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Reproductive biology of *Siganus rivulatus* (Forsskal, 1775) in the Red Sea, Suez Canal and the Mediterranean Sea, Egypt

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ABSTRACT

Siganus rivulatus, is one of the most economically successful Lessepsian migrant fish, but its reproductive strategy in Egypt needs more studies. A total of 1178 individuals from the Egyptian coasts (the Red Sea; 334, Suez Canal; 353, Mediterranean Sea; 491) were collected seasonally during autumn 2017-summer 2018 to study the important aspects of its reproductive biology. The total length recorded in the Red Sea population (14-28 cm) showed higher values than that in the Suez Canal and Mediterranean Sea (8-22 cm). The sex ratio (M:F) did not significantly vary with the expected ratio (1:1) during all seasons at all sites (chi-square, $P>0.05$). Seasonal changes in maturity stages of gonads and values of gonadosomatic index showed that the reproduction of *S. rivulatus* take place during spring, and extended to summer only in the Red Sea. No significant differences in ova diameter were recorded among sites (ANOVA, $P>0.05$). The means of absolute fecundity (F_{abs}) were 409330, 127497 and 95204 eggs in the Red Sea, Suez Canal, and the Mediterranean Sea, respectively. Relative fecundity (F_{rel}) was estimated as the number of eggs in ripe ovaries per unit of fish length and unit of fish weight. The F_{abs} and F_{rel} of *S. rivulatus* increased with increasing in fish length (L) and weight (W). Results of F_{abs} and F_{rel} displayed significant differences between sites (ANOVA, $P<0.05$), with higher values in the Red Sea than in the Suez Canal and the Mediterranean Sea.

INTRODUCTION

The reproduction of a fish species is very important for the assessment and management of its stock **(Froese, 2004)**. Therefore, the reproductive strategy of the species is one of the most important biological characters to be studied to manage fisheries resources. It gives a predictable future for fish production and recruits adding for the recent stock **(El Ganainy, 1992; Dinh, 2018)**. Since the completion of the Suez Canal in 1869, several Red Sea species invaded the Mediterranean Sea and known as the Lessepsian migrant species **(Por, 1978)**. Family Siganidae (rabbitfish) is native to Indo-Pacific **(Woodland, 1983)** and entered the Red Sea then transferred to the Mediterranean via Suez Canal. *Siganus rivulatus* (Forsskål, 1775) is one of the most successful Lessepsian migrant species **(Bariche *et al*., 2004)**. It was first recorded at Palestine coast in 1927 **(Steinitz, 1927)** then established in the Mediterranean Sea with a large population economic importance **(Aleem, 1969; George, 1972; Ben-Tuvia, 1985; Papaconstantinou, 1990)**.

Due to the increasing economic importance of *S. rivulatus* in Egypt, various biological and ecological traits of the species from different Egyptian coasts have been studied or reviewed (Mediterranean: **Mohammed, 1991; El-Okda, 1998;** Red Sea: **El-Gammal, 1988; El-Ganainy & Ahmed, 2002; Mehanna & Abdallah, 2002; Mehanna *et al*., 2018;** and Bitter Lakes: **El-Drawany, 2015**). The previous studies focused on the stock assessment and management by measuring some biological parameters of fish such as; age, growth, mortality, and yield per recruit.

Other studies manipulated different aspects in the reproduction of *S. rivulatus* in the Red Sea such as; seasonal changes in the ovaries **(Amin, 1985a)** and reproductive cycle of males in Jeddah **(Amin, 1985b)**. At the Mediterranean coast of Lebanon, **George (1972)** studied their breeding and movements while **Bariche *et al.* (2003; 2009)** studied sex ratio, maturity stages, length at first sexual maturity, gonadosomatic index (GSI) and fecundity. In Egypt, some studies were performed on the reproductive biology of *S. rivulatus* from Alexandria such as; sex ratio, gonadosomatic index (GSI), length at first sexual maturity, ova diameter, fecundity and time of spawning **(Hussein, 1986; Fahmy, 2019; El-Far, 2008)**.

Nevertheless, these studies presented fragmented and limited information on the reproductive biology of *S. rivulatus* in the Mediterranean, Suez Canal and Red Sea. It is important to fill the gap in information about the reproductive strategy of this economically important species to determine the exact spawning season and to convey the needed information to fisheries biologists before the standing stock declines to an uneconomic level. The present study aims to investigate the reproductive aspects of *S. rivulatus* such as sex ratio, maturity stages, length at first maturation, GSI and fecundity in its native environment (Red Sea) and the new environments (Mediterranean Sea and Suez Canal).

MATERIALS AND METHODS

- Sampling and study area

A total of 1178 specimens of *S. rivulatus* (334 from Red Sea (Hurghada), 353 from Suez Canal (Ismailia) and 491 from Mediterranean (Port-Said)) were collected seasonally from autumn 2017 to summer 2018 (Fig. 1). Specimens were put in crushed ice and transported to the laboratory immediately for further analysis. Total length (TL) and total weight (TW) for each fresh specimen were measured to the nearest centimeter and gram, respectively. Fish were dissected then gonads take out and weighed to the nearest 0.00l g.

- Sex ratio

The specimens were sexed by the naked eye; unsexed specimens were separated and the sex ratio (M:F) was determined. Chi-square test at $P< 0.05$ significance level was computed according to **Sendecor (1956)** to test the deviation from a (1:1) sex ratio.

Fig. 1: Location of the three studied sites; Red Sea (Hurghada), Suez Canal (Ismailia) and Mediterranean Sea (Port Said).

- **Gonadosomatic index (GSI)**

GSI was calculated for males and females separately according to **Anderson *et al.*, (1983)** by using the following formula: $GSI = (GW / TW) \times 100$

Where GW is the gonad weight and TW is the total weight of fish.

- **Maturity stages**

Maturity stages of *S. rivulatus* were classified into six stages according to the scale of **Gunderson (1993)** with some modifications as follows:

- *Thread:* Sex cannot be determined as the gonads appear as just filaments.

- *Stage I (Immature - virgin):* Gonads were still small extended along ¼ the length of the abdominal cavity. Testes are smaller and thinner than ovaries. Color of testes was brown to black, while ovaries were transparent and cylindrical.

- *Stage II (Mature - recovering spent):* The gonads are slightly enlarged extended $^{1}/_{3}$ of the abdominal cavity. The testes do not contain sperm and the color changed to be lightly brown, while the ovaries are yellowish to rosy, sometimes possess a few small eggs which can be distinguished by the naked eye.

