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Stock Analysis, Critical Lengths and Exploitation Status of the Gilthead Seabream, *Sparus aurata* (Linnaeus, 1758) in the Mediterranean Sea off Alexandria, Egypt

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ABSTRACT

The gilthead seabream *Sparus aurata* is a commercially significant fish species in the Egyptian Mediterranean fishing areas. The present study was directed to evaluate the stock status of *S. aurata* fishery from Alexandria fishing ground, Egypt. The data were collected from January to December 2022, and a total of 834 specimens were measured for length-weight and length-frequency distribution. The forked length (FL) ranged from 13.3 to 32.5cm, and the weight varied from 47.2 to 640.9g. Based on otolith readings, the growth and death rates were determined. The age composition of *S. aurata* comprises of six age groups from I to V plus age group zero. The length-weight relationship for combined sexes was $W = 0.0225\ L^{2.96}$ ($R^2 = 0.95$) showing an isometric growth. The von Bertalanffy growth parameters were $L\infty$ = 40.5cm, K = 0.236/ year, and t_o = -0.47 year. However, total mortality (Z), natural mortality (M) and fishing mortality (F) were 1.45, 0.55 and 0.90 $year^{-1}$, respectively. The exploitation ratio (E) was computed as 0.622, which is higher than the limit point (> 0.5) indicating that the stock of *S. aurata* is experiencing an overexploitation state. Critical lengths of this species were calculated giving that L_m was highly greater than L_c, forming another evidence for the overfishing situation. It may be suggested that particular management actions should be taken to conserve the stock of this fishery at a sustainable level for the forthcoming generations.

INTRODUCTION

The gilthead seabream, *Sparus aurata* (Linnaeus, 1758), locally known as "denis", is a very important fish along the Egyptian coast of the Mediterranean Sea. It is a demersal species, affiliated to the family Sparidae and is extremely valued for aquaculture, recreational and profitable purposes. It is established in a widespread range of marine habitats, from sandy to rocky bottoms, at depths between 0 to 500m, even though it is usually found at shallower depths of around 160m **(Abecasis *et al.*, 2008)**. This species is a sedentary fish that may be found solitary or in small masses.

The Egyptian coast in the Mediterranean extends nearly 1100km, covering the area from El-Salloum in the West to El-Arish in the East **(Mehanna, 2021)**. The average annual fish yield from this area does not exceed 60,000 tons **(LFRPDA, 2012, 2021)**. The total catch of the gilthead seabream along the Egyptian Mediterranean coast is recorded as 457 tons in 2021. Trawls, trammel nets and longlines are the main fishing gears used in catching the gilthead seabream **(LFRPDA, 2021)**.

The investigation of age and growth pattern is of unlimited importance to fisheries biology, where they form the basic information necessary for building a management strategy for any exploited stock **(Mehanna, 2009)**. An accurate valuation of mortality and utilization levels of commercially key fish species is vital since it is considered one of the basic input parameters for population dynamics models used in fisheries' analyses and for sustainable managing of these fisheries **(Hassanien *et al*., 2023)**.

Numeral studies have focused on diverse aspects of *S. aurata* like biology, growth, mortality & critical lengths in the Egyptian waters **(Abd–Alla, 2004; Mehanna, 2007; Al-Zahaby *et al*., 2018; Mokbel *et al*., 2020; Desouky *et al*., 2021; Mustafa *et al*., 2023)**.

The current study focused on length-weight relationship, growth, mortality, exploitation level and stock analysis of *S. aurata* from Alexandria fishing area. Findings of this study would deliver the knowledge about biological parameters and the current status of the *S. aurata* fishery from Alexandria waters. This knowledge would help fishery managers launch the applicable fishing objectives for the forthcoming generations.

MATERIAL AND METHODS

1. Sampling

Monthly *Sparus aurata* random samples were gathered from the commercial catch in the Alexandria landing site throughout the period from January to December 2022. The samples were transported in ice boxes to the Fish Population Dynamics Lab in NIOF Branch in Alexandria. For each individual fish, in cm, total length (TL) and forked length (FL)were measured using a measuring board, while weight (g) was recorded using a digital scale with a precision of 0.1g, and the sagital otoliths were taken and examined for age determination.

