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

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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 \( L_\infty = 25.356 \) 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, some 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.
- **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** (\(L_\infty\) 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:

    \[
    - \ln \left[ 1 - \left( \frac{L_t}{L_\infty} \right) \right] = - k^*t_0 + k^* (Pauly, 1984)
    \]

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

- **Theoretical Growth estimation**

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

\[ L_t = L_\infty \left[1 - e^{-k(t-t_0)}\right] \]  \hspace{1cm} \text{(Growth in length, } L_t \text{)}

\[ W_t = W_\infty \left[1 - e^{-k(t-t_0)}\right]^b \]  \hspace{1cm} \text{(Growth in weight, } W_t \text{)}

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

$L_\infty$ & $W_\infty$ are the expected theoretical maximum total length and total weight.

$K$ is the coefficient of growth that determines the rate at which $L_\infty$ 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 ($\Phi$)**

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

\[ \Phi = \log_{10} K + 2 \log_{10} L_\infty \]  \hspace{1cm} \text{(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:

\[ Ln \left( n / \Delta t \right) = a + bt \]

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

($\Delta t$) 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 $Y = Ln \left( n / \Delta t \right)$, $X = (t_1 + t_2)/2$ 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 ($K$) ($t_{max} = 3/K$)

\[ M = 4.899 t_{max}^{-0.916} \]

- **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:

\[ E = F / (F + M) = F / Z \]  \hspace{1cm} \text{(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:
\[ t_c = \left( -\frac{1}{K} \right) (Ln(1/L_c/L_\infty)) + t_0 \text{ (Beverton & Holt, 1957)} \]

Where: \( L_c \) is the length at first capture. \( L_c \) is the mean length of the catch. 
\( Z \) is the instantaneous total mortality coefficient.
\( K, L_\infty \) 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).

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

Where: \( m = (1-E)/(M/K) = (K/Z) \). - \( U = 1 - (L_c/L_\infty) \). 
\( E \) 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.
Management of *Siganus rivulatus* stock from the Suez Canal

**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:
  \[ L = 5.888 + 0.459R \ (r^2=0.7248). \]

**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)

<table>
<thead>
<tr>
<th>Age</th>
<th>No.</th>
<th>Observed length by otolith</th>
<th>Back calculation L at the end of each year</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>40</td>
<td>10.93</td>
<td>10.3</td>
</tr>
<tr>
<td>II</td>
<td>29</td>
<td>14.80</td>
<td>9.73</td>
</tr>
<tr>
<td>III</td>
<td>32</td>
<td>17.58</td>
<td>9.38</td>
</tr>
<tr>
<td>IV</td>
<td>32</td>
<td>19.75</td>
<td>8.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>9.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual Increment (cm)</td>
<td>9.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percentage of increment (%)</td>
<td>49.33</td>
</tr>
</tbody>
</table>

(b)

<table>
<thead>
<tr>
<th>Age</th>
<th>No.</th>
<th>Observe weight (g)</th>
<th>Back calculation weight at the end of each year</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>40</td>
<td>17.17</td>
<td>14.22</td>
</tr>
<tr>
<td>II</td>
<td>29</td>
<td>45.06</td>
<td>11.86</td>
</tr>
<tr>
<td>III</td>
<td>32</td>
<td>77.93</td>
<td>10.55</td>
</tr>
<tr>
<td>IV</td>
<td>32</td>
<td>112.87</td>
<td>8.83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>11.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual Increment (g)</td>
<td>11.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percentage of increment (%)</td>
<td>11.34</td>
</tr>
</tbody>
</table>

- **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](image)

**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 $L_\infty$ and $K$, estimated by Ford-Walford and Chapman methods, had the same values; $L_\infty = 25.353\text{cm}$ - $K=0.288\text{ y}^{-1}$. Whereas, Gulland and Holt method gave slightly higher values of $L_\infty (25.361)\text{ cm}$ and slightly smaller values of $K (0.289)\text{ y}^{-1}$ (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 $L_\infty = 25.356$ cm, $K = 0.288 y^{-1}$ and $t_0 = -0.81$ year.

![Ford-Walford plot](image)

**Ford-Walford.**

$y = 0.7495x + 6.3511$

$r^2 = 0.9994$

$L_\infty = 25.353$ cm

---

![Chapman plot](image)

**Chapman**

$y = -0.2505x + 6.3511$

$r^2 = 0.9947$

$L_\infty = 25.353$ cm

---

![Gulland and Holt plot](image)

**Gulland and Holt**

$y = -0.2861x + 7.2568$

$r^2 = 0.9931$

$L_\infty = 25.361$ cm

Fig. (6) Estimation of growth parameters ($K$ & $L_\infty$) of *S. rivulatus* in Suez Canal by three different methods; Ford–Walford plot, Chapman and Gulland and Holt.
- **Growth performance index** ($\Phi$)  
The computed growth performance index ($\Phi$) 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$^{-1}$.

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

- **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 ($L_{\infty}$, $K$, $t_0$, $W_{\infty}$, $\Phi$, $M$, $F$, $Z$, $L_c$, $L_m$, $E$, $t_c$ and $t_{\text{max}}$) 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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_\infty$ (cm)</td>
<td>25.356</td>
<td>$K$ (y$^{-1}$)</td>
<td>0.288</td>
<td>$t_0$ (y$^{-1}$)</td>
<td>-0.81</td>
<td>$W_{\infty}$ (g)</td>
<td>249.97</td>
<td>$\Phi$</td>
<td>2.267</td>
</tr>
<tr>
<td>$M$ (y$^{-1}$)</td>
<td>0.573</td>
<td>$F$ (y$^{-1}$)</td>
<td>1.002</td>
<td>$Z$ (y$^{-1}$)</td>
<td>1.575</td>
<td>$L_c$ (cm)</td>
<td>12.838</td>
<td>$L_m$ (cm)</td>
<td>male 14.5, female 15.15</td>
</tr>
<tr>
<td>$E$ (y$^{-1}$)</td>
<td>0.636</td>
<td>$t_c$ (y$^{-1}$)</td>
<td>1.641</td>
<td>$t_{max}$ (y$^{-1}$)</td>
<td>10.411</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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](image)

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 previous 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 4 years (8-22 cm, 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 Mediterranean (Mohammed 1991; El-Okda, 1998). On the other hand, El-Far (2008) recorded a higher maximal age of 5 years in Alexandria. Whereas a minimum 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 (10-27 cm, 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 ($L_{\infty}$, 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 (25.356 cm) 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 $L_{\infty}$ as recorded in many other regions; the Mediterranean Sea recording a range of 27.7-48.96 cm (Mouneime’, 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 ($K = 0.288 y^{-1}$) and growth performance index ($\Phi = 2.267$) in Ismailia region, compared to those in Bitter Lake ($K = 0.079-0.085 y^{-1}$ and $\Phi = 2.02$). The theoretical maximal weight was not observed in Suez Canal before, but generally, $W_{\infty}$ 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), in Gulf of Suez (0.55y⁻¹) by El-Ganainy and Ahmed (2002); and in Jeddah (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 (Lc) was found to be smaller than lengths of first maturation (Lm), 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 Lc (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 (Ecurr) in Suez Canal is higher than the exploitation rate E₀.1. 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 E₀.5 (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.
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