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Population structure of *Sardinella gibbosa* (Bleeker, 1849) with special reference to spawning ground in the Gulf of Suez, Egypt

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ABSTRACT

Identifying population and reproductive structure of *Sardinella gibbosa* in the Suez Gulf is the main objective of the current study. About 786 specimens of *S. gibbosa* were collected from purse seine catch in the Suez Bay with a range of 4.6 to 18.1cm for total length; where the highest frequency was observed for length group 12 cm. The length weight relationship showed an isometric growth pattern (b=3.01). Three life spans were confirmed from otolith reading with a rapid length increasement during the first one. Sex ratio was 1.0:1.75 for males and females respectively (X^2, $P < 0.05$). Gonadosomatic index revealed that *S. gibbosa* spawns once during winter. Length at first sexual maturity was 13.0 and 13.2 cm for male and female respectively, in addition to 11.3 cm for length at first capture (Lc_{50}), revealed the occurrence of overfishing. Total mortality (Z) was 2.75; natural (M) and fishing (F) mortality were 1.06 and 1.69 respectively. Comparing the value of fishing mortality with biological reference points ($F_{Optimum}$ = 0.53 year^{-1} and F_{Limit} = 0.69 year^{-1}) in addition to 0.62 for exploitation rate; confirmed the occurrence of overexploitation. The Gulf of Suez was found to be a confirmed spawning and rearing ground for *S. gibbosa*. As a result of overexploitation, some modifications in size selectivity of fishing gear are required and reduction of fishing effort is a goal to be achieved.

INTRODUCTION

Sardinella gibbosa; a species of the family Clupeidae; is a coastal pelagic species which is native to shallow tropical waters and associated with coral reefs but possible to exist at depths exceeding 70 m **(Nguyen *et al.*, 2016)**. It is one of the most abundant Sardinella global capture; 186980 tons **(FAO, 2016)**; in Indo West Pacific coasts, east Africa, Madagascar, northern Australia **(Whitehead, 1985)** and the Red Sea **(Dor, 1984)**. The Red Sea was excluded from the geographical map as a confirmed area for the existence of this species **(FAO, 1985)** due to some doubtful classifications **(Whitehead, 1985; Golani and Bogorodsky, 2010)**. The occurrence of *S. gibbosa* in the eastern Mediterranean coasts was recorded in 2014 as a result of its migration from the Red Sea via the Suez Canal, which confirms the validity of its previous presence in the Red Sea **(Nir *et al.*, 2015)**.

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The Suez Gulf is located in the far north of the Red Sea to the west of Sinai Peninsula with an extension representing the left arm of the Red Sea. It's one of the most productive sectors in the Egyptian Red Sea fisheries where more than 64% of the total production was obtained **(GAFRD, 2017)**. Three major fishing gears were operated in the Gulf; trawl, purse-seine and artisanal fisheries **(Mehanna and El-Gammal, 2007)**. Many studies have been done to evaluate the fishery status in the Gulf **(Mehanna, 1999 c; Osman *et al*., 2019; Osman *et al.*, 2020; Saber *et al.*; 2020)**. Available studies on biological aspects and population characteristics of *S. gibbosa* in the Suez Gulf are scanty and almost non-existent. Therefore, the present study is an attempt to provide a comprehensive view of these issues, and suggests some management measures to protect this valuable fishery resource.

MATERIALS AND METHODS

1. Sampling and study area

A total of 786 *Sardinella gibbosa* specimens were seasonally collected from purse seine catch of the Gulf of Suez; El-Slakhan landing site (Fig. 1); during 2019-2020 fishing season. Samples were transported to the laboratory for examination, where total length, total weight, gonad weight, sex, maturity stage and age examination were carried out.

Fig.1: Satellite Map of the Gulf of Suez and landing site in Suez Bay.

2. Growth aspects

Specimens of *Sardinella gibbosa* were grouped into 1.0 cm length groups in total length for both sexes. The length frequency distribution was estimated as a percentage and number.