- *Stage III (Nearly ripe - developing):* Gonads are larger nearly occupy the two-third of the body cavity. Testes were more flattened, creamy white and opaque without sperm. Ovaries color varied between pale yellow and slightly whitish with small eggs. It is easy to observe the blood vessels with a naked eye in the ovaries.

- *Stage IV (Active-ripe or developed):* Gonads became larger; occupy the most of body cavity. It is usually easy to observe the blood vessels with the naked eye. Testes were white had smooth texture, and some sperm is expelled from the core when cut. Ovaries color varied between pale yellow and pinkish and solid with fully formed eggs.

- *Stage V (Running - spawning):* Gonads became soft with loose wall. Sexual product (milt or eggs) start expelled from the genital openings on the application of slight pressure to the two sides of the genital tract. Volume of gonads decreased gradually, milts and eggs still run out and gonads started to be hollow again. Color of tests became opaque white and the ovaries became red to reddish-brown. Blood vessels became bright reddish, gorged with blood.

- *Stage VI (Spent):* In this stage, volume of gonads and blood vessels were reduced; ovaries became translucent and reddish in a form of a flaccid bag with leftover of a very few eggs, while the testes were grayish or dirty white, slender with thin flaccid and almost empty. From this stage of maturation (sexual cycle) begins a new stage II (mature) in the surviving spawners.

- **Length at first sexual maturity (L_{50} or L_m)**

For estimation the length at which 50% of fishes reached their sexual maturity (L_{50}), each sex was separately grouped into a 1 cm length classes. The frequency percentage of mature males and females of *S. rivulatus* during the spawning season (stages III, IV or V) were plotted against the mid-length using Excel **(Sendecor, 1956; king, 1995)**.

- Fecundity

About 25-30 specimens with maturing ovaries (stages III, IV and V) were examined for fecundity during the spawning season from each study area. Maturing ovaries were carefully removed, weighed to the nearest 0.01 gm, and preserved in 4 % formalin. Three subsamples (0.5-1.0 g) were taken from the center and the posterior part of the right and left lobes, weighed to the nearest 0.01 g, and placed in a divided Petri-dish containing some drops of water. Ova were separated from the ovarian tissue with dissecting needle and the ripe eggs were counted under a binocular microscope. The diameters of about 100 ripe eggs in each subsample of each ovary were measured to the nearest 0.001 mm using an eye-piece micrometer with magnification of 25X **(Zacharia & Jayabalan, 2007)**.

Absolute fecundity (F_{abs}) which represent the actual number of eggs in the ovaries, and relative fecundity (F_{rel}) which indicate the number of eggs per unit fish length or weight were calculated according to **Nikolosky (1963)** as follow:

$$F_{abs} = \text{number of ripe ova in sub samples} * \text{weight of ovary} / \text{weight of sub samples}$$

$$F_{rel} = F_{abs} / \text{total body lengh (L) or weight (W)}$$

Both F_{abs} and F_{rel} were studied in relation to (L or W) by the formula:

$$F = a \times L^b \text{ and } F = a + bW.$$

Where, F is absolute or relative fecundity, L and W are independent variables total length and total weight of fish respectively, “a” is a constant and “b” is the exponent value **(Bagenal, 1978)**.

RESULTS

- Sex ratio

After the separation of the unsexed specimens at all regions (105 specimens), sex ratio was estimated. Of the total sexed *S rivulatus* specimens (1073) which collectively obtained from Red Sea, Suez Canal and Mediterranean; 173 (52.58%), 162 (52.94%) and 234 (53.42%) were males, and 156 (47.42%), 144 (47.06%) and 204 (46.58%) were females, giving an overall ratios of 1:0.90, 1:0.88 and 1:087, respectively (Table 1). The total sex ratio indicated slight increase of males, giving insignificant differences (*P>0.05*) compared to the expected ratio (1:1) ($\chi 2$ = 2.454, 2.247 and 1.666 for Red Sea, Suez Canal and Mediterranean, respectively). Seasonal variation of sex ratio showed approximately close values in all studied regions with the dominance of males during all seasons except in spring when females were dominant. However, seasonal values of sex ratio showed insignificant differences (*P>0.05*) in all studied regions.

Table 1: Seasonal variation in sex ratio (M:F) of *S. rivulatus* at studied regions during 2017-2018

Sex / Seasons	Red Sea			Suez Canal			Mediterranean		
	Male (%)	Female (%)	Ratio M:F	Male (%)	Female (%)	Ratio M:F	Male (%)	Female (%)	Ratio M:F
Autumn	55.88	44.12	1:0.79	55.56	44.44	1:0.8	55.56	44.44	1:0.8
Winter	58.11	41.89	1:0.72	58.02	41.98	1:0.72	56.04	43.96	1:0.78
Spring	47.37	52.63	1:1.11	47.25	52.75	1:1.12	49.38	50.63	1:1.03
Summer	52.05	47.95	1:0.92	52.5	47.5	1:0.9	55.66	44.34	1:0.8
Average	52.58	47.42	1:0.9	52.94	47.06	1:0.89	53.42	46.58	1:0.87
$\chi 2$ value	2.454			2.247			1.666		

The range of total length in the Red Sea was (14 - 28 cm), and (8 - 22 cm) in both Suez Canal and Mediterranean Sea. The fish population of each region was divided into 14 size classes with 1 cm interval. The variation of sex ratio of *S. rivulatus* in relation to length frequencies was estimated (Fig. 2). In the Red Sea, females had higher proportion in mid-length between 14.5 and 16.5 cm, then acquired opposite trend where males became the higher at mid-length range (17.5-24.5) cm except for mid-length of 21.5 cm where both were similar. Males in Suez Canal population showed higher proportion than females for all lengths except for 8.5, 12.5-14.5 and 18.5-19.5 cm, but the variation was small. Also, males in Mediterranean Sea had the higher proportion for all length classes except for the length ranged between 16 and 20 cm.

