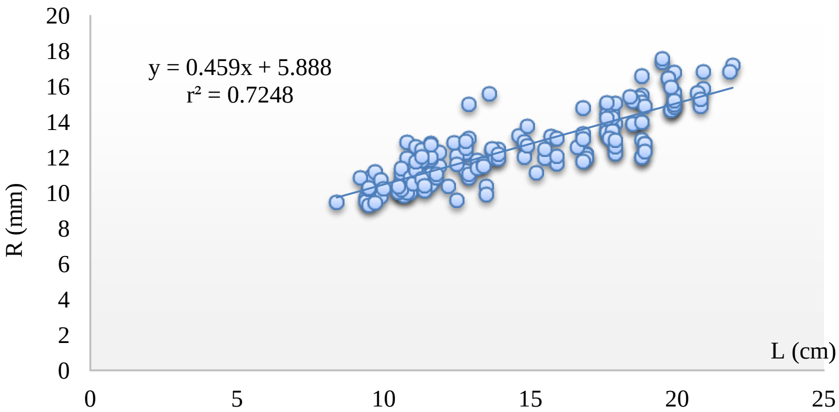


Fig. 4 Relationship between otolith radius-total length of *S. rivulatus* in Suez Canal.

- **The back-calculated lengths and weight**

The back-calculated lengths for *S. rivulatus* were estimated at the end of each year of life according to the following equation:

$$L_t = (L - 5.888)\, S_t/S + 5.888$$

The back-calculated lengths for *S. rivulatus* are shown in Table (1a). The lengths at end of age I, II, III and IV were 10.3, 14.1, 16.85, 19.027 cm, respectively. The average of length at each age, the annual increment in cm and the percentage of annual increment (%) to the maximum obtained length were calculated. The highest growth in length was recorded in the first year, then it decreased gradually with age. The percentage of increment at first year was 49.33 %, then decreased gradually in the following age groups (18.33, 17.1 and 14.28) %.

The back-calculated weight at the end of each year of life was obtained by applying the back-calculated length to the corresponding length–weight equation of $W=0.0085L^{3.1825}$ **(Abdelhak *et al.*, 2020b)**. The calculated weights were 14.22, 38.62, 68.09 and 100.23 g at the end of I, II, III and IV, respectively. The averages back-calculated weights at the end of each year, the annual increments in weight (gram) and the percentage of the weight increment of the maximum calculated weight were obtained (Table 1b). Notably, the annual increments increased with age. The lowest rate of weight growing was recorded at first year (11.34%) in Suez Canal, then it increased gradually as 19.28, 27.86 and 41.52% at age II, III and IV, respectively.

Table (1) Back-calculated lengths (a) and weight (g) at the end of each year of *S. rivulatus* in Suez Canal.

(a)

Age	No.	Observed length by otolith	Back calculation L at the end of each year			
			I	II	III	IV
I	40	10.93	10.3			
II	29	14.80	9.73	14.1		
III	32	17.58	9.38	13.07	16.85	
IV	32	19.75	8.87	12	15.77	19.027
Average			9.57	13.06	16.31	19.027
Annual Increment (cm)			9.39	3.49	3.253	2.717
Percentage of increment (%)			49.33	18.33	17.1	14.28

(b)

Age	No.	Observe weight (g)	Back calculation weight at the end of each year			
			I	II	III	IV
I	40	17.17	14.22			
II	29	45.06	11.86	38.62		
III	32	77.93	10.55	30.34	68.09	
IV	32	112.87	8.83	23.12	49.15	100.23
Average			11.37	30.69	58.62	100.23
Annual Increment (g)			11.37	19.32	27.93	41.61
Percentage of increment (%)			11.34	19.28	27.86	41.52

- Age composition

Frequency percentage of different age groups was close to each other in Suez Canal population (Fig. 5), ranged from 21.8% of age II to 30.08% of age I, whereas age III and IV were the same percentage (24.06%).

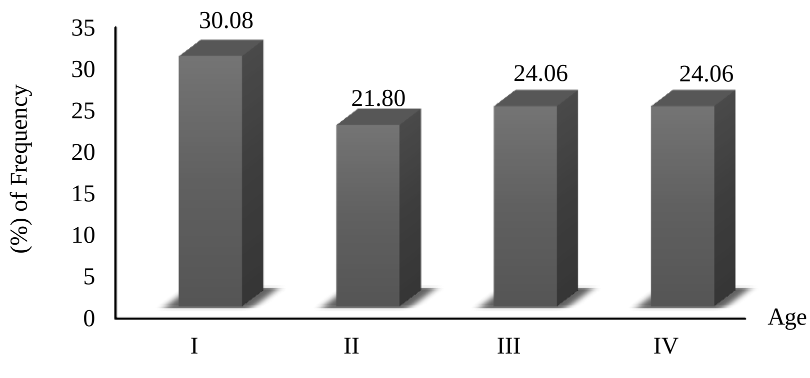


Fig. 5 Frequency of age composition of *S. rivulatus* in studied area according to the observed length by otolith.

- Growth parameters estimation

The constants of L_∞ and K, estimated by Ford-Walford and Chapman methods, had the same values; L_∞ = 25.353cm - K=0.288 y^{-1}. Whereas, Gulland and Holt method gave slightly higher values of L_∞ (25.361) cm and slightly smaller values of K (0.289) y^{-1} (Fig. 6). The values of t_0 (size at which the fish would theoretically be zero of age) was calculated from the Figure (7). The average of the von Bertalanffy growth model parameters for *S. rivulatus* was L_∞= 25.356cm, K= 0.288y^{-1} and t_0 = -0.81 year.