Length weight relationship was obtained according to the allometric equation **(Sparre *et al*., 1989): $W = a L^{b}$**

Where, (W) is the total body weight (g), (L) is the total length (cm), (a) is constant and (b) is exponent value.

Otoliths were obtained and preserved in special envelops for age examination. The Von Bertalanffy parameters; the asymptotic length ($L\infty$) and growth coefficient (K) were estimated by using a non-liner least square technique **(Prager *et al*., 1989)**.

3. Reproductive aspects

Sex ratio was estimated as the percentage of males to females (M : F) in the total catch, where sex differentiation was observed after specimens dissection.

Gonadosomatic indexes (GSI) were estimated for both sexes (male and female) to determine the time of spawning. The GSI was estimated according to **Wydoski and Cooper (1966)** by the following equation:

$$GSI (\%) = GW/W * 100$$

Where, (GW) is the weight of gonad in gram and (W) is the weight of specimen in gram.

The length at first sexual maturity (L_{m50}) was estimated by fitting a logistic curve according to **White (2007)**; where the proportion (PL) of those individuals that were mature at length LT was calculated as follows;

$$PL= \{1+e^{[-\ln (19) (L_T - L_{T50}) (L_{T95} - L_{T50})^{-1}]}\}^{-1}$$

Where, L_{T50} and L_{T95} are Parameters for the logistic regressions fitted to the total length (L_T) at maturity data.

4. Population structure

Total and natural mortality coefficient "Z" and M were estimated using the method of **Pauly (1983)**. The M / K ratio was estimated according to **Beverton and Holt (1956)**. 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 follows:

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

Fishing mortality coefficient (F) was estimated by subtracting the value of natural mortality coefficient (M) from the value of total mortality coefficient (Z) as follows: **$F = Z – M$**

Length at first capture (Lc_{50}) was obtained by plotting the curve for probability of capture by length **(Pauly, 1984)**. While, the exploitation rate was determined according to **Cushing (1968)**:

$E = F / Z$

5. Statistical Analysis

The descriptive statistics, chi-square test (for sex ratio) and one-way ANOVA (for GSI values) were applied by using SPSS program version 16.0, at a significant level of 0.05.

6. Ethical Statements

This study does not need any formal approval, as no live fish was used in an experimental form. Samples were collected from commercial catches of non-living fish. Nevertheless, the minimum number of specimens that meet the requirements of the study was collected. The study area is neither a natural reserve nor restricted to fishing activities or subjected to species protection in any way. The species is designated as 'least concern' by IUCN's Red List of threatened species. In the present study, the directives of the NIOF Committee for Ethical Care of Marine Organisms and Experimental Animals, Egypt (NIOF - IACUC) were not violated in any way.

RESULTS

1. Growth aspects

1.1. Length frequency distribution

The length frequency of *Sardinella gibbosa* in the Gulf of Suez is represented in Fig. (2). The data revealed that the total catch of *S. gibbosa* was represented by lengths ranging from 4.6 to 18.1cm. Dominant sizes were represented by length groups of 12, 11 and 13 cm with percentages of 38, 25.7 and 20%, respectively and occupied the highest frequency. Other sizes were less common in the total catch and were represented by lower percentages.