2. Methods

2.1 Length-weight relationship

Relation of length (FL) - weight (W) was estimated according to the method of **Le Cren (1951)**.

Where, $W= a\ FL^b$, and a & b are constants whose values were predictable by the least square method.

2.2 Age determination

Age was determined through counting yearly growth rings on the otolith of fish. The whole sagittal otoliths immersed in glycerol were read against a black background using a compound microscope. Each otolith showed clearly a focus and concentric rings formed during growth. The total otoltih radius "S" and the distance between the focus of the otolith and the consecutive annuli were measured. The S – FL relationship was investigated based on the formula FL= a + b*S.

2.3 Back-calculations

Back-calculated forked lengths at the end of every year of lifespan were predicted using the formula of **Lee (1920)** as follows: $L_n = (L - a) S_n / S + a$

Where, "L_n" is the predicted length at the end of n^{th} year; "L" is the length (TL or FL) at capture; "S_n" is the otolith radius to n^{th} annulus, and "a" is the intercept of the regression line with the Y-axis.

2.4 von Bertalanffy growth function VBGF

VBGF was applied to designate the theoretical growth of *S. aurata*. The coefficients of the VBGF (L_∞ and K) were estimated by fitting the **Ford (1933)** and **Walford (1946)** plot, while ''t_o'' was computed by the inverse von Bertalanffy growth equation.

2.5 Growth performance indices ($Ø_L$ and $Ø_{wt}$)

Growth performance index of length ($Ø_L$) and of weight ($Ø_{wt}$) were determined according to **Moreau *et al.* (1986)** equations as follows:

$Ø_L = \text{Log } K + 2 \text{ Log } L_\infty$

$Ø_{wt} = \text{Log } K + 2/3 \text{ Log } W$

2.6 Mortality and exploitation levels

The total mortality coefficient (Z) was estimated using the catch curve method as designated by **Ricker (1975)**, where Z= -b. The natural mortality coefficient (M) was calculated based on the equation of **Pauly (1980)** as follows:

$$\text{Log } M = -0.0066 - 0.279 \text{ Log } L_\infty + 0.6543 \text{ Log } K + 0.4634 \text{ Log} T.$$

Where, 'T'' is the annual mean temperature of the habitat. The fishing mortality coefficient (F) was calculated as F= Z – M, while the exploitation ratio (E) was calculated from the ratio F/Z **(Gulland, 1971)**.

2.7 Critical lengths

The length at recruitment (L_r) was determined as the smallest length of fish specimen in the catch, while the length at first capture (L_c); the length at which 50% of *S. aurata* retained in the gear was estimated by the analysis of catch curve using the method of **Pauly (1984)**. The length at first sexual maturity was estimated using the mathematical formula of **Froese and Binohlan (2006)**.

RESULTS

1. Length frequency distribution and TL-FL relationship

Fig. (1) represents the length frequency distribution of *S. aurata* which covers a length range from 13.3 to 32.5cm FL (18.31± 2.61). This corresponds to total length range of 15.5 – 36.5cm (TL) (21.55± 2.87). The length range (16 - 18) represented the majority of the observed sample (55.91%), followed by length group 19 which constituted a percent of 10.2%. After that the length distribution percentage decreased gradually as the fish length increases till it reached the lowest value (0.33%) at the length group of 32cm.

To facilitate the comparison between lengths used, the total length-forked length relationship was fitted, and the resultant equation was FL= 0.1904 + 0.8748 TL (Fig. 2).