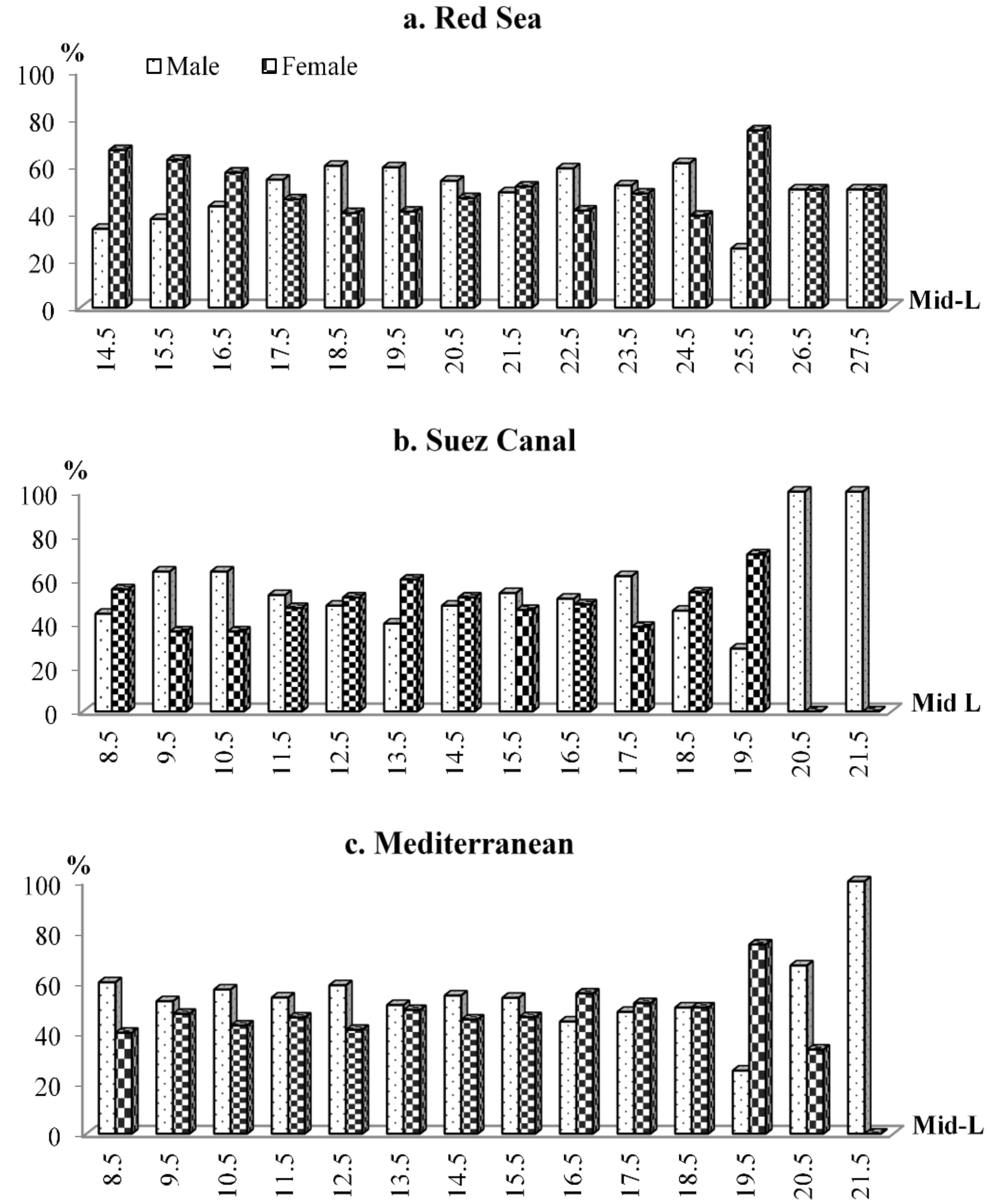

Fig. 2: Variation in the sex ratio percentage of *S. rivulatus* with length group at studied regions during 2017-2018.

- **Gonadosomatic index (GSI)**

The highest values of GSI with a peak were always recorded in spring season for all studied regions; with higher values for males (4.249, 11.37 and 7.224) than those for females (2.343, 8.13 and 6.415) in the Red Sea, Suez Canal and Mediterranean Sea, respectively (Fig. 3). A drastic fall in GSI values was observed during summer in the Suez Canal and Mediterranean Sea, but it decreased gradually in the Red Sea. It is worth mentioning that the GSI values in the peaked season (spring) showed significant differences ($p<0.05$) among studied regions, giving the highest values in the Suez Canal followed by Mediterranean then Red Sea. Apart from peaked season, the GSI values were approximately close throughout all regions ranging between 0.060 and 0.51 for males, and 0.09 and 0.32 for females.

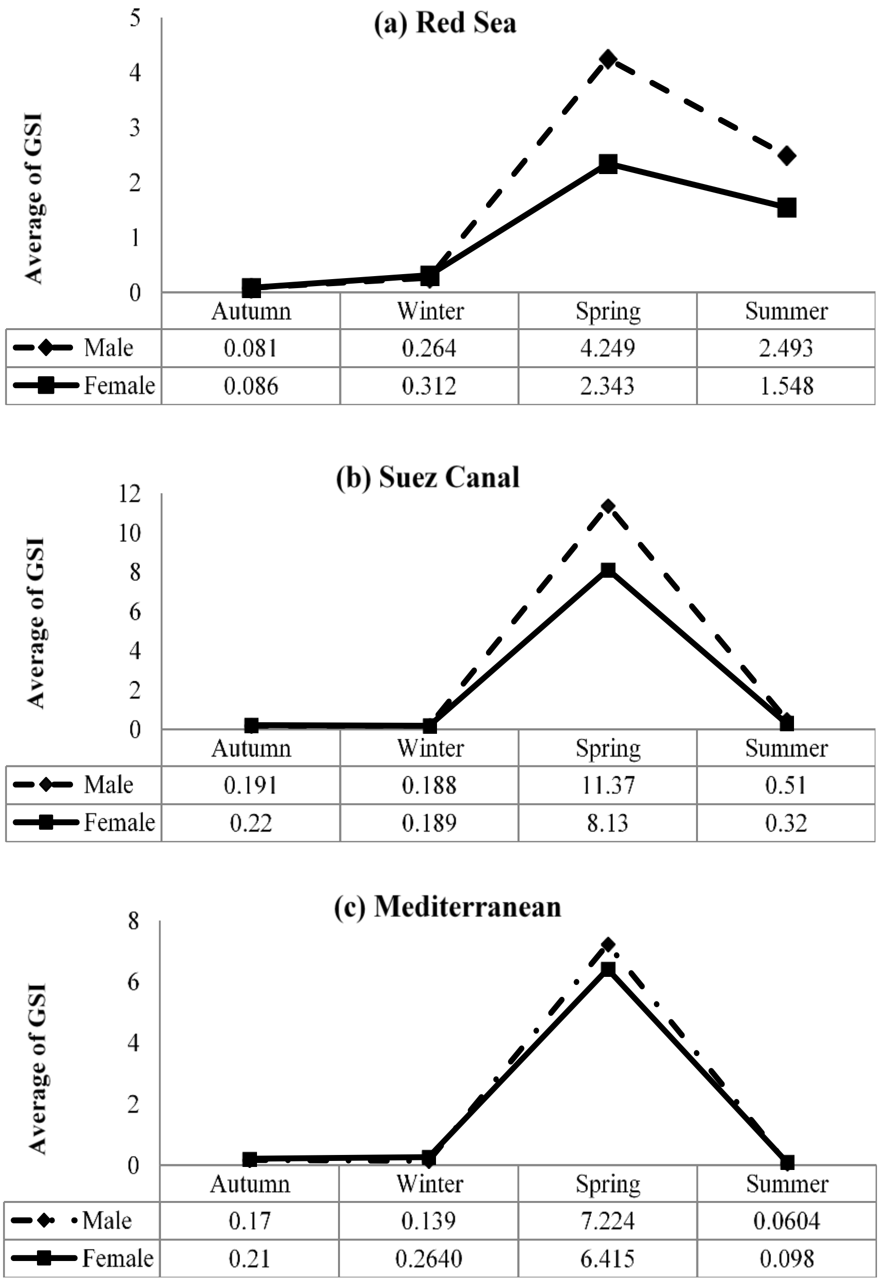

Fig. 3: Seasonal variation of GSI for males and females of *S. rivulatus* from studied regions during 2017-2018.

- **Maturity stages**

The differences in gonad maturity stages in males and females of *S. rivulatus* were represented in Figure (4).

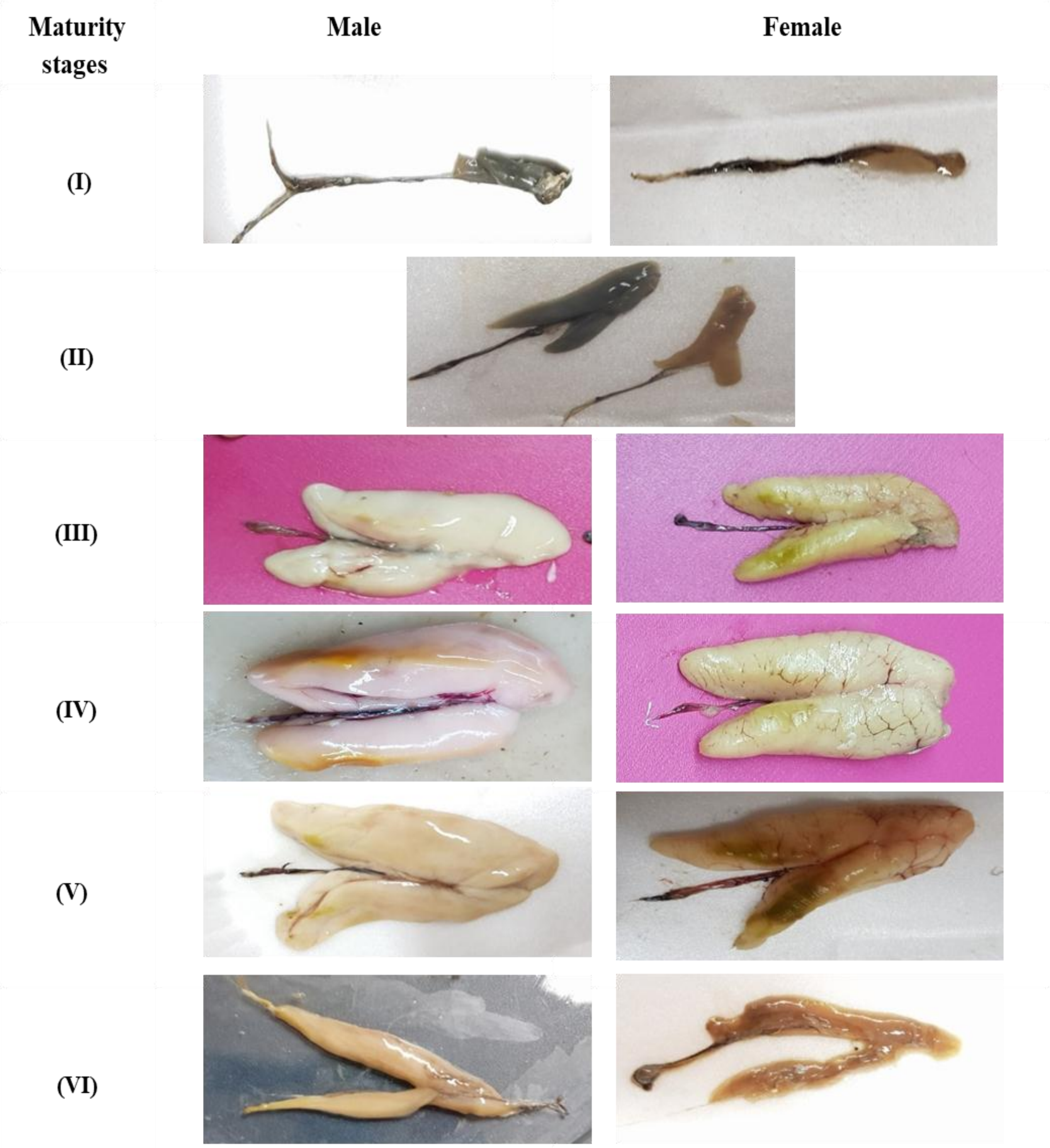

Fig. 4: Different maturity stages in male and female gonads of *S. rivulatus;* (I) Immature, (II) Mature, (III) Developing (nearly ripe), (IV) Fully ripe, (V) Running or spawning and (VI) Spent.

Seasonal variation in maturity stages of *S. rivulatus* displayed a complete absence of ripe stages (III-V) for males and females with the dominance of immature stage during autumn and winter in the Suez Canal and Mediterranean (Fig. 5). In the

Red Sea, the same situation occurred in autumn only while in winter, about half of the population showed a nearly active ripe stage (stage III). In spring, the ripening stages appeared for the first time in the Suez Canal and Mediterranean, giving the highest proportion throughout all studied regions. Few ripe gonads continued during summer in the Red Sea while in Suez Canal, some ovaries and testes showed running stage and in Mediterranean, the mature gonads did not appear anymore (Fig. 5).