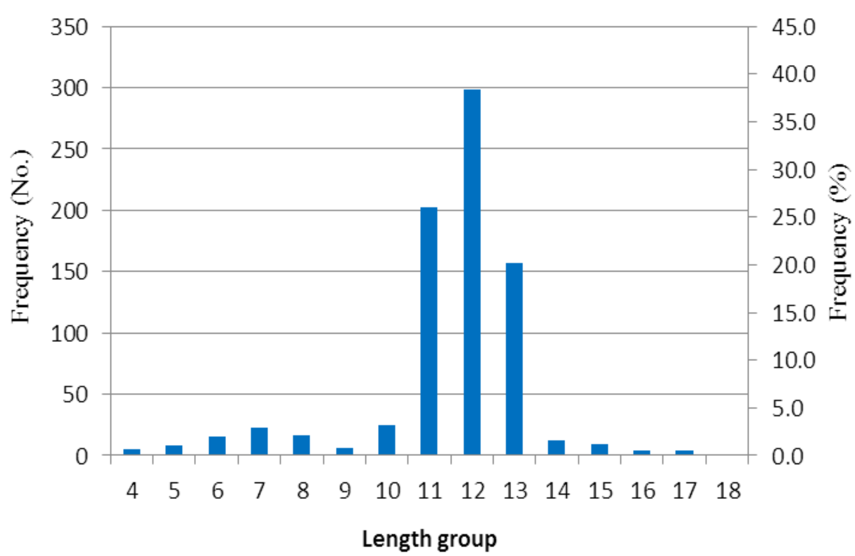

Fig. 2: The overall frequency of different length intervals of *S. gibbosa* in the Suez Gulf.

1.2. Length– weight relationship

Length– weight relationship for combined sexes of *S. gibbosa* was determined by the following equation:

$W = 0.008L^{3.01}$ ($R^2 = 0.9676$) for combined sexes, where:

W: weight in gram, L: total length in centimeters, the constant (a) found to be 0.008 and the coefficient (b) was 3.01(least squares method). R^2 (coefficient of determination) is a statistical measure of how well the regression predictions approximate the real data points. The R^2 was found to be 0.9676 which indicates that the regression predictions perfectly fit the data. The graphical representations of the length- weight relation are shown in Fig. (3).

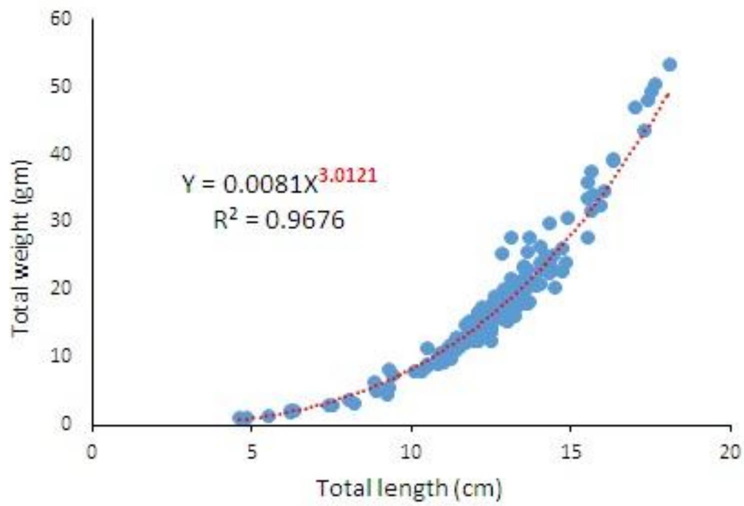

Fig. 3: Length-weight relationship of *S. gibbosa* in the Suez Gulf.

1.3. Age and growth

In the present study, 223 Otoliths were used for age determination of *S. gibbosa*. It was found that the population was classified to four age groups; 0^+, 1^+, 2^+ and 3^+ years of life span; with the mean length of 7.7 cm ± 1.90, 12 cm ± 0.68, 14.3 cm ± 0.84 and 16.4 cm ± 0.22 for each age group, respectively. Individuals of age group 1 were dominant in the population, constituting about 54.7% of the total catch, while the frequency of fishes of age-group 3 was the least and contributed about 7.2% (Table 1). On the other hand, the pattern of length increasement according to age was obtained in Fig. (4).The growth parameters of Von Bertalanffy were estimated and found to be $L\infty = 19.6$ and $k = 0.43$.

Table 1. Length composition according to age groups of *S. gibbosa* in the Suez Gulf.

Age group	Number	Min.	Max.	Mean	S.D
0	27	4.6	10.9	7.7	1.90
1	122	10	12.9	12	0.68
2	58	12.9	15.7	14.3	0.84
3	16	15.5	18.1	16.4	0.22

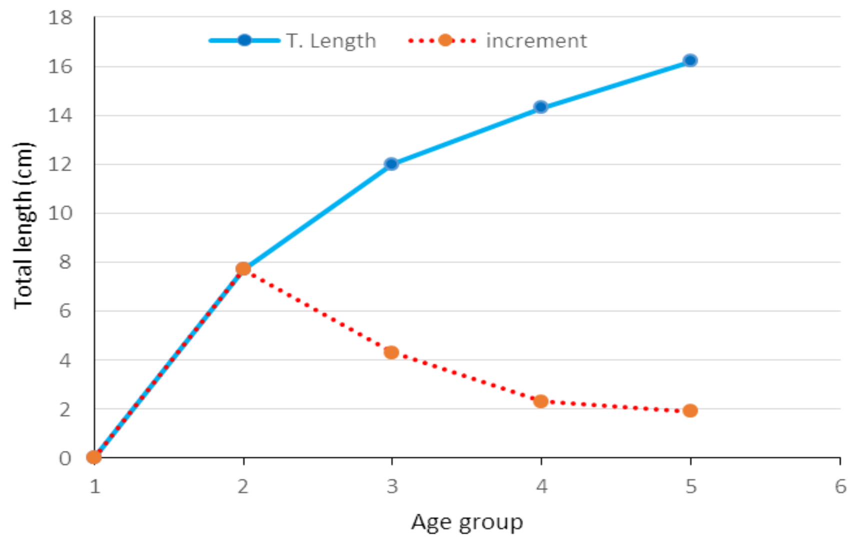

Fig. 4: The growth and increment in length according to age groups for *S. gibbosa* in the Suez Gulf.

2. Reproductive aspects

2.1. Sex ratio

The overall sex ratio was found to be 1:1.75, males to females, which provided highly significant variation from the expected ratio 1:1 (X^2, $P < 0.05$). According to length classes, males were dominating in the early sizes ((length groups 8 and 9) then, females were abundant in length groups >9 except 15. Males were completely absent from the population at length groups >16 (Fig. 5).

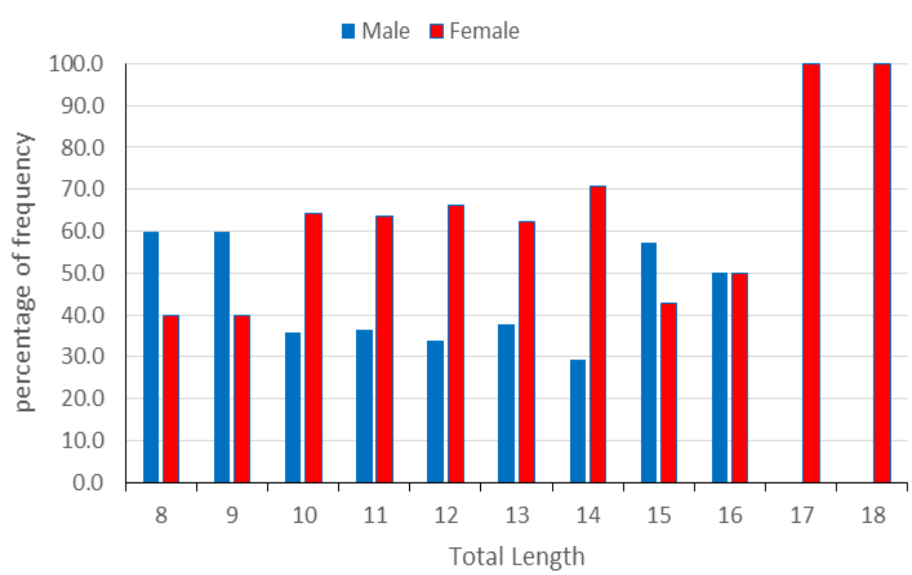

Fig. 5: The percentage of male and female of *S. gibbosa* according to length groups.