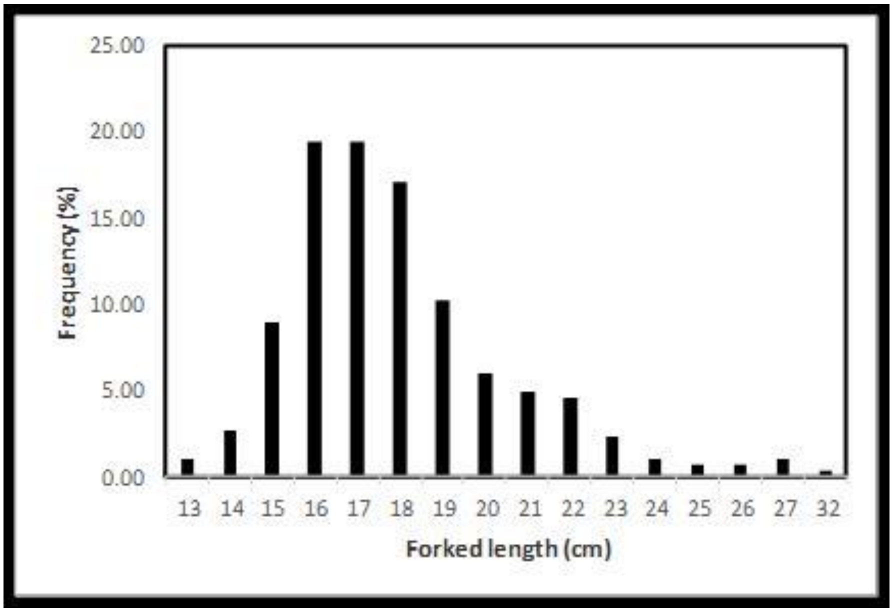

Fig. 1. Length frequency distribution of *Sparus aurata* from Alexandria

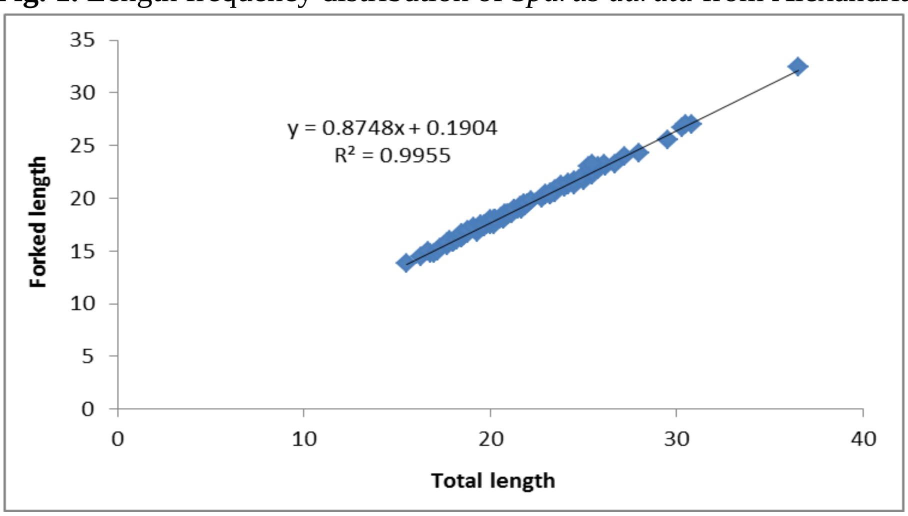

Fig. 2. Length-length relationship of *Sparus aurata* from Alexandria

2. Length- weight relationship

A power relation (Fig. 3) was applied to a sample of 834 specimens (combined sexes). The forked length (FL) of *S. aurata* varied from 13.3 to 32.5cm (18.31±2.61), while the total weight (W) ranged between 47.2 and 640.9g (132.60±67.73) and the resultant equation was:

$$W = 0.0225\ FL^{2.964}$$

With $R^2 = 0.955$ and 95% confidence limits of b = 2.789 – 3.139.