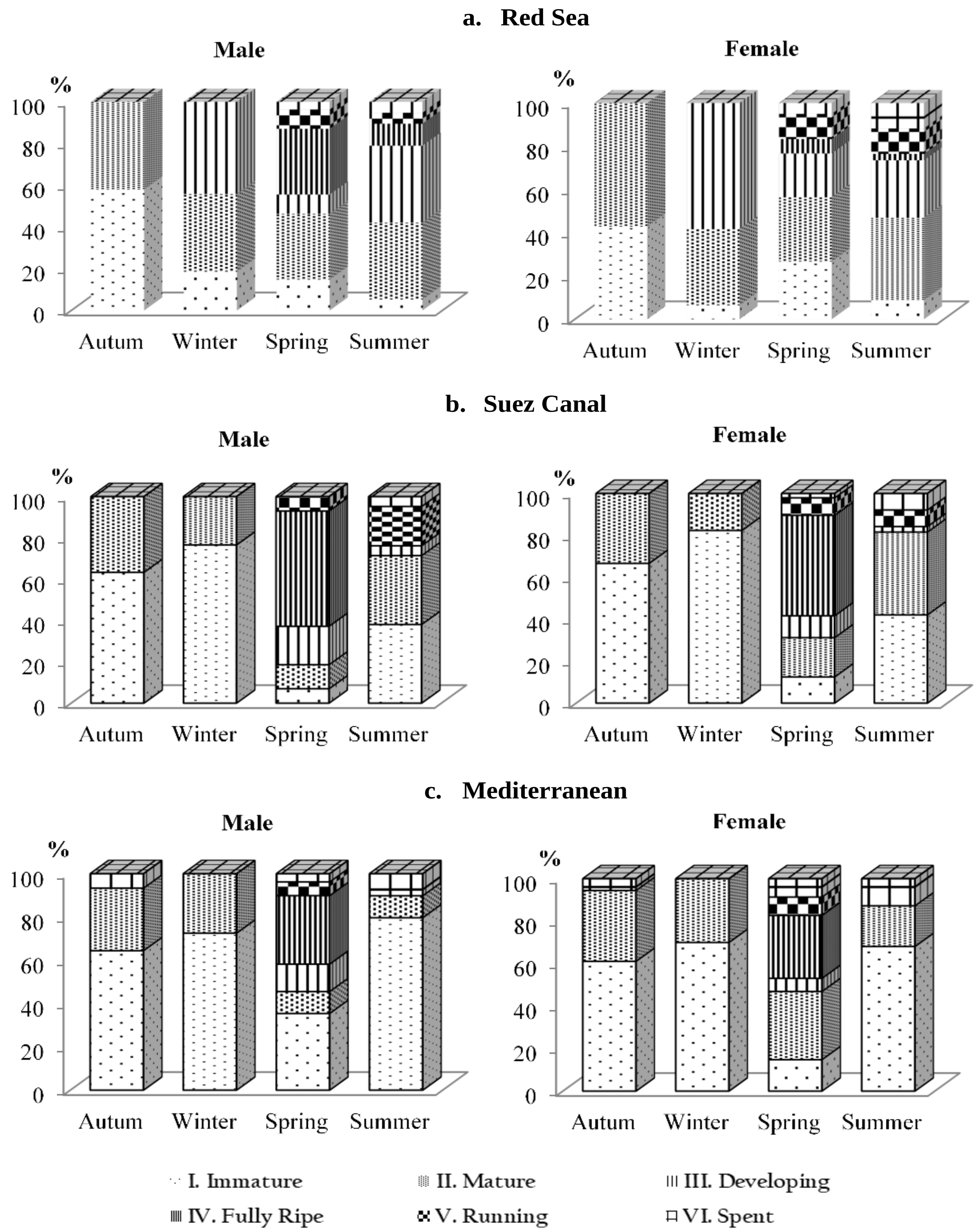

Fig. 5: Seasonal distribution of maturity stages of males and females of *S. rivulatus* in the Red Sea (a), Suez Canal (0b) and Mediterranean (c) during 2017-2018.

- **Length at first sexual maturity (L_{50})**

The percentage of maturity increased with increasing length but with different patterns according to the study region. The length of immature males in the Red Sea was up to 14.5 cm while in Suez Canal and Mediterranean, it was the same for males and females (13.3 cm and 11.5 cm, respectively) (Fig. 6). The length at 50% maturity (L_{50}) for Red Sea population illustrated higher values than those of other regions. L_{50} for males and females ranged between 20.5 and 20.2 cm, 14.5 and 15.15 cm, 14 and 14.3 cm in Red Sea, Suez Canal and Mediterranean, respectively (Fig. 6). In the Red Sea, both sexes became mature at length of 22.5 cm while in the Suez Canal and Mediterranean; males reached maturity at length > 16.5 cm and females at length > 17.5 cm.