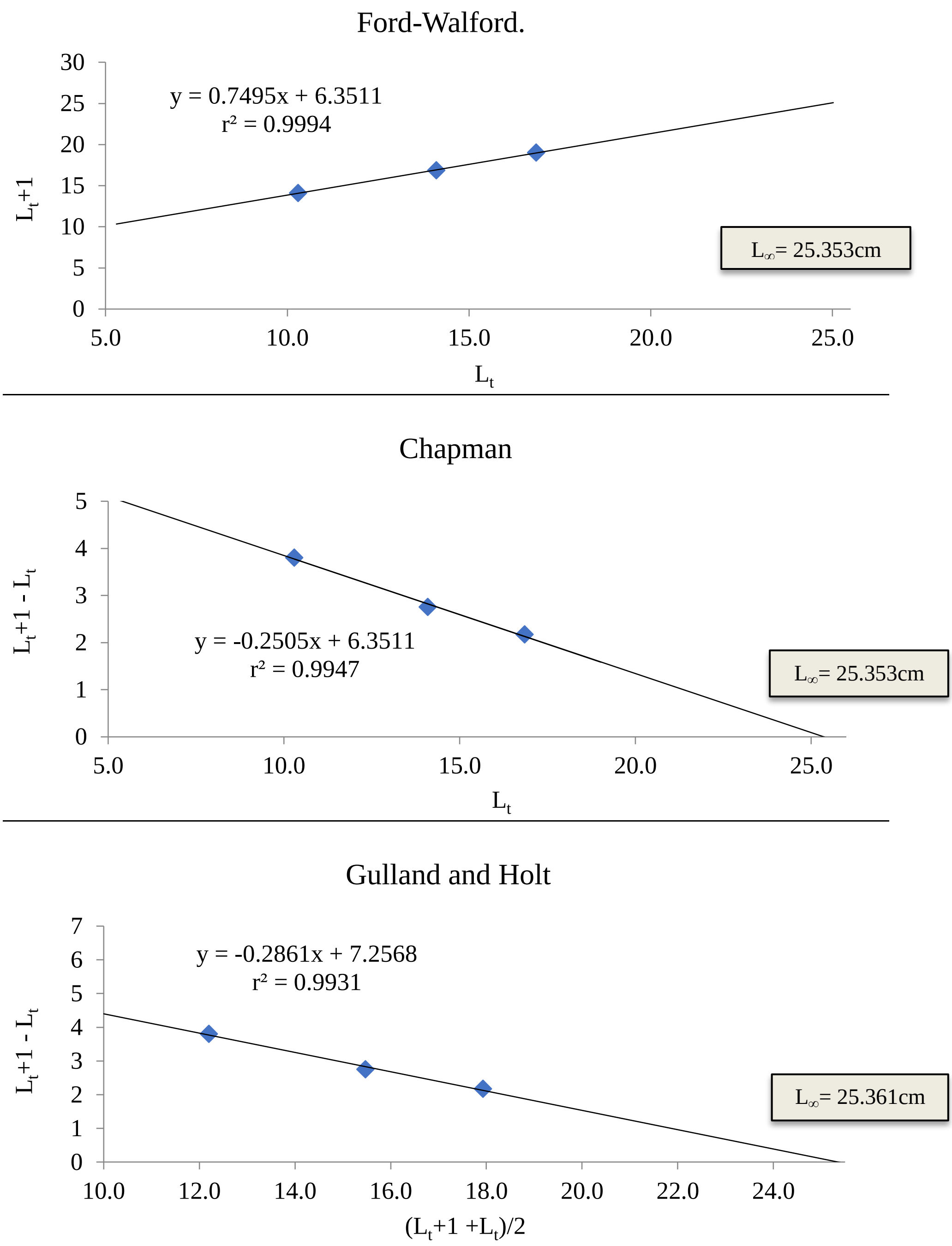


Fig. (6) Estimation of growth parameters (K & L_∞) of *S. rivulatus* in Suez Canal by three different methods; Ford–Walford plot, Chapman and Gulland and Holt.

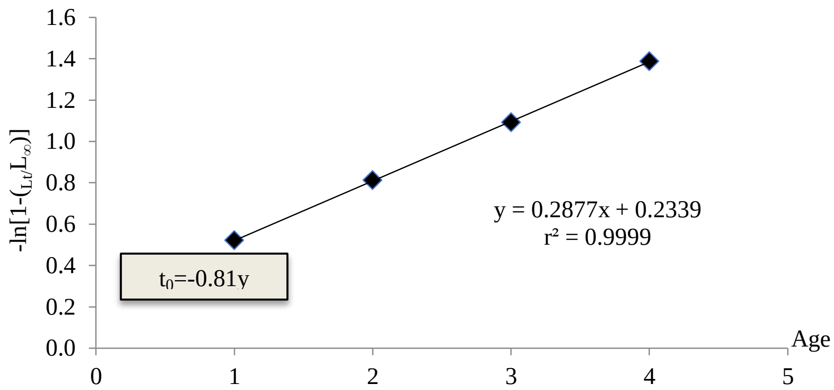


Fig. 7 Von Bertalanffy plot of *S. rivulatus* at the Suez Canal.

- **Growth performance index (*Φ*)**

The computed growth performance index (*Φ*) was estimated at 2.267.

- **Mortality Estimation**

Total mortality coefficient (Z) was estimated by applying the length-converted catch curve. The points used for calculation were those of the fully recruited part of the catch on the descending right limb of the catch curve (Fig. 8). The result of Z was 1.57 $year^{-1}$. Natural mortality coefficient (M) was estimated at 0.573 $year^{-1}$ using the maximum absolute age of 10.41 years. Fishing mortality coefficient (F) was estimated at 1.002 $year^{-1}$

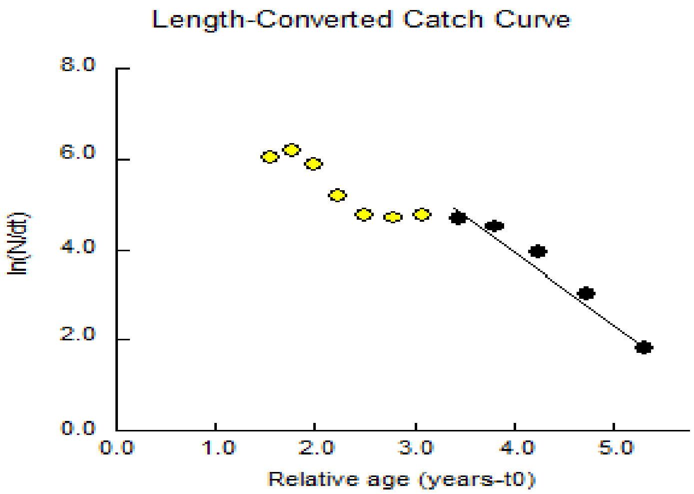


Fig. 8 Total mortality coefficient (Z) estimation of *S. rivulatus* from length-converted catch curve.

- **Exploitation rate (E)**

Using the obtained results of Z and F of *S. rivulatus* in the Suez Canal led to the following exploitation rates: E= 0.636y^{-1}.

- **Length and age at first capture (L_c & t_c)**

The length at the first capture (L_c) value was 12.838 cm, and the corresponding age at first capture (t_c) which marked the beginning of the exploited phase was 1.641 year. All population parameters (L_∞, K, t_0, W_∞, *Φ*, M, F, Z, L_c, L_m, E, t_c and t_{max}) of *S. rivulatus* collected from the Suez Canal are summarized in Table (2).

Table 2 Estimated population parameters of the rabbit fish *S. rivulatus* in Red Sea, Suez Canal and Mediterranean Sea.

L_∞ (cm)	K (y^{-1})	t_0 (y^{-1})	W_∞ (g)	Φ	M (y^{-1})	F (y^{-1})	Z (y^{-1})	L_c (cm)	L_m (cm)		E (y^{-1})	t_c (y^{-1})	t_{max} (y^{-1})
									male	female			
25.356	0.288	-0.81	249.97	2.267	0.573	1.002	1.575	12.838	14.5	15.15	0.636	1.641	10.411

Relative Yield and Biomass per Recruit (Y'/ R) & (B'/ R)

For a series of exploitation rate (E= F / Z) from 0.05 to 1.00 as a variable input parameter, the resulting relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) are represented in Figure (9). Then, values of E_{max}, $E_{0.1}$ and $E_{0.5}$ were estimated by using the first derivative of this yield function with the present value of exploitation rate as shown in figure (9). The maximum (Y\`/R) was obtained at E_{max}= 0.729 y^{-1}. The values of $E_{0.1}$ of *S. rivulatus* was 0.618 y^{-1}, while $E_{0.5}$ was estimated at 0.355 y^{-1}.

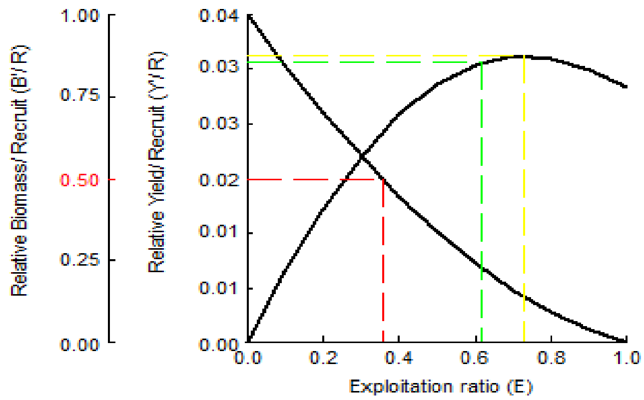


Fig. 9 Relative yield per recruit (Y\`/R) and biomass per recruit (B\`/R) of *S. rivulatus* collected from Suez Canal.

DISCUSSION

The results of seasonal length frequency distribution in Suez Canal revealed that the smallest individuals (<11 cm) were collected during spring and constituted about 45.41% of the population, referring that the recruitment occurs during this season. That finding is in parallel with the observation of **Abdelhak *et al.* (2020a)** considering spring as the spawning season.

The present modal length of *S. rivulatus* was smaller than that recorded in a previous study in a similar location; 18cm at Bitter lake **(El-Drawany, 2015)**. The variability in the most frequented length could be due to various fishing gears used in sampling, as reported in the study of **El-Far (2008)**, who recorded a difference in the most frequented length of *S. rivulatus* at the same site and time (13, 16 and 17 cm) caught by nylon trammels with different mesh sizes (2.08, 2.27, 2.5 cm, respectively).

Age determination is one of the most important parameter to evaluate the population structure and the state of exploited resources **(Allain & Lorance, 2000)**, and it forms the basic knowledge required for fisheries management. Otoliths are more suitable and satisfactory to determine fish age, as they appear earlier than scales and are more difficult to be damaged **(Gulland, 1958; Williams & Bedford, 1974)**. As showed in many previous studies of *S. rivulatus* **(El-Gammal, 1988; Mohammed, 1991; Bariche, 2005; El-Far, 2008; Shakman *et al.*, 2008; El-Drawany, 2015)** which used otolith in age determination, only one ring was formed annually, and composed of an opaque and translucent zone. While the opaque zone on the otoliths were formed during a rapid growth, the translucent zone corresponded to a slow growth of the fish. **Bariche (2005)** recorded a rapid growth in *S. rivulatus* exposed to high temperature (above 17°C), and a slow growth at lower temperatures(less than 17°C). The previuos author added that although water temperature has an influence on growth rate of the fish, there are other factors that radically affect fish growth, namely; seasonal availability of algal resources and spawning season **(Bariche *et al.*, 2003)**.

The age composition of the sample is rather similar to the actual population composition **(El-Far, 2008)**. The present findings revealed that the abundance of age group I (30.08%), followed by age III and IV with the same percentage (24.06%), was relatively similar to the observation of dominance of age III (27.6 and 28.1 % for male and female, respectively) in Bitter Lake **(El-Drawany, 2015)**.

The maximum age, assigned for *S. rivulatus* in Suez Canal in the present study, was 4years (8-22cm, TL), in congruent with that found by some authors in other locations; as in the Red Sea **(El-Gammal, 1988; El-Ganainy & Ahmed, 2002; Gabr *et al.*, 2018)** and the Mediterenean **(Mohammed 1991; El-Okda, 1998)**. On the other hand, **El-Far (2008)** recorded a higher maximal age of 5 years in Alexandria. Whereas a miximum age of 6 years was recorded in the studies of **Mouneimné (1978)** and **Bariche (2005)** in Lebanon, **Hashem (1983)**and **Shiekh-Eldin (1988**) in Saudi Arabia and **Shakman *et al* (2008)** in Libya. Additionally, a 7 years of age was observed **(Yeldan & Avşar, 1998)** in Turkey. These differences in age determination may be related to the sampling technique, the range of lengths of capture samples, or the method used in age determination **(Bariche, 2005)**. That was proved in the observation of **Bilecenoglu and Kaya (2002)**,who using a posterior body scale reading, reported a maximum age of 8 years, with 20 cm total length for fish. The same length was recorded for fish of 3 or 4 years in other researches **(Hussein, 1986; Mohammed, 1991; Bariche, 2005; El-Far, 2008)**.

In comparison with the only study conducted on the same region, the maximum age was less than that found in Bitter Lakes in the study of **El-Drawany (2015)**; 6 years old fish (10-27cm, TL) with longer back calculated length; 10.46, 14.15, 17.68, 20.19, 23.44 and 25.36 cm for male, and 10.32, 15.5, 20.35, 21.56, 23.12 and 24.97 cm for female. That result was in agreement with the present observation with respect to the fish length during the first year of its life, noting a sharply decrease in the rate of length growth at the second year, followed with a gradual decrease with the increase of age.It is worthy to mention that the differences in age determination may be related to the sampling technique, the range of lengths of capture samples, or the method used in age determination **(Bariche, 2005)**. Contrarily, back calculations weight results showed gradual increasing in the weight growth rate of *S. rivulatus* with age in all studied areas. The same observation was reported in Alexandria coast by **El-Far (2008)**, **El-Drawany (2015)** in Bitter Lakes and **Gabr *et al.* (2018)** in Red Sea, who recorded an increase in the growth rate of the weight in the first two or three years followed by a decrease.

Many investigators suggested various methods to compute the constants of the von Bertalanffy growth parameters (L_∞, K and t_0) such as; **Ford (1933)**, **Walford (1946)**, **Gulland and Holt (1959)**,and **Chapman (1961)**. The three followed methods in this study were of **Tomlinson and Abramson (1961)**, **Fabens (1965)**, **Allen (1966)**, **Gulland (1969)**, **Rafail (1973**) and **Wetherall (1986)**. These growth parameters are the basic input data required to construct the managing strategy of the exploited fish stock. That can be used in the comparisons between growth of different species or between the same species at different habitats and different times **(Farrag, 2008)**.

The theoretical maximal length (25.356cm) seems to be realistic, since the longest sampled specimen were 21.1 cm. It was longer than that recorded in Turkey by **Yeldan and Avşa (1998)** and **Bilecenoglu and Kaya (2002)**. Moreover, it was less than L_∞, as recorded in many other regions; the Mediterranean Sea recording a range of 27.7-48.96 cm (**Mouneimne´, 1978**; **El-Okda, 1998**; **Bariche, 2005**; **Shakman *et al.*, 2008**; **Ergenler, 2016**; **Soykan *et al.*, 2020)**, and Red Sea with range of 29.41-38.16 cm **(El-Gammal, 1988**; **El-Okda, 1998**; **El-Ganainy & Ahmed, 2002**; **Gabr *et al.*, 2018**). In addition, **El-Drawany (2015)** recorded higher values of 36.5 and 35.5 cm for male and female, respectively, in Bitter Lakes. Results showed a higher growth coefficient (K= $0.288y^{-1}$) and growth performance index (Φ= 2.267) in Ismailia region, compared to those in Bitter Lake (K= 0.079-0.085 y^{-1} and Φ= 2.02). The theoretical maximal weight was not observed in Suez Canal before, but generally, W_∞ was within ranges of the studies performed on *S. rivulatus* in Mediterranean Sea and smaller than those in Red Sea.

Such variations in growth parameters can be attributed partially to the difference in size of the largest individual sampled and different observed total lengths in each study, but more likely represent epigenetic responses of the species to the different environmental conditions prevailing in different areas and times **(Bagenal & Tesch, 1978; El-Ganainy & Ahmed, 2002)** such as; salinity **(Popper & Gundermann, 1975)**, food **(Golani, 1993)** and temperature **(Bruton, 1990)**. **Weatherley & Gill (1987)** reported effect of water temperature directly on fish growth through affecting the physiology of the fish and **Ross (1988)** observed that cool waters produce larger, older and later maturing individuals of species than warm waters.

As known, the effective management of a fish stock is essential for its conservation **(Beverton & Holt, 1957)**. Such a conservation can be achieved by the equilibrium between rates of its birth, growth and death **(Farrag, 2008; Abd-Allah, 2015)**. Thus, to estimate population parameters such as; mortality, length and age at first capture, length and age at first recruitment and exploitation rates is important to detect over fishing on the present *S. rivulatus* stock in Suez Canal, and also contribute to its fishing management strategies **(Zhang *et al.*, 2017)**. Comparison of the mortality rates between different locations is difficult as the total mortality coefficient is not a species-specific parameter, but an area specific parameter **(El-Ganainy & Ahmed, 2002).**

The exploitation rate (E) is defined as the ratio of fishing mortality (F) to total mortality (Z). The optimum fishing mortality in an exploited stock should equal the natural mortality (F=M) that generates E=0.50 **(Gulland, 1971)**. The exploitation rate ,higher than 0.5, indicates an unsustainable fishery stock, that suffers from overexploitation (overfishing) and decline in stock biomass **(Patterson, 1992)**.

Froese *et al.* (2016) suggested the ratio of F ≈ 0.5M as the precautionary target for a sustainable fishery.

The exploitation rate of $0.636y^{-1}$ proved that the stocks of *S. rivulatus* is overexploited in Suez Canal. Although the mortality rates in Bitter lakes were smaller than that in this study (M=0.221, Z= 0.884 and F=0.663 y^{-1}), the overexploitation of $0.75y^{-1}$ also was observed (**El-Drawany, 2015)**. Overexploitation of *S. rivulatus* was reported in many regions: in Alexandria coast ($0.815y^{-1}$) by **El-Far (2008)**, inGulf of Suez ($0.55y^{-1}$) by **El-Ganainy and Ahmed (2002)**; and inJeddah ($0.8y^{-1}$) by **Gabr *et al.* (2018**). On the other hand, the exploitation rate on Turkish coasts was slightly above 0.5, as recorded in Aegean Sea ($0.52y^{-1}$) by **Cerim *et al.* (2020)**, and it was approximately in the safe side in İskenderun Bay ($0.474y^{-1}$), as recorded by **Ergenler (2016)**. This phenomenon is related to the less fishing pressure compared to the lower latitudes as *Siganus rivulatus* is not the target species in Turkey **(Cerim *et al*., 2020)**.

Since the length at first capture (L_c) was found to be smaller than lengths of first maturation (L_m), harvesting of small pre-spawning fishes would cause a greater reduction in the stock. To maintain fish population, it is important to give a chance to each individual to reproduce at least one time in its lifespan to renew the stock, and therefore, the length at first capture should be bigger than the length at first sexual maturity. **El-Drawany (2015)** recorded higher L_c (16.4cm) in Bitter Lakes.

Future yields and stock biomass levels are the basic elements in assessing any fish stock. These levels can be predicted by means of mathematical models. The aim of the modeling exercise is to accurately predict changes in population abundance as a result of various fishing strategies. The prediction models can be used to forecast the effects of development and management measures, such as increases or reductions of fishing fleets, changes in minimum mesh size, closed seasons and closed areas. Therefore, these models form a direct link between fish stock assessment and fishery resource management.

The results indicated that the current value of the exploitation rate (E_{curr}) in Suez Canal is higher than the exploitation rate $E_{0.1.}$ Consequently, this generates economic yield per recruit (the level of exploitation at which the marginal increase in yield per recruit reaches 1/10 of the marginal increase and much higher, approximately double, of the $E_{0.5}$ (exploitation rate that conserve 50% of the spawning biomass), and near to E_{max}, the maximum yield per recruited (as the exploitation rate increases beyond this value the relative yield per recruit decreases). This is an indicative that the fishing pressure exerted has exceeded the critical levels, and that the *S. rivulatus* populations are suffering from overfishing. If this intensive fishing activities continued to meet a desire of fishermen and consumer without a management plan for the resources, *S. rivulatus* stocks will decline drastically within a certain time.

Finally, the stock of *S. rivulatus* can be conserved by some urgent actions; reduce the exploitation rate in Suez Canal from 0.636 to 0.355 y^{-1}, by eliminating fishing effort to maintain a sufficient (50%) spawning stock biomass. In addition, a map should be prepared for the spawning and nursery grounds and times to periodic spatial closure of the spawning and nursery areas, and restrictions on the size of the captured fish to give each individual a chance to reproduce once at least. Finally, the effects of the upper-mentioned factors are recommended to be considered for further study as a management strategy.

REFERENCES

Abd-Allah, E.M. (2015). Some fisheries and biological studies on the areolate grouper *Epinephelus areolatus* (Family, Serranidae) from the Gulf of Suez (M.Sc. Thesis). Zoology Department, Faculty of Science, Al-Azhar University, Egypt.

Abdelhak, E.M.; Madkour, F.F; El Ganainy, A.A; Abu El-Regal, M.A. and Ahmed, M.I. (2020a). Reproductive biology of *Siganus rivulatus* (Forsskal, 1775) in the Red Sea, Suez Canal and the Mediterranean Sea, Egypt. Egyptian Journal of Aquatic Biology & Fisheries, 24(6): 117-134. DOI: 10.21608/ EJABF. 2020.110701

Abdelhak, E.M.; El Ganainy, A.A; Madkour, F.F; Abu El-Regal, M.A. and Ahmed, M.I. (2020b). Comparative study on morphometric relationships and condition factor of *Siganus rivulatus* inhabits the Red Sea, Suez Canal and the Mediterranean Sea, Egypt. Egyptian Journal of Aquatic Biology & Fisheries, 24(7): 955-972. DOI: 10.21608/ejabf.2020.131399

Aleem, A. (1969). Marine resources of the United Arab Republic. General Fisheries Council for the Mediterranean (FAO), 43: 1-22. https://www.un.org/ Depts/ los/general_assembly/contributions_2015_2/ESCWA_Contribution.pdf

Allain, V. and Lorance, P. (2000). Age estimation and growth of some deep-sea fish from the northeast Atlantic Ocean. Cybium, 24: 7-16.

Allen, K.R. (1966). A method of fitting growth curves of the Von Bertalanffy type to observed data. Journal of the Fisheries Board of Canada, 23(2): 163-179.

Arreguín-Sánchez, F. (2000). Octopus–red grouper interaction in the exploited ecosystem of the northern continental shelf of Yucatan, Mexico. Ecological modelling, 129(2-3): 119-129.

Bagenal, T.B. and Braum, E. (1978). Eggs and early life history. International Biological Program Hand-Book No.3. Methods for assessment of fish production in fresh waters, 101-103.

Bariche M. (2005). Age and growth of Lessepsian rabbitfish from the eastern Mediterranean. J. App. Ichthyol., 21: 141-145. DOI: 10.1111/j.1439-0426. 2004.00619.x

Bariche M.; Letourneur, Y. and Harmelin, M. (2004). Temporal fluctuations and settlement patterns of native and Lessepsian herbivorous fishes on the Lebanese coast (eastern Mediterranean). Environmental Biology of Fishes, 70: 81-90.

Bariche, M.; Harmelin-Vivien, M. and Quignard, J.P. (2003). Reproductive cycles and spawning periods of two Lessepsian siganid fishes on the Lebanese coast. Journal of Fish Biology, 62(1): 129-142. http://doi:10.1046/j.1095-8649.2003.00014.x

Beverton, R.J.H. and Holt, S.J. (1956). A review of methods for estimating mortality rates in fish populations, with special references to sources of bias in catch sampling. Rapp. P.-V. Réun. CIEM, 140: 67-83.

Beverton, R.J.H. and Holt, S.J. (1957). On the dynamics of exploited fish populations. Fish. Invest., London Ser., 11: 583p. DOI:10.1007/978-94-011-2106-4

Bilecenoglu, M. and Kaya, M. (2002). Growth of marbled spinefoot, *Siganus rivulatus*, Forsskål, 1775 (Teleostei: Siganidae) introduced to Antalya Bay, eastern Mediterranean Sea (Turkey). J. Fish. Res., 54(2): 279-285. DOI: 10.1016/S0165-7836(00)00296-4

Bruton, M.N. (1990). The conservation of the fishes of Lake Victoria, Africa. An ecological perspective, Springer.

Cerim, H.; Soykan, O. and Gülşahin, A. (2020). Mortality and exploitation of marbled spinefoot, *Siganus rivulatus* (Actinopterygii: Perciformes: Siganidae), from southern Aegean Sea small-scale fishery. Acta Ichthyol. Piscat., 50(2): 183-190.

Chapman, D.G. (1961). Statistical problems in dynamics of exploited fisheries populations. Proc. 4th Berkeley Symp. Math. Stat. Prob. Cont. Biol. Prob. Med., 4: 153-168.

Ehrhardt, N.M. and Deleveaux, V.K. (2007). The Bahamas' Nassau grouper (*Epinephelus striatus*) fishery–two assessment methods applied to a data–deficient coastal population. Fisheries Research, 87(1): 17-27.

El-Drawany, M. (2015). On the biology of *Siganus rivulatus* inhabits Bitter Lakes in Egypt. J Aquac. Res. Dev., 6(6), 342p. DOI: 10.4172/2155-9546.1000342

El-Far, A.M.M. (2008). Artisanal fisheries along Alexandria coast area with special reference to the fishery biology of *Siganus* spp. (M.Sc. Thesis), Department of Zoology, Faculty of Science, Zagazig University, Egypt.

El-Gammal, F.I. (1988). Age, growth and mortality of the rabbit fish *Siganus rivulatus* (Forsskål, 1775), from the Red Sea. Bull. Inst. Oceanogr. Fish. ARE., 14: 13-21.

El-Ganainy A.A. and Ahmed, A.I. (2002). Growth, mortality and yield -per- recruit of the rabbitfish, *Siganus rivulatus*, from the eastern side of the Gulf of Suez, Sinai Coast, Red Sea, Egypt. Egypt. J. Aquat. Biol. Fish, 6(1): 67-81.

El-Okda, N.I. (1998). Comparative studies on certain biological aspects of *Siganus* in marine waters of Egypt (Ph.D. Thesis). Fac. Sci. Zagazig, Univ.

Ergenler, A. (2016). The Investigation of Some Biological Characteristics of Marbled Spinefoot (*Siganus rivulatus* (Forsskal 1775)) Living in Iskenderun Bay (M.Sc. Thesis). İskenderun Teknik Üniversitesi, Mühendislikve Fen Bilimleri Enstitüsü, 53p.

Fabens, A.J. (1965). Properties and fitting of the Von Bertalanffy growth curve. Growth, 29(3): 265-289.

Farrag, E.F.E. (2008). Population dynamics and management of some sparid fish species in Abu Qir-Bay (M.Sc. Thesis). Faculty of Science, Alexandria University, Egypt.

Fischer, W. and Bianchi, G. (1984). FAO species identification sheets for fishery purposes. Western Indian Ocean (Fishing Area 51), FAO, Rome, (2): 1-6.

Ford, E. (1933). An account of the herring investigations conducted at Plymouth during the years from 1924 to 1933. J. Mar. Biol. Assoc., U.K., 19: 305-384.

Froese, R.; Winker, H.; Gascuel, D.; Sumaila, U. R. and Pauly, D. (2016). Minimizing the impact of fishing. Fish and Fisheries, 17(3): 785-802. DOI: 10.1111/faf.12146

Gabr, M.H.; Bakaili, A.S and Mal, A.O. (2018). Growth, mortality and yield per recruit of the rabbit fish *Siganus rivulatus* (Forsskål 1775) in the red sea coast of Jeddah, Saudi Arabia, International Journal of Fisheries and Aquatic Studies, 6(1): Part B

GAFRD (2019). General Authority for Fishery Resources Development, Fish Statistics Yearbooks Ministry of Agriculture and Land Reclamation, Cairo, Egypt.

Gayanilo, Jr.F.C. and Pauly, D. (1997). The FAO ICLARM stock assessment tools (Fi-SAT) reference manual. FAO computerized information series: fisheries., No. 8, FAO, Rome, 262p.

George, C.J.; Athanassiou, V.A. and Boulos, I. (1964). The fishes of the coastal water of Lebanon, Misc. Pap. Nat. Sci. Am. Univ. Beirut, 4: 27.

Golani, D. (1990). Environmentally-induced meristic changes in Lessepsian fish migrants, a comparison of source and colonizing populations, Bull. Inst. Océanogr. (Monaco) Spécial Issue, 7: 143-152.

Golani, D. (1993). Trophic adaptation of Red Sea fishes to the eastern Mediterranean environment - review and new data. Isr. J. Zool., 39: 391-402.

Gulland, J. (1971). Science and fishery management. ICES. Journal of Marine Science, 33(3): 471-477.

Gulland, J.A. (1958). Age determination of cod by fin rays and otoliths. International Commission for the Northwest Atlantic Fisheries, Special Publication, 1: 179-190.

Gulland, J.A. (1969). Manual of methods for fish stock assessment: Part 1 Fish population analysis. FAO Manuals in Fisheries Science, 4: 154p.

Gulland, J.A. and Holt, S.L. (1959). Estimation of growth parameters for data at unequal time intervals. J. Cons. Perm. Int. Explor. Mer., 25(1): 47-49.

Hashem, M.T. (1983). Biological studies on *Siganus rivulatus* (Forsk.) in the Red Sea, Journal of the Faculty of Marine Science, Jeddah 3: 119-127.

Hassan, M.; Harmelin-Vivien, M. and Bonhomme, F. (2003). Lessepsian invasion without bottleneck: example of two rabbitfish species (*Siganus rivulatus* and *Siganus luridus*), J. Exp. Mar. Biol. Ecol., 291: 219-232.

Holden, M.J. and Raitt, D.F. (1974). Manual of fisheries science. Part 2. Methods of resource investigations and their application. FAO Fish. Tech. Pap., 115(1): 214p.

Hussein, K.A. (1986). Timing of spawning and fecundity of Mediterranean *Siganus rivulatus* Forsskal. Bulletin of the Institute of Oceanography and Fisheries, Cairo, 12: 175-186.

Lee, R.M. (1920). A review of the methods of age and growth determination in fishes by means of scales. Fishery Investigations, Ministry of Agriculture and Fisheries, Ser. 2, 4(2): 1-32.

Mohammed, N.I. (1991). Biological and biochemical studies of some siganid fishes from the Mediterranean waters off Alexandria (M.Sc. Thesis). Faculty of Science, Alexandria University.

Mouneimné, N. (1978). Poissons des côtes du Liban (méditerranée Orientale), biologie et pêche. Thèse de doctorat d' Etat ès-Sciences Naturelles. Université Pierre et Marie Curie, Paris VI, France.

Papaconstantinou, C. (1990). The spreading of Lessepsian fish migrants into the Aegean Sea (Greece). Scientia Marina, 54: 313-316.

Patterson, K. (1992). Fisheries for small pelagic species: An empirical approach to management targets. Reviews in Fish Biology and Fisheries, 2(4): 321-338. DOI: 10.1007/BF00043521

Pauly, D and Munro, J.L. (1984). Once more on the comparison of growth in fish and invertebrate. International Center for Living Aquatic Resources Management, Fishbyte, 2(1): 1-21. http://pubs.iclarm.net/Naga/na_1951.pdf

Pauly, D. (1983). Some simple methods for the assessment of tropical fish stocks. FAO.

Pauly, D. (1984). Length-converted catch curves. A powerful tool for fisheries research in the tropics (part II), ICLARM Fishbyte, 2(1): 17-19.

Pauly, D. and Soriano, M.L. (1986). Some practical extensions to Beverton and Holt's relative yield-per-recruit model. In: Maclean, J. L. Dizon L. B. and Hosillo L. V. (eds). The First Asian Fisheries Forum, 491-496.

Popper, D. and Gundermann, N. (1975). Some ecological and behavioral aspects of siganid populations in the Red Sea and Mediterranean coasts of Israel in relation to their suitability for aquaculture. Aquaculture, 6: 127-141.

Por, F.D. (1978). Lessepsian migration: The influx of Red Sea biota in the Mediterranean by the way of the Suez Canal. Springer Verlag, Berlin, 228p.

Rafail, S. (1973). A simple and precise method for fitting a von Bertalanffy growth curve. Marine Biology, 19(4): 354-358.

Ricker, W.E. (1975). Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Canada, 191: 382p.

Ross, S.W. (1988). Age, growth, and mortality of Atlantic croaker in North Carolina, with comments on population dynamics. Transactions of the American Fisheries Society, 117(5): 461-473.

Shakman, E.A.; Winkler, H.; Oeberst, R. and Kinzelbach, R. (2008). Morphometry, age and growth of *Siganus luridus* Rüppell, 1828 and *Siganus rivulatus* Forsskål, 1775 (Siganidae) in the central Mediterranean (Libyan coast). Revista de Biología Marina Oceanografía, 43(3): 521-529. DOI:10.4067/S0718-19572008000300011

Shiekh-Eldin, M.Y (1988). Biological studies on certain marine teleosts (M.Sc. Thesis). Faculty of Science, Ain Shams University, Egypt.

Soykan. O.; Gülşahin, A. and Cerim, H. (2020). Contribution to some biological aspects of invasive marbled spinefoot (*Siganus rivulatus*, Forsskål 1775) from the Turkish coast of southern Aegean Sea. Journal of the Marine Biological

Association of the United Kingdom, 100(3): 453-460. https://doi.org/10.1017/S0025315420000351

Suradi, W.; Solichin, A.; Taufani, W.T. and Sabdono, A. (2017). Population dynamics of exploited species west shrimps P*arapenaeopsis coromandelica* H. Milne. Edwards 1837 from the Teluk Penyu coastal waters, Indonesian ocean. The Egyptian Journal of Aquatic Research, 43(4): 307-312.

Then, A.Y.; Hoenig, J.M.; Hall, N.G. and Hewitt, D. (2014). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. journal of Marine Science, 72(1): 82-92. https://doi.org/10.1093/icesjms/fsu136

Tomlinson, P.K. and Abramson, N.J. (1961). Fitting a Von Bertalanffy Growth Curve by Least Squares. Fishery Bulletin, California, 116: 1-69.

Udoh, J.P. and Ukpatu, J.E. (2017). First estimates of growth, recruitment pattern and length-at-first-capture of *Nematopalaemon hastatus* (Aurivillius, 1898) in Okoro River estuary, southeast Nigeria. Aquaculture, Aquarium, Conservation & Legislation, 10(5): 1074-1084.

Von Bertalanffy, L. (1938). A quantitative theory of organic growth. Hum. Biol., 10: 181-243.

Walford, L.A. (1946). A new graphic method of describing the growth of animals. Biol. Bull., 90(2): 141-147.

Weatherley, A. and Gill, H. (1987). Tissues and growth. The biology of fish growth, 147-175.

Wetherall, J. (1986). A new method for estimating growth and mortality parameters from length frequency data. Fishbyte, 4(1): 12-14.

Whitney, C.S. and Cohen, E. (1956). Guide for ultimate strength design of reinforced concrete. Journal Proceedings.

Williams, T. and Bedford, B.C. (1974). The use of otoliths for age determination. In: Baginal, T. B. (Ed). Proceedings of an International Symposium on the Ageing of Fish. Sponsored by EIFAC of FAO, Fisheries Society of the British Isles and the Freshwater Biological Association. Old Woking Surrey, the Gresham Press; Unwin Brothers Ltd., 114-123.

Yeldan, H. and Avşar, D. (1998). The identification of exploitation rate on the rabbitfish (*Siganus rivulatus* Forsskali 1775) stock from the northeastern Mediterranean (in Turkish). Ulusal Biyoloji Kongresi, Samsun, 2: 152-162.

Zhang, Y.; Chen, Y.; Zhu, J.; Tian, S. and Chen, X. (2017). Evaluating effectiveness of biological reference points for bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) fisheries in the Indian Ocean. Aquaculture and Fisheries, 2(2): 84-93. DOI: 10.1016/j.aaf.2017.01.004