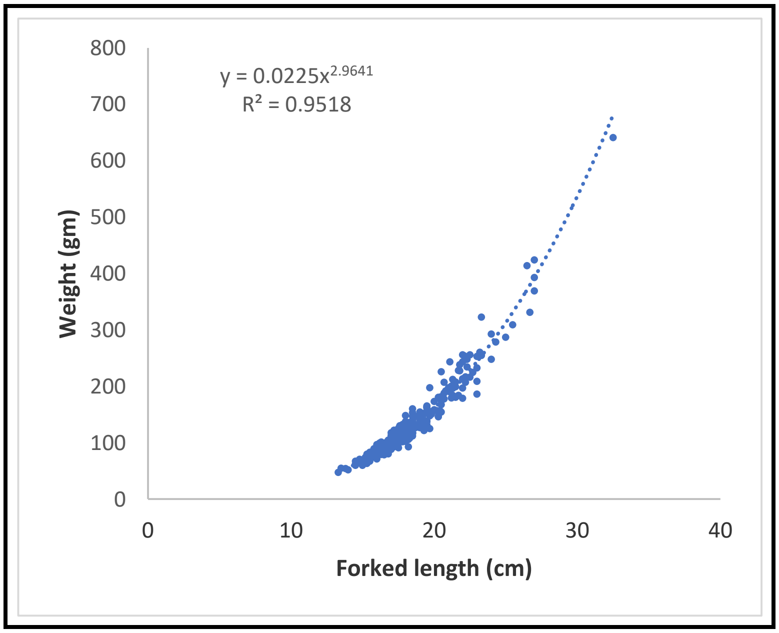

Fig. 3. Length-weight relationship of *Sparus aurata* from Alexandria

3. Length-otolith relationship

The linear regression of forked length versus otolith radius was Lt = –15.15 + 8.755 S ($R^2 = 0.873$), as shown in Fig. (4).

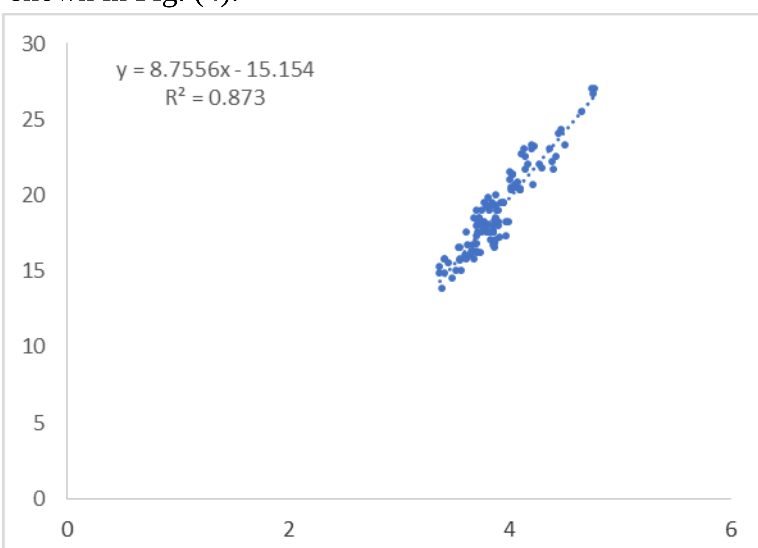

Fig. 4. Length-otolith relationship of *Sparus aurata* from Alexandria

4. Age determination

Aging of fish is an important biological variable for determining growth parameters and mortality **(Campana, 2001)**. Ages of *S. aurata* were determined by reading growth annuli on the sagittal otoliths. The population of *S. aurata* in the Egyptian Mediterranean water consists of 6 age groups; from age group I to age group V plus age group zero. The studied sample was dominated by age group I and age group II, while other ages formed minor percentages.

5. Back calculation and growth in length and weight

The average length by age was back-calculated for *S. aurata* as 17.84, 22.97, 26.52, 29.63 and 32.34cm for age groups I, II, III, IV and V, respectively (Table 1). It was observed that the higher increment in length was attained at the first year of life (17.84cm) then it gradually decreased to reach the lowest value at the age of five years (2.71cm). By using the corresponding length- weight equation on the back calculated lengths, the estimated weights at the end of every year of lifespan were valued. It seems that with the increase of age, the annual gain of weight rises, reaching its maximum value at age group V (Table 2).

Table 1. Average length at the end of each year of life of *S. aurata*

Age	I	II	III	IV	V
I	18.13				
II	18.07	23.17			
III	17.82	22.98	27.05		
IV	17.70	22.91	26.40	30.01	
V	17.50	22.83	26.12	29.25	32.34
Avr.	17.84	22.97	26.52	29.63	32.34
incr.	17.84	5.13	3.55	3.11	2.71
%	55.16	15.86	10.97	9.61	8.38

Table 2. Average weight at the end of each year of life of *S. aurata*

Age	I	II	III	IV	V
I	120.80				
II	119.62	249.93			
III	114.78	243.91	395.48		
IV	112.51	241.71	367.97	538.02	
V	108.78	239.22	356.53	498.63	671.51
Avr.	115.24	243.67	373.09	518.08	671.51
incr.	115.24	128.43	129.42	144.99	153.43
%	17.16	19.13	19.27	21.59	22.85

6. Growth parameters

The values of von Bertalanffy growth parameters were K= 0.236/year, L_∞ = 40.5cm, and t_o = -0.47 year. The growth performance in length ($Ø_L$) was 2.59, and the growth performance in weight ($Ø_{wt}$) was 1.45.