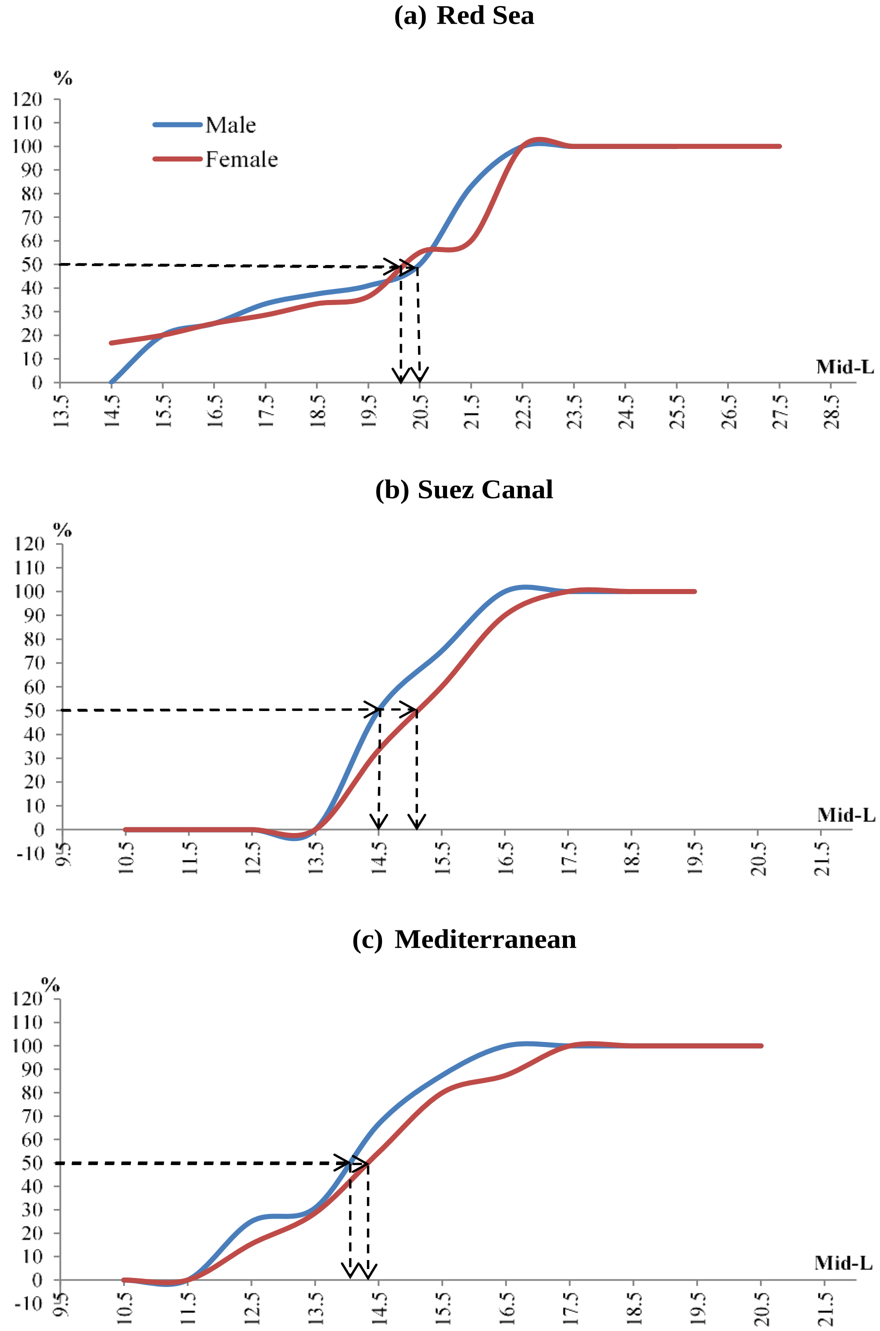

Fig 6: Proportion of maturity and length at first sexual maturity (L_{50}) of males and females of *S. rivulatus* in the Red Sea (a), Suez Canal (b) and Mediterranean (c) during 2017-2018.

- **Fecundity**

Absolute fecundity (F_{abs}) was estimated by counting the eggs in about 25 ovaries of *S. rivulatus* at each studied region during spring 2018 (Table 2). The F_{abs} in the Red Sea fluctuated between 18154 and 735040 eggs with an average of 409330 ± 191079 eggs for fish length range of 19.5-27.5 cm and weight range of 101-200 gm. In the Suez Canal, F_{abs} decreased with the average of 127497±71609 eggs (range: 50414-235453 eggs) for fish length ranging from 14.5 to 19.5 cm and weight from 39.5 to 115.2 gm. The minimum F_{abs} were recorded in Mediterranean Sea (average: 95204±51170 eggs, range: 35782–187473 eggs), for fish length (12.5-19.5 cm) and weight (21.6-83.9 gm). The number of eggs in ripe ovaries per unit length and weight was calculated to estimate the relative fecundity (Table 2).

Absolute and relative fecundity increased with increasing of fish length and weight. They displayed significant differences (ANOVA, $P<0.05$) among three regions with higher values in Red Sea than those in Suez Canal and Mediterranean.

The relation of the F_{abs} and F_{rel} with length (L) for *S. rivulatus* was best described by a power equation ($y = ax^b$), while a linear equation ($y = a + bx$) describes the relationship between fecundity (F_{abs} or F_{rel}) and weight (W).

The regression equations between the absolute fecundity and fish length were as follows:

- Red Sea $F_{abs} = 0.9001L^{4.1021}$ $r^2= 0.9906$
- Suez Canal $F_{abs} = 0.0323L^{5.3209}$ $r^2= 0.9949$
- Mediterranean $F_{abs} = 3.9265L^{3.6072}$ $r^2= 0.9939$

The regression equations between the absolute fecundity and fish weight were as follows:

- Red Sea $F_{abs} = 5726.5W - 430053$ $r^2= 0.9784$
- Suez Canal $F_{abs} = 2979.3W – 93369$ $r^2= 0.9521$
- Mediterranean $F_{abs} = 2385.5W – 23301$ $r^2= 0.979$

The regression equations between the relative fecundity and fish length were as follows:

- Red Sea $F_{rel} = 0.9128L^{3.0986}$ $r^2= 0.9871$
- Suez Canal $F_{rel} = 0.0323L^{4.3209}$ $r^2= 0.9923$
- Mediterranean $F_{rel} = 3.9265L^{2.6072}$ $r^2= 0.9884$

The regression equations between the relative fecundity and fish weight were as follows:

- Red Sea $F_{rel} = 19.935W - 261.07$ $r^2= 0.9354$
- Suez Canal $F_{rel} = 17.68W + 299.88$ $r^2= 0.9012$
- Mediterranean $F_{rel} = 8.9639W + 1400$ $r^2= 0.8633$

Ova diameter showed insignificant differences (ANOVA, $P>0.05$) among different regions, ranged between 0.292 to 0.347 mm. The averages were: 0.308, 0.319 and 0.338 in the Red Sea, Suez Canal and Mediterranean, respectively.

Table (2): Absolute and relative fecundity of *S. rivulatus* in Red Sea, Suez Canal and Mediterranean during the reproductive season

Area	Fecundity	Min.	Max.	Average ± SD
Red Sea	**F_{abs}**	181543	735040	409330± 191079
	F_{rel} / cm	9215	26345	16825±5990
	F_{rel} / g	1779	3666	2660±680
Suez Canal	**F_{abs}**	50414	235453	127497±71609
	F_{rel} / cm	3476	12074	7197±3344
	F_{rel} / g	1084	2290	1610±436
Mediterranean	**F_{abs}**	35782	187473	95204±51170
	F_{rel} / cm	2862	9614	5654±2251
	F_{rel} /g	1657	2245	1845±204

DISCUSSION

Understanding the reproductive strategy of fish species is very important for fisheries assessment and management, as reproductive biology plays an important role in determination of the productivity of population and exploitation or disturbance caused by fisheries and other human activities **(Morgan, 2008)**. This study presents a detailed evaluation of the reproductive potential of lessepsian migrant species, *S. rivulatus*, in the Egyptian waters of Red Sea, Suez Canal and Mediterranean Sea.

The present study revealed that, the TL range of *S. rivulatus* in the Red Sea (14-28 cm) was much longer than those in both Suez Canal and Mediterranean (8-22 cm). This was close to the previously recorded total length range for *S. rivulatus* in Alexandria (9-22 cm by **El-Far, 2008** and 14-24 cm by **Fahmy, 2019**), and that recorded in the Egyptian Red Sea (13-27 cm) by **El-Ganainy and Ahmed (2002)**, while **Mehanna *et al.* (2018)** recorded little higher length range (17-30). In the Red Sea population, the absence of samples smaller than 14 may be due to the mesh size of fishing gears that allowed to be used and increasing the maximum length may be because Red Sea constitutes the endemic environment for *S. rivulatus* that provide favorite requirements.

The study of sex ratio is useful in studying the spawning population **(Faltas, 1983)**. In the present study, the annual averages of sex ratio were 1:0.9, 1:0.89 and 1:0.87 in the Red Sea, Suez Canal and Mediterranean, respectively which is insignificantly different ($P>0.05$) with the expected sex ratio (1:1). This was in agreement with that recorded for the same species in the Turkish coast **(Yeldan & Avsar, 2000)** and Lebanese waters **(Bariche *et al.*, 2003)**. Males showed predominance over females during all seasons except in spring; which is accepted as spawning season, when female percentage became slightly higher throughout the whole regions. This is in accordance with **El-Far (2008)** who observed that the percentage of females was 51%, (1:1.04) at the reproductive season and **Hashem (1983)** who estimated M:F sex ratio of 1:1.3 during April in Red Sea. Such little deviation and predominance of one sex could be a result of a several reasons such as: 1- migration for spawning and feeding **(Yeldan & Avsar, 2000)**, 2- a partial segregation of mature forms through habitats preference **(Reynolds, 1974)**, 3- the higher catch ability of one sex than other, or 4- high mortality of one sex due to its vulnerability to the fishery **(Wahbeh, 1992; Cherif *et al.*, 2007; Sabrah *et al.*, 2016)**. Also, the variation of (M:F) sex ratio of *S. rivulatus* between size classes did not deviate significantly from 1:1, which agree with **Bariche *et al.* (2003)** in Lebanese waters.

The spawning season of *S. rivulatus* was determined by following the changes in the mean value of the gonadosomatic index (GSI) for both sexes and monitoring the shift from mature to spent gonads during various seasons. The GSI for both sexes displayed one peak with maximum values during spring in all studied regions, this peak decreased sharply during summer in Suez Canal and Mediterranean, while in the Red Sea the decreasing of the peak was gradually. This indicates that *S. rivulatus* reproduces once a year then enters in a resting period, with a spawning season exclusive to spring in Suez Canal and Mediterranean while in the Red Sea, it is a prolonged season extends to summer. The higher values of GSI for males than females during the reproductive season were reported in previous studies on *S. rivulatus* in the southern Mediterranean of the Egyptian **(El-Far, 2008)** and Libyan coasts **(Shakman, 2008)**. In contrast, **Yeldan and Avsar (2000)** recorded higher values of GSI in females during the reproductive season in the northeastern Mediterranean. Increasing GSI values in Suez Canal and Mediterranean than that found in Red Sea could be due to the bigger size of fish in its original habitat (Red Sea).

GSI values could be used to distinguish between different stages of maturation **(Pitt, 1964; Hickling, 1970)**. In the present study, the seasonal distribution of maturity stages throughout the year confirmed the results of GSI, when the smallest GSI values observed during autumn and winter seasons and the maturing stages were rare or absent, while the values of GSI increased with advance development in maturation.

In Suez Canal and Mediterranean; the ripe stages of gonads started and reached to the highest record in spring, which was accepted as the spawning season, and then totally disappeared in summer, indicating the end of the spawning season. While in the Red Sea, ripe and running stages started to appear in spring and continued to summer for both sexes. **El-Far (2008)** and **Fahmy (2019)** concluded that variations of the GSI values of females of *S. rivulatus* were directly related to the ovarian maturity stages.

In agreement with our results, consideration of spring as the spawning season for Mediterranean population of *S. rivulatus* was reported in different locations such as; Turkey **(Akşiray, 1987)**, Israel **(Golani, 1990)**, Lebanon **(Bariche *et al.*, 2003)** and Egypt **(El-Far, 2008)**. However, previous studies on the Mediterranean population of *S. rivulatus* recorded a great difference in the timing and duration of its reproductive season **(Shakman, 2008)**. For instance, longer spawning season durations were observed such as; May to August by **Moharram (1994)** and **El-Okda (1998)** and May to mid of July by **Fahmy (2019)** in Egypt, and April to August by **Yeldan and Avsar (2000)** in Turkey and sometimes extends to November **(Mouneimne, 1978)**. In contrast to our results, **George (1972)** suggested that there might be a second spawning event for *S. rivulatus* during September in the Lebanese coast. For the Red Sea, a prolonged spawning period, extending from May to August, was observed for *S. rivulatus* population **(Golani, 1990; Popper & Gundermann, 1975)**. On the other hand, larvae of *S. rivulatus* collected from the Egyptian Red Sea at Hurghada and Sharm El-Sheikh in late May by **Abu El-Regal (2013)** and **Abu El-Regal *et al*. (2019)** were small and in preflexion stage indicating that they have been delivered recently in a few days. In the Gulf of Aqaba, fully ripped stages were earlier in March and April **(Popper *et al*., 1973; Hashem, 1983)** while in the central Red Sea at Jeddah, the timing of the spawning season shifted earlier to be from February to April **(Amin, 1985 a & b)**.

The variation in the spawning duration between Red Sea and Mediterranean populations of *S. rivulatus* was documented by several studies. **Barchie *et al*. (2003)** recorded that *S. rivulatus* from Lebanese coast have a shorter breeding period comparing with those from Red Sea. In general, most previous studies reported a combination of both shifting and shortening of the spawning season for Mediterranean populations comparing with Red Sea population and explained it as a result of the difference in the climatic conditions and the available resources of the two seas. The different temperature regimes in the two seas seemed to be a principal limiting factor in the gonadal development of *S. rivulatus* **(Golani, 1990; Barchie *et al*., 2003; Shakman, 2008)**.

Knowledge of the length at first sexual maturity (L_{50}) has great benefit in fishery management as it helps to predict the harvestable size of the fish by determining the minimum legal size needed to maintain the suitable spawning stock and to ensure at least one spawning for the mature individual **(Amin *et al*., 2016)**. The L_{50} recorded in the present study for *S. rivulatus* from Mediterranean (males: 14 cm, females: 14.3 cm) was close to the range of L_{50} recorded by some previous studies (males: 13.25-14.2 cm, females: 13.65-15 cm) in the Egyptian Mediterranean of Alexandria **(Mouneimne, 1978; Hussein, 1986; El-Far, 2008)** and Lebanese coasts **(Barchie *et al.*, 2003)**, while it was lower than those recorded in Alexandria (16 cm for females) by **Fahmy (2019)** and in Syria (males: 17.85 cm, females: 17.22 cm) by **Saad and Sabour (2001)**. The mid-length (12.5 cm) was the length at which the mature gonads recorded for the first time in Mediterranean for both sexes. This result in agreement with the findings of **El-Far (2008)** and **Barchie *et al.* (2003)** (Range: 12-12.6 cm for both sexes). However, no individual larger than 18 cm was immature as mentioned previously **(El-Far. 2008; Fahmy, 2019)**.

Specimens of *S. rivulatus* from Suez Canal (Ismailia) showed smaller L_{50} (males: 14.5 cm, females: 15.15 cm) than those recorded at Bitter Lakes (16.4 cm for both sexes) by **El-Drawany (2015)**. In Red Sea specimens, the mid-length of the smallest mature (15.5 cm for males and 14.5 cm for females) was higher than that recorded for female (13 cm) in Jeddah, Red Sea **(Hashem, 1983)**. The earlier maturation of males than females in Suez Canal and Mediterranean could be related to a shorter life span of males **(Allam, 1996)**. Higher L_{50} of Red Sea population than those of Suez Canal and Mediterranean could be attributed to the variation in length among specimens collected from each area (Suez Canal and Mediterranean: 14-28 cm, Red Sea: 8-22 cm), in addition to different environmental conditions especially water temperature.

The range of average diameter of mature eggs (0.292-0.347 mm) recorded at all studied areas fall in the range of previous studies in Jeddah, Red Sea (0.30-0.48 mm) **(Amin, 1985b)**; and in Alexandria, Mediterranean (0.23-0.50 mm) **(Hussein, 1986; Fahmy, 2019)**. However, **Mohammed (1991)** and **El-Far (2008)** reported a wider range of ripe oocytes diameter in Mediterranean of Alexandria (0.36-0.45 mm); and (0.36 to 0.64 mm) respectively.

Fecundity is a key index that measures the number of ripening eggs ready to be spawned in the spawning season. In the present study, the average of F_{abs} in the Red Sea (409,330 eggs) were more than about three folds that of Suez Canal (127,497 eggs) and four folds of the Mediterranean (95,204 eggs). By comparing the absolute fecundity obtained in the present study with results from other parts of the Mediterranean and the Red Seas, some variations were observed (Table 3). It seems that these variations is related to many variables such as; temperature, fish total length, egg size, stage of maturation and timing of spawning **(Shakman, 2008)**, varying techniques used for eggs count **(Hussein, 1986)** and dietary and food resources availability **(Fagade *et al.*, 1984; Hussein, 1986; Plaza *et al*., 2007)**. Nevertheless, these variables are common in other fish species **(Doha & Hya, 1970; Hussein *et al.*, 2003)**. However, the fecundity of fish is mostly related to biological factors; Length, weight, and age **(Nikolsky, 1963; Bagenal, 1978)**.

Table (3): Absolute fecundity (F_{abs}) that reported in the literature for *S. rivulatus* at different geographical locations

Authors	Area	TL (cm)	F_{abs}	
			range	Average ± SD
Hashem (1983)	Jeddah, Red Sea	15-17	40,000-300,000	-
Hussein (1986)	Alexandria, Mediterranean	15-28	103,200-396,600	-
Yeldan & Asvar (2000)	North-eastern Mediterranean	15.5-22	-	434,76±181,006
Shakman (2008)	Libyan coast, South Mediterranean	16.4-32	94,259-490,898	226,289±123,189
Bariche *et al*. (2003)	Lebanese coast, Mediterranean	12.6-25.2	-	250,000
El-Far (2008)	Alexandria, Mediterranean	14.4-20	64,292-380,772	-
Bariche *et al.* (2009)	Eastern Mediterranean	15-28	49,830-708,537	272,043±144,666
Fahmy 2019	Alexandria, Mediterranean	15-24	200,504-881,320	-
Present study	Hurghada, Red Sea	19-28	181,543-735,040	409,330±191,079
	Ismailia, Suez Canal	14-20	50,414-235,453	127,497±71,609
	Port-Said, Mediterranean	12-20	35,782-187,473	95,204±51,170

There were positive relationships between the number of eggs and both total length and body weight at all study regions. The relative fecundity increased with increasing length at all studied areas, and showed fluctuations in its relation with the body weight in agreement with observation of **Elfar (2008)**, this fluctuation may be attributed to the presence of each variation in the well-being which may cause fluctuation in eggs number in its relation with weight **(Oso *et al.*, 2011)**. The values of correlation of coefficient (r^2) were close to 1 for all relationships, especially for F_{abs} & F_{rel} with TL, indicating the goodness of fit. Increasing in fecundity of *S. rivulatus* (absolute or relative) with increasing TL and TW of the fish explains increasing F_{abs} in the Red Sea. This observation was confirmed by many studies **(Hashem, 1983; Hussein, 1986; Yeldan & Avsar, 2000; Shakman, 2008; El-Far, 2008).**

The values of the constants (a and b) may vary according to the studied population and environmental variations **(Kartas & Quignard 1984)**. Constant “a” describes the population fecundity, while constant “b” shows the nature of the algometry. In the present study, values of constant “b” for the relationship between F_{abs} and TL (4.1021, 5.3209 and 3.6072 for Red Sea, Suez Canal and Mediterranean, respectively) fall in the range (1-7) recorded by **Wootton (1979)** for 62 fish species. Also, “b” values were close to those recorded for *S. rivulatus* in Alexandria, Egypt (4.606; **El-Far, 2008)**, northeastern Mediterranean (4.61; **Yeldan & Asvar, 2000)** and eastern Mediterranean (3.7; **Bariche *et al.*, 2009)**.

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