2.2. Gonadosomatic Index (GSI)

Seasonal values of gonadosomatic index are presented in Fig. (6) showing that, *S. gibbosa* reached the peak of GSI in winter season with a mean value of 3.7 and 7.5 for males and females respectively. A significant decrease was detected during other seasons where, the mean values varied according to season (ANOVA, $P < 0.05$).

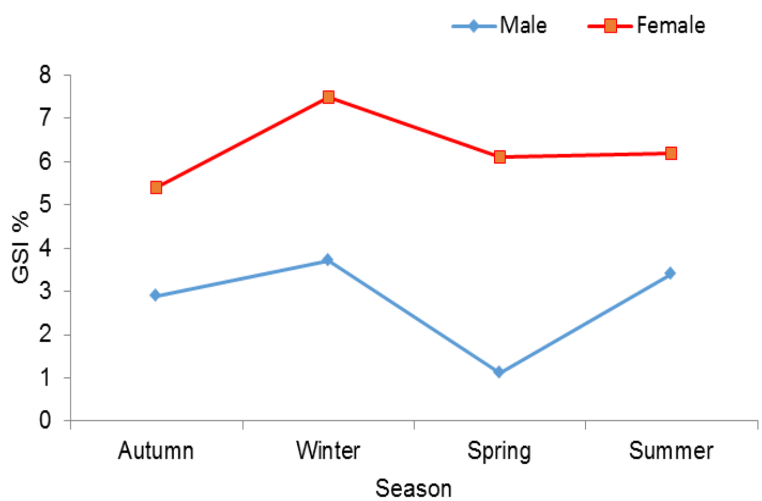

Fig. 6: Seasonal variations in GSI values of *S. gibbosa* in the Suez Gulf.

2.3. Length at first sexual maturity (L_{m50})

From the data obtained in Fig. (7), it is obvious that females of *S. gibbosa* attained its first sexual maturity (L_{m50}) at length 13.2 cm, while all females became mature at length group 17 cm. At length 13 cm,whereas males of *S. gibbosa* attained its (L_{m50}). All males in the population were fully mature at the length group of 16 cm.

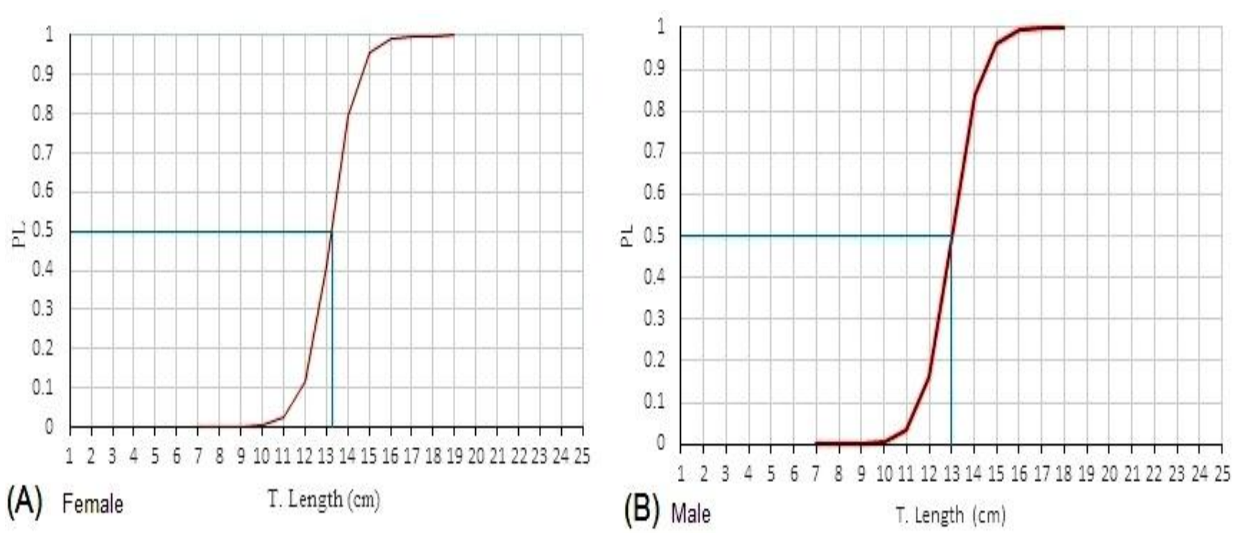

Fig. 7: Length at first sexual maturity (L_{m50}) for females (A) and males (B) of *S. gibbosa*.

3. Population structure

3.1. Length at first capture (Lc)

The length at first capture (Lc) is the length at which 50% of the population at that size are vulnerable to capture and was estimated at 11.3 cm (Fig. 8).

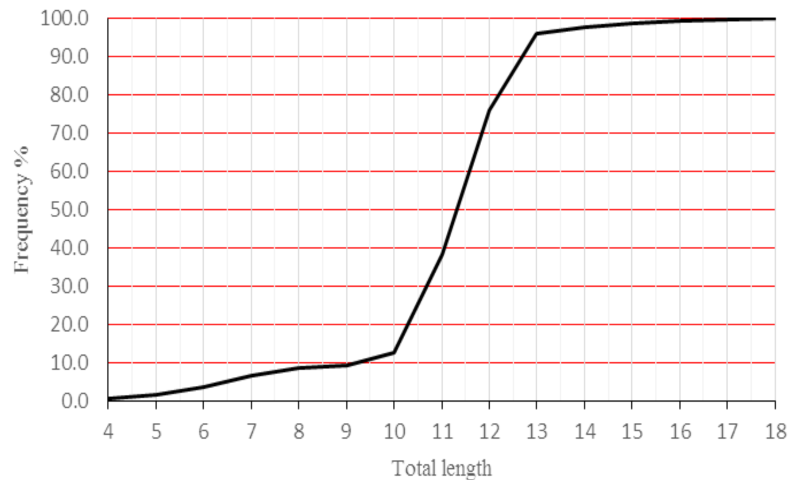

Fig. 8: The length at first capture of *S. gibbosa* in the Suez Gulf.

3.2. Mortality and exploitation rate

Length converted catch curve (Fig. 9) was applied and total mortality (Z) was estimated to be $2.75y^{-1}$. Natural (M) and fishing (F) mortality coefficient were1.06 y^{1} and 1.69 y^{-1}, respectively. The biological reference points were $F_{Opt} = 0.53$ $year^{-1}$, and $F_{Limit} = 0.69$ $year^{-1}$. The estimated M / K ratio found to be 2.46, where M is the natural mortality and K is the growth coefficient. By using Natural (M) and fishing (F) mortality coefficient, the exploitation rate (E) was estimated and the value of 0.62 was reported.

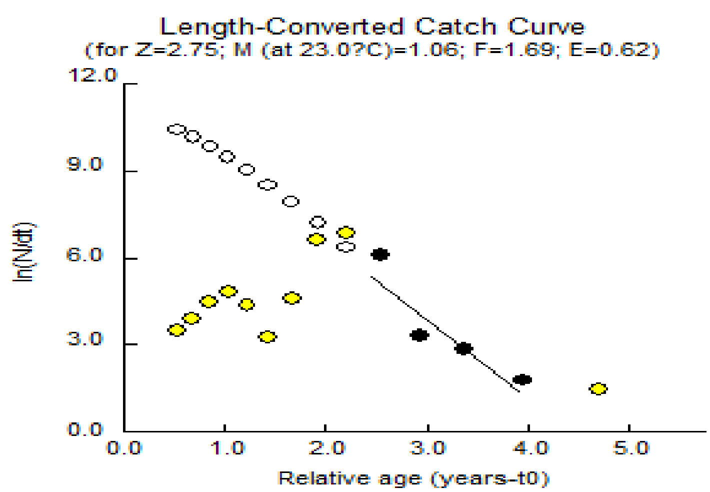

Fig. 9: Length converted catch curve with mortality indication and exploitation rate.

DISCUSSION

Investigating the size structure of any fish population is a snapshot which clearly expose the interactions of the dynamic rates of mortality, growth and recruitment **(Neumann & Allen, 2001)**. Concerning the data of length frequency of *S. gibbosa*, it is clear that the medium length groups (12, 11 and 13 cm) are dominant in the total catch; constituting about 83% of the total catch; which indicates the presence of high fishing effort that deprives the fish the opportunity to reach larger sizes. The present results coincides with **Ghosh *et al.* (2012)** who found that, the mean length of *S. gibbosa* from the North West Bay of Bengal was 128.1 ± 12.3 mm, which indicates exploitation of juveniles in large numbers. **Nguyen *et al*. (2016)** found the same observation for *S. gibbosa* in the near shore area in Vietnam, where the length groups of 12-14 cm were the dominant size, constituting about 48.5% of the total catch, and hence supports the idea of high exploitation.

Length-weight relationships (LWR) were estimated for combined sexes of *S. gibbosa* and the “b” value found to be 3.01, expressing isometric growth patterns, with mean growth that occursed at the same rate for the whole body and the dimensions of the body were fixed to each other. Therefore, R^2 value (0.9676) confirmed the best performing and accurate allometric model. The previous results differed from those of **Ghosh *et al*. (2012)** and **Nguyen *et al*. (2016)**, who explained that, *S. gibbosa* represented negative allometric growth pattern (become lighter in weight and slimmer in body diameter compared to length). The functional regression "b" expresses the general form of the body growth in various dimensions and is closely related to weight, as it is affected by ecological factors such as temperature, food supply and spawning conditions **(Goncalves *et al*., 1997)**.

Concerning age and growth, *S. gibbosa* in the Suez Gulf is represented by four age groups. About 47% of its population was caught during the first year of life, which indicated a relative short longevity as most pelagic species. The growth rate in length was rapid during the first year, followed by a marked slow rate. The current results coincide with the work of **Nguyen *et al*. (2016)** who detected the same four age groups for *S. gibbosa* as well as the dominance of individuals of age group 1^+ (53.7%). **Sanders *et al*. (1984)** reported four age groups for *S. gibbosa* in the Suez Gulf. 13cm was the maximum length of *S. gibbosa* after 1 year as reported by **Pauline and Jakob (1986)**. The same species provided 3 age groups in the Indian coast **(Annigeri, 1989)**. The difference in age groups number may be due to the difficulty of ensuring the presence of the largest size within samples, as well as the differences in environmental conditions.

The model of individual growth by **Von Bertalanffy (1934)** has been shown to conform to the observed growth of most fish species. The asymptotic length ($L\infty$) = 19.6 and the growth coefficient (K) = 0.43 for *S. gibbosa* in the Suez Gulf. A closed value of ($L\infty$) was reported; 19.7 **(Nguyen *et al*., 2016)** and 17.0 **(Devaraj, 1983)** for the same fish species; while the growth coefficient (K) values were 0.249 and 1.42, respectively. It is clear that the present results are more or less similar to those revealed from the previous studies. It is noteworthy that, the differences in growth parameters are due to age, sex, maturity and sampling period for the same species **(Amin *et al*., 2015)**.

The estimated sex ratio, 1:1.75 males to females, differs from that of previous studies of the same species in other regions, where it was 1:1 **(Eleanor *et al*., 2016)** and

1:1.07 **(Nguyen *et al*., 2016)**. Sex ratio may be varying according to years in the same population **(Nikolsky, 1963)** as well as, according to region **(El-Betar, 2016)**. Regional variations in temperature are considered as a limiting factor which controls the pathway of sex differentiation in many fish species **(Devlin & Nagahama, 2002).**

The dominance of females in the large sizes with completely abundance in some cases may be attributed to the differences in growth performance between sexes, where only females attained larger sizes. Considerably, some populations are characterized by early mortality and short life span for males **(El-Boray, 1993)**.

Furthermore, gonadosomatic index for both sexes showed the same pattern and represented one peak during winter, which expresses the gonadal maturation and indicates the approach of the spawning season. Lower mean values of GSI were detected during spring (post spawning) and summer (resting season). **Ghosh *et al.* (2012)** reported that, the peak of GSI for *S. gibbosa* varied according to location, where the peak was detected in February (winter), March and April in three different regions. Another detection for GSI peak in March was reported by **Nguyen *et al*. (2016)**. For the same fish species, regional variations in GSI values may be attributed to changes in regional temperature which highly correlated with gonadal activity **(Duponchelle, 2000; El-Betar, 2016)**. The presence of GSI peak, as well as the post-spawning period, suggests that the Gulf of Suez is a potential place for the reproduction of this species. This is supported by the results obtained from the length frequency distribution and the presence of small fish within samples. Fry could be obtained if fishing nets with narrow mesh were applied, although this was not available during this study.

The present results of “L_{m50}”; 13and 13.2cm for male and female respectively; coincide those of **Ghosh *et al.* (2012)** and **Abdussamad *et al*. (2010)**, who reported 13.03 and 13.3 cm respectively for “L_{m50}” as a mean value for both sexes. **Eleanor *et al*. (2016)** detected 13.25 cm in females and 12.75 cm in males. The differentiation of “L_{m50}” may be due to the variation in latitudes, food availability and the size and properties of water bodies **(Nikolsky, 1963; Babiker & Ibrahim, 1979)**.

The length at first capture (Lc) was estimated to explain the fishing regime of *S. gibbosa* in the Suez Gulf. The estimated Lc was 11.3cm, which related to an age group 1^+. Juvenile and sub adults were the mainly construction of *S. gibbosa* catch, where ‘L_{m50}” were 13.0 and 13.2 cm for male and female respectively. Effective methods must be applied to prevent over fishing, which depletes the stock of this species. In addition, *S. gibbosa* in the Suez Gulf should be given the opportunity to spawn at least once before they are caught.

However, the estimated natural mortality (M) was found to be 1.06 y^{-1}, a higher values were reported by various authors **(Abdussamad *et al*., 2010; Devaraj *et al*., 1997)**. They reported a range of 2.16 to 3.2 y-1 for Sardinella species. The estimated M / K ratio was found to be 2.46 and was within the normal range (1- 2.5) reported by **Beverton and Holt (1956)**, who investigated the direct relation between growth coefficient (K) and natural mortality (M). The same results were obtained by **Ghosh *et al*. (2012)** for *S. gibbosa* in Indian region. Concerning fishing mortality coefficient (F), the estimated value was 1.69 y^{-1}, which found to be higher than biological reference points (F_{opt} = 0.53 y-1 and F_{Limit} = 0.69). The present results suggest the higher fishing effort.

The high value of the exploitation rate (E = 0.62 y^{-1}) confirms the occurrence of over exploitation and ensures the suggestion of the highly fishing effort. The over exploitation of different fish stocks in the Suez Gulf was reported and explained in detail by **Mehanna and El-Gammal (2007)**.

Generally, available studies on *Sardinella gibbosa* are extremely rare and most of them have been conducted in the Indian Ocean region. Some differences in results may be due to the confirmed genetic differences that have been recently proven among the global population of this species **(Stern *et al*., 2016)** which affected the biological response to environmental conditions and variables. On the other hand, the spread of *Sardinella gibbosa* and its distribution to all regions of the Red Sea has not been proven, although its presence was confirmed in the Gulf of Suez, which confirms it's inhabiting and spawning in this region more and its arrival to the coasts of the Eastern Mediterranean via the Suez Canal.

CONCLUSION

The present study investigates some biological and population structure of Sardinella gibbosa in the Suez Gulf, which is found to be a confirmed spawning and rearing ground for certain fish species. Compared to other studies, mild differences in the biological aspects were obtained according to region, ecological parameters and genetic differentiations. Sardinella gibbosa in the Suez Gulf exposed to overexploitation, in addition to the abundance of sub adults. To conclude, illegal nets must be inhibited and reduction of fishing effort is recommended.

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