7. Mortality, exploitation and critical lengths

The estimated mortalities of *S. aurata* were 1.45 per year for total mortality, 0.55 per year for natural mortality, and 0.90 per year for fishing mortality (Fig. 5 & Table 3). The length at recruitment (Lr), length at first capture (Lc) and the length at first sexual maturity were 13.3, 15.71 and 20.11cm, respectively. The exploitation ratio (E) of *S. aurata* was 0.622, which is greater than the optimum one suggested by **Gulland (1971)** to be around 0.5.

Table 3. Some population indices of *S. aurata* from Alexandria, Mediterranean Sea

Parameter	Value
Total mortality (Z)	1.45
Natural mortality (M)	0.55
Fishing mortality (F)	0.90
Length at capture (Lc)	15.71
Length at recruitment (Lr)	13.3
Length at sexual maturity (Lm)	20.11
Exploitation ratio (E)	0.622

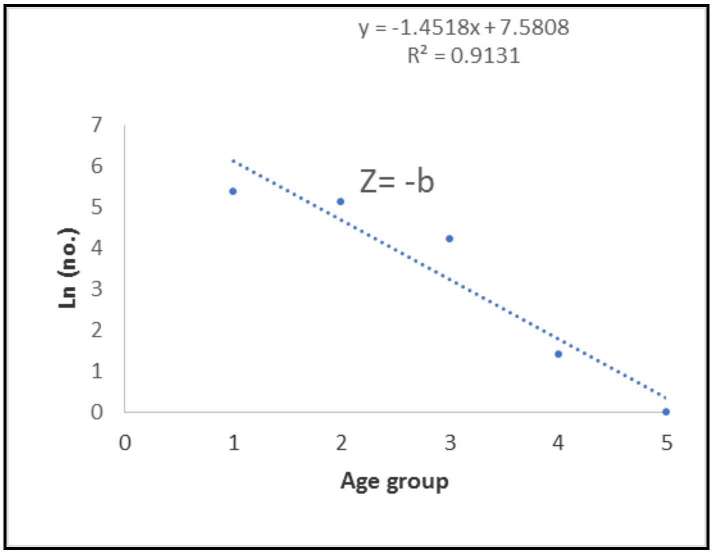

Fig. 5. Linearized catch curve for *S. aurata* to estimate total mortality (Z)

DISCUSSION

Fish belonging to the family Sparidae are commonly established along the Eastern Atlantic coasts and in the Mediterranean Sea **(FAO, 2005)**. Due to its extraordinary quality of meat, it is one of the species raised most comprehensively in fish farms in the Mediterranean countries **(Faggio *et al*., 2014)**. Coastal lagoons and estuaries are among the brackish and marine water settings where the species can be found, especially in the early phases of its life cycle **(Moretti *et al*., 1999)**.

Length and weight measurements of fish species have been frequently directed toward two objectives; first to deliver mathematical expression between the two measurements as that one may be converted to the other, and second to compute the condition factor which can be used as an indication of fatness or general wellbeing of fish **(Le Cren, 1951)**. Length- weight relationship of fish is an significant biological tool in the fish population management. For the ideal fish, the value of the exponent "b" of the LWR should be 3, indicating an isometric growth rate **(Allen, 1938)**. In the present study, the value of the exponent "b" for *Sparus aurata* was 2.964 with a CI of 2.789 – 3.139 demonstrating an isometric growth. A negative allometric growth was observed by **Akyol and Gamsız (2011)** in Turkey and by **Mustafa *et al.* (2023)** in Bardawil lagoon, Egypt (Table 4). While, an isometric growth was recorded in the studies of **Khalifa (1995)**, **Tharwat *et al*. (1998)**, **Chaoui *et al*. (2006)**, **Mehanna (2007)**, **Mercier *et al*. (2011)**, **El-Zahaby *et al*. (2018)**, **Mokbel *et al*. (2020)**, **Desouky *et al*. (2021)** and **Ozgur Cengiz (2022)**. These variations in the estimated values of "b" are acceptable where it is affected by various factors, such as fish physiology, growth, sex, sexual maturity, season, fullness of stomach, length range, sampling size, habitat, feeding rate, diet and health **(Froese *et al*., 2011; Mondol *et al*., 2017; Mehanna & Farouk, 2021)**.

Table (4) displays the number of age groups of *S. aurata* according to different studies compared to the recorded age groups in the present studies. The variations among the different results are ascribed to various reasons, such as variability in the ecological conditions in each habitat, sampling size and time, and the methodology used.

One of the most used methods for determining the growth rate of an individual fish is to back calculate its lengths in previous years of lifecycle from relative locations of annuli on its hard structures such as otolith. Fish forked length at the end of each year of life of *S. aurata* was back calculated according to **Lee (1920)**. The annual increment in length displayed the maximum value (17.84cm) during the first year of life, followed by a gradual decrease during the remaining years of life to reach its lowest value (2.71cm) at the age group V. Table (5) exhibits the average length at the end of every year of life from different areas. In Egypt, it was found that the lowest average length (16.31cm) at age group I was reported by **Mustafa *et al*. (2023)**, in Bardawil lagoon and 27.28cm at the age group V. On the other hand, the highest length was reported by **Mehanna (2007)** in Port said (21.26cm TL at age group I and 34.30cm TL at age group IV). In the present study, the average lengths estimated were 17.84, 22.79, 26.52, 29.63, 32.34cm at the end of age groups I, II, III, IV, V, respectively.

Regarding growth parameters, one of the most widespread techniques for examining theoretical growth in fisheries' science is the von Bertalanffy growth model. Growth parameters, such as $L\infty$, K, and t_o, permit the comparison of fish growth from different species or the same species at different times and in varying localities. These parameters are necessary input data for a diversity of models used in the management and evaluation of exploited fish stocks **(Mehanna *et al*., 2018)**. In the present study, the VBGF for length was $Lt = 40.5\ [1-e^{-0.236\ (t+0.47)}]$, where the asymptotic length ($L\infty$) = 40.5cm, the curvature parameter (K) = 0.236 $year^{-1}$ and age at zero length (t_o) = -0.47 year. Table (4) shows the different values of VBGP according to different authors. The current $L\infty$ is slightly more than that mentioned in the previous studies, while the values of K varied among the different studies, as shown in Table (4). These alterations in growth parameters may be attributed to a number of factors, comprising food quantity & quality, in addition to water temperature **(Santic *et al*., 2002)**, sample characteristics (sample sizes and length range), geographic variations and ageing methods (**Monterio *et al*., 2006**), inaccurate age interpretation **(Matić-Skoko *et al*., 2007; Bayhan *et al*., 2008)**. Furthermore, the estimates of growth parameters may potentially be impacted by the fishing tool's selectivity **(Ricker, 1969; Potts *et al*., 1998)**.

Table 4. Values of length- weight constants and growth parameters of *Sparus auratus* from different studies

Author	Location	Length range(cm)	Growth parameters			Age range (year)	L-wt constants	
			L∞	K	to		a	b
Ameran (1992)	Bardawil Lagoon		38.00	0.25	-1.92	1– 3		
Khalifa (1995)	Bardawil Lagoon		34.50	0.24	-1.41	1– 6	0.014	2.98
Tharwat *et al.* (1998)	Bardawil Lagoon		38.50	0.29	-1.08		0.013	3.03
Abd-Allah (2004)	Bardawil Lagoon		34.00	0.58	-0.70	–	–	
Chaoui *et al.* (2006)	Mellah Lagoon (Algeria)	15.7 – 61.0	55.30	0.51	-0.22	1– 7	0.013	3.06
Mehanna (2007)	Port Said (Egypt)	10 – 35.5	37.90	0.50	-0.60	0– 4	0.012	3.02
Akyol and Gamsız (2011)	southern Aegean Sea (Turkey)		64.90	0.14	-2.47	2– 7	0.052	2.73
Mercier *et al.* (2011)	Gulf of Lion (France)		72.30	0.10	-2.20	1–6	0.009	3.11
Hadj Taieb *et al.* (2013)	Gulf of Gabes (Tunusia)	10 –35	38.20	0.20	-1.88	0– 8	0.011	3.07
Hadj Taieb *et al.* (2015)	Gulf of Gabes (Tunusia)	10 –35	47.10	0.11	-2.95	0– 7	0.011	3.07
Al- Zahaby *et al.* (2018)	Bardawil Lagoon	10–34.2	39.17	0.37	-0.65	0 – 4	0.015	3.01
Mokbel *et al.* (2020)	Bardawil Lagoon	10.2–31	32.10	0.33	-1.33	0 – 5	0.013	3.02
Desouky *et al* (2021)	Abu Qir Bay, Alexandria	10.2–32.2	35.49	0.25	-1.27	0 – 5	0.014	3.01
Özgür Cengiz (2022)	northern Aegean Sea (Turkey)	29.5– 48	52.80	0.29	-1.25	2 – 6	0.005	3.03
Mustafa *et al.* (2023)	Bardawil Lagoon	9.7–29	39.38	0.16	-2.31	0 – 5	0.024	2.83
The present study	Alexandria (Egypt)	13.3–32.5	40.50	0.24	-0.47	0 – 5	0.023	2.96

Table 5. Average length at the end of each year of life according to different localities

Author	**Location**	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**
Abd-Allah (2004)	Bardawil fishing season 2000	19.36	23.83	28.45	31.54	32.84		
	Bardawil fishing season 2001	20.20	25.20	27.60	29.80	32.30		
Chaoui *et al*. (2006)	Mellah Lagoon (Algeria)	26.46	38.74	45.27	48.35	51.58	53.14	54.41
Mehanna (2007)	Port Said (Egypt)	21.26	27.80	32.25	34.30			
Al- Zahaby *etal*. (2018)	Bardawil Lagoon (Egypt)	17.90	24.48	29.02	32.16			
Mokbel *et a*l. (2020)	Bardawil Lagoon (Egypt)	19.10	23.10	25.20	27.00	28.50		
Özgür Cengiz (2022)	Northern Aegean Sea (Turkey)		31.10	37.00	40.00	43.00	46.00	
Mustafa *et al*. (2023)	Bardawil Lagoon (Egypt)	16.31	19.77	22.62	25.20	27.28		
The present study	Alexandria (Egypt)	17.84	22.97	26.52	29.63	32.34		

By studying the population indices of *S. aurata*, the value of forked length at first capture was 15.71cm, while the length at recruitment (Lr) was 13.3cm. Based on these results, it was revealed that the value of Lc is greater than that documented in Port Said by **Mehanna (2007)**, and also greater than that mentioned by **Al-Zahaby *et al*. (2018)** in Bardawil Lagoon (Table 6). On the other hand, **Desouky *et al*. (2023)** determined the highest value of Lc in Abu Qir Bay (18.96cm). In the present study, the estimated length at first maturity (Lm) of *S. aurata* is 20.11cm, which is higher than the length at first capture (15.71cm). This indicates that growth overfishing has just started for this species along the Egyptian Mediterranean Sea as the majority of fish were being caught before their maturation and spawning.

By assessing mortality coefficients, the obtained values were 1.45 year^{-1}, 0.55 year^{-1}, 0.90 year^{-1} for total, natural, and fishing mortality, respectively. The value of total mortality in the present study is comparable with that obtained by **Mehanna (2007)** in Port Said (1.95 year^{-1}) and also with that estimated in Abu Qir Bay by **Desouky *et al*. (2021)** which was 1.16 year^{-1}. However, it is higher than that determined by **Mokbel *et al*., (2020)** and **Mustafa *et al.* (2023)** in Bardawil Lagoon (Table 6). The exploitation ratio (E) of *S. aurata* in the present study was 0.62. **Gulland (1971)** stated that the ideal exploitation ratio (E) should be approximately 0.5, but the General Fisheries Commission for the Mediterranean **(GFCM, 2013)** recommended that E should be equal to 0.4. The general compromise was that if the exploitation ratio is greater than 0.5, this means that the fish is overexploited, and if it is less than 0.4, this means that the fish is underexploited. Therefore, we concluded that *S. aurata* in the present study suffers from overexploitation since the value of E is more than that suggested by **Gulland (1971)** and **GFCM (2013)**. This result is in agreement with other authors from different regions **(Mehanna, 2007; Al-Zahaby *et al*., 2018; Mokbel *et al*., 2020; Desouky *et al*., 2021; