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Length-based estimates of growth parameters and population structure of *Siganus rivulatus* (Forsskål, 1775) from the Gulf of Suez, Red Sea, Egypt

Hanan M. Osman*, Azza A. El Ganainy, Kariman A. Sh. Shalloof and **Tamer A. El-Betar**

National Institute of Oceanography and Fisheries (NIOF), Egypt

***Coresponding author: hanan_zxcv@yahoo.com**

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ABSTRACT

Siganus rivulatus is an economic species that has been proven to move from the Red Sea to the Mediterranean region via the Gulf of Suez and its vital canal. Clarifying the current status of this species in the Gulf of Suez is the goal of the current study. 1161 individuals (10-24 cm of total length) were collected and examined during the 2022 fishing season from Attaka fishing harbor, Suez. The distribution of length frequency indicated the predominance of small sizes (12 and 13 cm). Body weight and length indicated an isometric growth pattern. Body girth and length were found to be correlated significantly with a linear relationship (r^2= 0.824). The overall mean value of the condition factor (1.25) referred to a suitable habitat for growth. Four age groups were observed where 65% and 33.7% of the population belonged to the first and the second age groups, respectively. Von Bertalanffy growth parameters were estimated as 29.2 cm, 0.373y^{-1} and -0.902y^{-1} for L_{∞}, K and t_0, respectively. The growth performance index (Ø= 2.50) expresses a good fit for habitat. Mortality coefficients indicated a high value of fishing mortality (F=1.62 y^{-1}), exceeding the biological reference points. The length at first capture (14.90 cm) was less than that of first maturity (17.90 cm) and the optimum length (17.71 cm). The exploitation rate's value (E= 0.69) confirmed the state of over-exploitation. The study recommended tightening control over landing points, preventing the fishing of illegal sizes, and also reducing fishing effort with a rate of 46.4% to preserve the stock.

INTRODUCTION

The Gulf of Suez is a highly productive fishing area, accounting for more than 60% of the Red Sea production in Egypt **(GAFRD, 2010-2020)**. This Gulf is a global shipping corridor that leads directly to the Suez Canal. It is considered a vital area that plays a pivotal role in the dynamics of fish populations. It is one of two arms of the Red Sea extending towards the eastern Mediterranean, allowing the exchange of species after the digging of the Suez Canal **(Golani & Bogorodsky, 2010)**. It extends for a length of 314 km and a maximum width of 32 km. The Gulf is characterized by intense human activities, represented by the passage of container ships and giant oil tankers, in addition to the presence of many oil fields and the industrial activities based on them **(Lindquist, 1998)**.

The Gulf of Suez is a habitat for many species shared with the Eastern Mediterranean region **(Osman *et al.*, 2019)**. Represented by 27 fish species, the siganidae family is widespread in the tropical and subtropical coastal waters of the Indian Ocean and Indo-Pacific **(Woodland & Randall, 1979)**. It's commonly known as rabbitfishes, where their jaws resemble a rabbit in appearance; in addition to peaceful behavior **(Prithiviraj &**

Annadurai, 2014). Siganids are diurnal herbivores, inhabiting along reef edges and sea grasses, where they graze individually or school according to species. The given family is characterized by small sizes and short life spine (4-6 years) **(Shakman *et al.*, 2008)**. Four *Siganus* species inhabits the Red Sea; S. *luridus*, *S. rivulatus*, *S. stellatus* and *S. argenteus*; where two species; *S. rivulatus* and *S. luridus*; invaded and settled in the eastern Mediterranean via the Suez Canal **(Ben-Tuvia, 1966)**.

Siganus rivulatus spread along the eastern coast of Africa, penetrating into the Red Sea. It's recorded firstly in the eastern Mediterranean, Palestine, in 1924. It's rarely lives alone, but rather in a school of several hundred **(Insacco & Zava, 2016)**. In Egypt, 1710 tons of *Siganus sp*. were captured annually **(GAFRD, 2010-2020)**, which currently depleted to 1258 tons **(GAFRD, 2010-2020)**. They can be easily found in markets and landing points in coastal areas.

Several countries have begun siganid mariculture researches **(Lam, 1974)**, where *Siganus* species are the most promising marine aquaculture fishes and have economic activity used as bio-control agents for aquatic weeds **(Jaikumar, 2012)**.

The biological aspects of *Siganus rivulatus* have been subject to many comparative studies in both the Mediterranean and the Red Sea populations **(Lundberg, 1989; Lundberg & Golani, 1995; Bariche, 2006** and **Shakman *et al.*, 2009)**; biological and population aspects in the Red Sea **(El-Gammal, 1988; El-Ganainy & Ahmed, 2002** and **Abdelhak *et al.*, 2020)** and genetic and biochemical studies **(Mohammed, 1991** and **Hassan *et al*., 2003)**.

This study aimed to concern with the updating population aspects of *Siganus rivulatus* in the Gulf of Suez. Such information could be employed for best planning of fishing in the Egyptian waters; moreover managing its stock in the areas of study. Such information is very important in Egyptian fisheries management strategies.

MATERIALS AND METHODS

Specimens sampling and measurements:

The study was conducted during the 2022 fishing season by collecting monthly samples from Attaka fishing harbor **(Fig. 1)**, with a total number of 1161 individuals of *Siganus rivulatus* **(Fig.2)**. Each fish total weight (g) and total length (cm) were recorded. Body girth (G) was measured as body diameter (cm) in front of the dorsal fin.

Fig. (1). Map shows the Gulf of Suez and sampling site (Attaka fishing harbor)

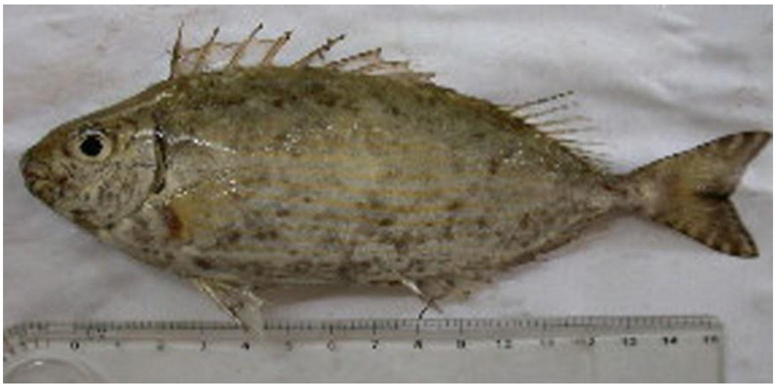

Fig. (2). Photograph showing *Siganus rivulatus*, rabbit fish, family: Siganidae

Data Analysis:

The relationship between length and weight was described by the potential equation of **Ricker (1975)**: $\mathbf{W = a\ L^b}$

Where: **W** is the total weight (g), **L** is the total length (cm) and **a** & **b** are constants.

The relationship between length and girth was estimated using equation:

$$\hat{G} = a + b \times L$$

Where: $\hat{G}$ is the observed girth (in front of the dorsal fin), **L** is the observed length and ***a*** and ***b*** are the intercept and regression coefficient (slope) respectively **(Santos *et al.*, 2006)**.

Fulton's condition factor was calculated monthly as:

$$K = (W * 100) / L^3$$

Where: **K** = condition factor, **W** = total weight (g) and **L** = total length (cm), according to **Hile (1936).**

Estimation of population parameters based on length frequency distribution using routines in FAO-ICLARM Stock Assessment Tools (FISAT) II software package **(Gayanilo *et al.*, 2005)**. In order to identify the different age groups (cohorts) and the mean length of each group, Battacharya's method **(Bhattacharya, 1967)** incorporated in the FISAT II software was applied. Asymptotic length (L_∞) and the growth coefficient (K) of the Von Bertalanffy Growth Formula (VBGF) were estimated by means of ELEFAN-I according to **Pauly & Morgan (1987)**, Then VBGF was fitted to estimates of length-at-age by the equation;

$$L_t = L_\infty [1 - e^{-k (t - to)}]$$

Where: L_t = mean length at age t, L_∞= asymptotic length, **K**= growth coefficient, **t**= age, t_0= age at which the length is theoretically zero **(Gayanilo *et al*, 2005)**.

The growth performance index (Ø) was calculated according to **Pauly (1983):**

$$Ø = \log K + 2*\log L_\infty$$

Where: L_∞ = the asymptotic length and **K** = growth coefficient.

Total mortality (**Z**) was estimated by length-converted catch curve method **(Pauly, 1983)** incorporated in the FISAT II software. Natural mortality (**M**) was estimated according to **Pauly (1980)** as:

$$\text{Log } M = [- 0.0066 - 0.279 \log L\propto + 0.6543 \log K + 0.4634 \log T]$$

Where: ($L_\propto$) and (**K**) are Von Bertalanffy parameters and (**T**) is average annual surface temperature. Fishing mortality **(F) =Z-M** and The exploitation rate **(E) =F/Z (Gulland, 1971)**.

The biological reference point (**BRP's**); Fishing mortality rate with target (F_{opt}) and fishing mortality limit (F_{limit}) were calculated using the two formulas described by **Patterson (1992)**, as follow:

$$F_{opt} = 0.5 M \text{ and } F_{limit} = 2 / 3 M$$

Where: **M**=Natural mortality.

The length at which 50% of the catch retains in the net (L_c) (length at first capture) was estimated from the catch curve analysis (probability of capture by length), according to **Pauly (1984 a & b)**. Length at first sexual maturity (L_m) was obtained according to **Froese & Binohlan (2000)** as follow:

$$\text{Log } L_m = 0.8979*\text{Log } L_\infty - 0.0782$$

The optimum length (L_{opt}) was calculated according to **Beverton (1992)** as follow:

$$L_{opt} = L_\infty * [3 / (3 + M/K)]$$

RESULTS

Size distribution

The range of 10 to 24 cm was observed for the total length of *S. rivulatus*. The frequency distribution of lengths showed that length groups 12 and 13cm were achieved the highest frequencies, constituting about 18.6 and 18% respectively, whereas length groups 22 and 24 cm were the lowest represented in the catch **(Fig. 3)**.

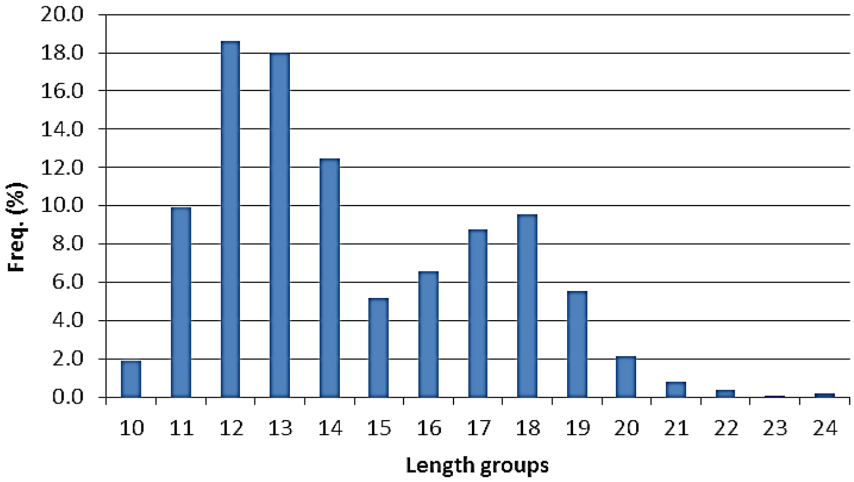

Fig. (3). Length frequency distribution of *S. rivulatus* from Suez Gulf, Red Sea, Egypt

Length-weight relationships and condition factor (K):

In the present study, 9.6 - 23.9 cm was the observed rang of total length of *S. rivulatus*. The total weight was ranged between 12.3 and 159g. The length – weight relationship was described by the power equation as: **W= 0.0118 L $^{3.0175}$** (R^2 = 0.9586), expressing an isometric growth pattern **(Fig. 4)**. For all length groups, average condition factor (K) varied between 0.86 - 2.04 and the mean K of *S. rivulatus* recorded in the present study was 1.25.

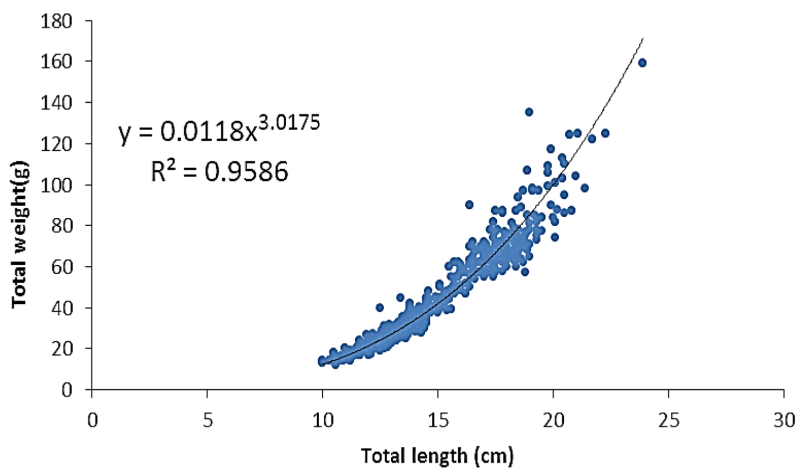

Fig. (4). Length weight relationship of *S. rivulatus* from Suez Gulf, Red Sea, Egypt.

Length- Girth Relationship:

The length-girth relationship of *S. rivulatus* **(Fig. 5)** was estimated and expressed in the following linear equation: **G = 0.6254+ 0.5173 L**

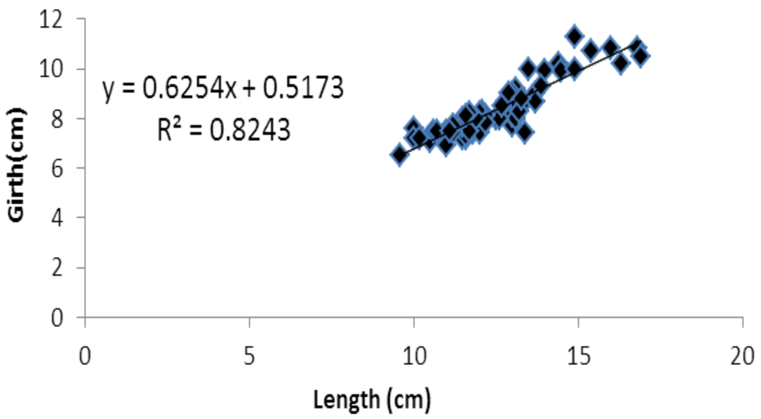

Fig. (5). The length-girth relationship of *S. rivulatus* from the Gulf of Suez.

Age and Growth

Plotting the decomposition of the length frequency distribution **(Fig. 6)** clarified four age groups; I^+, II^+, III^+ and IV^+; for *S. rivulatus* in the Gulf of Suez, which sharing about 65, 33.7, 0.7 and 0.3% of the population respectively **(Table 1)**. The maximum age (t_{max}) was detected as 8.04 years. Von Bertalanffy growth parameters were estimated as 29.2 cm, 0.373y^{-1} and -0.902y^{-1} for L_∞ and K and t_0 respectively. Theoretical growth in length was clarified as; L_t =29.2[1-e $^{-0.373 (t +0.902)}$]. The growth performance index was found to be 2.50.

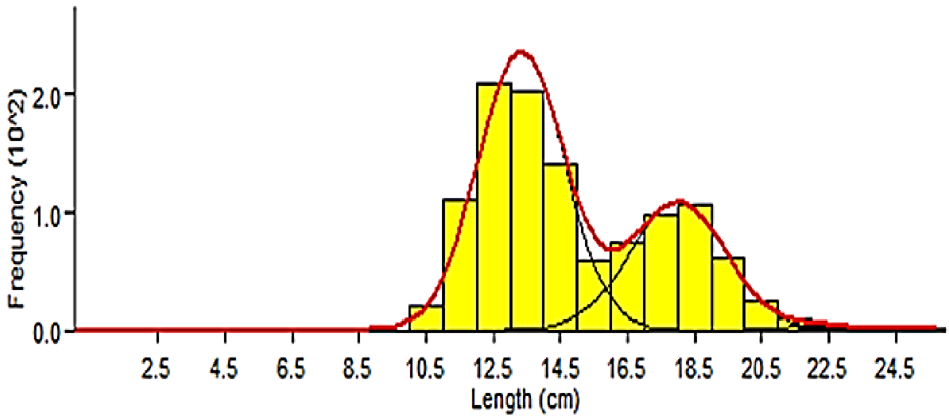

Fig. (6). Bhattacharya plot for the decomposition of the length frequency distribution of *S. rivulatus* from the Gulf of Suez, Egypt

Table (1): The estemated mean length at age of *S. rivulatus* in the Gulf of Suez, Egypt

Age group	Mean (L)	Population	Frequency	S.D.	S.I.
I	13.33	760	65	1.28	n.a
II	18.01	391.03	33.7	1.44	2.27
III	22.09	7.64	0.7	0.87	2.18
IV	24	3.28	0.3	1.25	1.98

Mortality

Applying the length converted catch curve showed that, mortality coefficients gave the following values; total mortality (Z) was 2.35y^{-1}, natural mortality (M) was 0.726 y^{-1}, fishing mortality (F) was 1.62 y^{-1} in addition to 1.95for M/K ratio **(Fig. 7)**.The biological reference points were calculated as; F_{opt}.= 0.363y^{-1} and F_{limit} = 0.484y^{-1}.

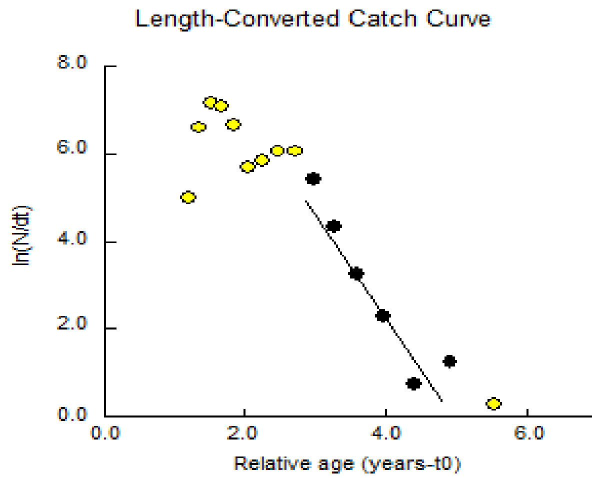

Fig. (7). Length converted catch curve based on length composition of *Siganus rivulatus* from Suez Gulf, Red Sea, Egypt

The length at first capture (L_c)

The potential length of 50% of the population being captured was estimated as 14.90 cm, which corresponding to an age of 1.95 year^{-1} **(Fig. 8)**. The length at first sexual maturity (L_m) was found to be 17.92cm, in addition to 17.71cm for the optimum length, which generate the maximum sustainable yield.

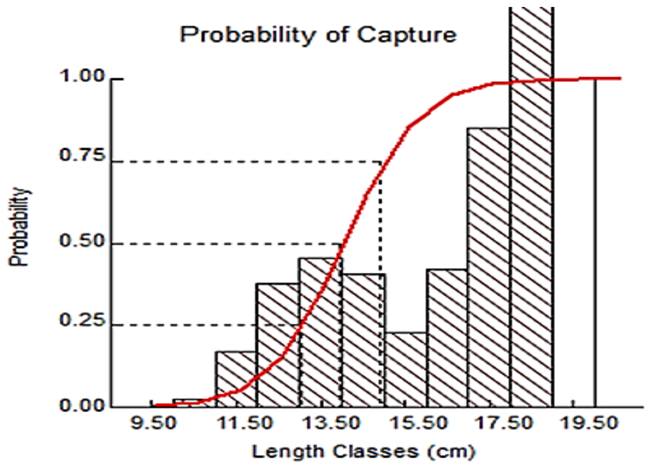

Fig. (8). Probability of capture of *S. rivulatus* from the Gulf of Suez, Egypt

Fishery assessment

The analytical model of relative yield per recruit was applied to clarify the current and optimal status of *S. rivulatus* stock in the Gulf of Suez. The value of relative yield per recruit (Y/R) was 0.033 at the current rate of exploitation (E = 0.69). The maximum sustainable yield would be achieve at an exploitation rate equal to 0.79, with the economic yield per recruit E_{10}= 0.653 and the yield per recruit that sustain 50% of the stock E_{50}= 0.368 **(Fig. 9)**.

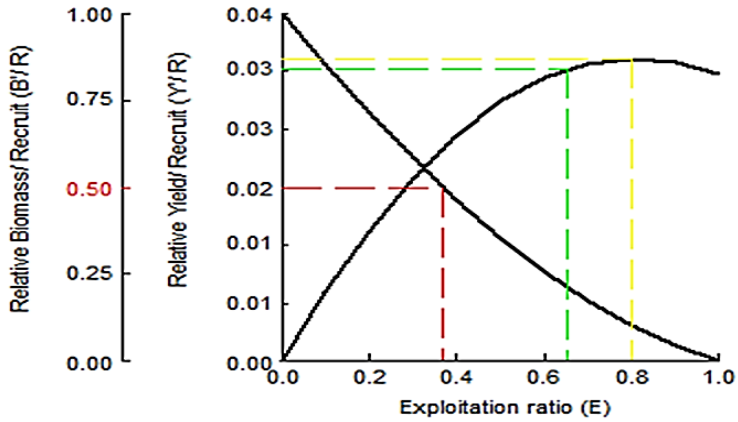

Fig. (9). Relative yield per recruit (Y/R) and relative biomass per recruit (B/R) of *S. rivulatus* from the Gulf of Suez, Egypt

DISCUSSION

The Gulf of Suez is a vital bioregion that is extremely important in the dynamics of fish populations and marine life, due to its direct connection to the eastern Mediterranean. The Gulf has a wide diversity of fish species and is considered the most important production area in the Red Sea. Siganidae is one of the commercially important families present in the Gulf, it's widespread, productive and popular with consumers **(Lam, 1974)**. We shed light on some population characteristics of a related species, *Siganus rivulatus.* Which mainly grasped by trammel and trawls net **(Saber & Gewida, 2020).**

The size structure of *S. rivulatus* in the Gulf of Suez revealed the predominance of small sizes, 12 and 13cm, constituting about 18.6 and 18% for each respectively, compared to the maximum observed length (24cm at 0.7%). Almost similar results were revealed by other studies of the same species, where 8-22cm was the obtained range of **Abdelhak *et al*. (2020)**, clarifying the predominance of individuals belongs to 10 and 12cm length groups in the Gulf of Suez and the Mediterranean Sea, respectively. Larger sizes were the most frequent in other regions; 16.2cm at Alexandria coast **(El-Far, 2008)**, 18cm at Bitter lake **(El-Drawany, 2015)**. The difference in the prevailing sizes may be due to the difference in fishing gears and sampling method **(El-Far, 2008** and **El-Betar *et al*., 2022).** Variation in size may be attributed to the decrease in fishing effort in that area, habitat preference, and food availability **(Atar & Seçer, 2003).**

Length and weight data and their multiple relationships are usually used to obtain biological indications related to the status of fisheries and stocks. These relationships are a standard and authentic method of evaluation **(Suresh *et al.*, 2006)**. Length- weight relationship of *S. rivulatus* in the Gulf of Suez showed an isometric growth pattern (b= 3.0175), within the range of **Gayanilo & Pauly (1997)**, expressing a symmetrical growth in length and weight. The same growth pattern was reported for *S. rivulatus* in the Red Sea **(Abdelhak *et al*., 2020** and **Saber & Gewida, 2020).** In contrast, **El-Gammal (1988)** reported a positive allometric growth pattern for the same species. Deviation from the usual growth pattern for a specific species may be due to genetic and environmental differences **(Abinawanto *et al*., 2018)**. The condition factor is considered one of the most important measures based on length and weight data, which gives a clear indication of the suitability of the environment for the studied species **(El-Far, 2008** and **Hile, 1936)**. In the present study, individuals of *S. rivulatus* showed a wide range of K, 0.85- 2.04, with overall mean 1.25, expressing general willbeing and suitable habitat. Closed results were reported for the same species (**Tharwat & Al-Owafier, 2003)**. The wide variation in the individual K value reflecting the diversity of sizes and therefore the needs, where larger sizes give priority to fill the stomach and develop the gonads, while smaller sizes have a higher growth rate and consequently, a higher K value. For the same size and location, temperature and biological activities are limiting factors in K value **(El-Far, 2008)**.

Body girth is an important morphometric measurement that essentially determines the characteristics and selectivity of the mesh used. It is also a biological indication of the general condition **(Daliri *et al*., 2012)**. In the current study, a linear relationship was found between body girth and total length, as body girth increases with length. For all individuals, girth was found to be correlated significantly with body length ($R=0.824$ & $P<0.05$). These results were in agreement with the finding of **Santos *et al*. (1998)** and **Stergiou & Karpouzi (2003)**.

S. rivulatus in the Gulf of Suez was represented by four age groups, where 65% of individuals were belonging to the first group. Many authors indicated five age groups for the same species in different locations; the Mediterranean Sea **(El-Far, 2008** and **Desouky *et al*., 2022)** and the Red Sea **(El-Gammal, 1988,** and **Gabr *et al*., 2018)**, and even six age groups in the findings of **Hashem (1983)** and **Shiekh-Eldin (1988)**. A relatively long lifespan of 8 years was observed in the current study compared to 5 years shown in other studies **(El-Gammal, 1988,** and **Desouky *et al*., 2022**). This may be due to the difference in the method of estimating age, location, sample size ranges and ecology **(Bariche, 2005)**.

The von Bertalanffy growth parameters were estimated, where the asymptotic length (L_∞) = 29.22cm and the growth coefficient (K) = 0.373 year^{-1}. Growth measurements are subject to change and vary according to age, sex, sexual maturity and location **(Amin *et al*., 2015)**.

The growth performance index was estimated as 2.50, indicating suitable habitat and favorable conditions for achieving good growth. The current value exceeds those of the same species in the Mediterranean; where the values of, 2.486 and 2.360 and 2.313 were reported by **El-Okda (1998), Bariche (2005)** and **El-Far (2008)**, respectively. This may be due to the suitability of the environment and the availability of food **(Gabr *et al*., 2018)**.

The estimation of mortality coefficients indicated the values of 2.35, 0.63 and 1.62 year^{-1} for total (Z), natural (M) and fishing mortality, respectively. The current value of fishing mortality sharply exceeds the optimal (0.363 year^{-1}) and the limit (0.484 year^{-1}) values of the biological reference points, which draws attention to the possibility of overfishing. M/K ratio was obtained as 1.946 according to **Beverton & Holt (1956)**, which falls within the normal range (1-2.5) of **Afzaal *et al*. (2016)**.

The length at first capture was observed as 14.90 cm, which corresponding to the age of 1.59 year^{-1} and is considered a young age for the observed age groups. The current value of Lc is lower than those reported for the same species in the Mediterranean sector, 15.6 cm **(El-Far, 2008)**. On the other hand, comparing the value of Lc with the length at first sexual maturity (L_m= 17.92cm), as well as the optimal length (L_{opt}= 17.71cm), reflecting the extent of population's suffering from overfishing. There is not enough opportunity to reproduce before captivity nor approaching maximum sustainable yield.

The results clarified that, continuing the current high level of the exploitation rate (E=0.69) and the fishing mortality (1.62 y^{-1}), will severely hinder achieving the maximum (Y/R). The current level of exploitation rate exceed the target level (E0.5= 0.37), which maintain 50% of the stock. The reduction of exploitation rate should be occurred from 0.69 to 0.37 with a rate of 46.4%.

Hard work must be done to reduce fishing effort in general and tighten control over landing sites and fishing ports to ensure compliance with the minimum allowable size of the catch.

CONCLUSION

The Gulf of Suez is a vital area for the dynamics of fish populations. Growth measurements reflect the suitability of the Gulf's habitat for *S. rivulatus*, through the values of the condition factor, the growth performance index and achieving a symmetrical growth pattern for length and weight. This was achieved in light of the exposure to overfishing, where 50% of the population was subject to capture before reaching sexual maturity. The occurrence of overexploitation was confirmed by the high values of both fishing mortality and exploitation rate, in addition to limited age groups. The study recommended tightening control over landing points, preventing the fishing of illegal sizes, and also reducing fishing effort to preserve the stock.

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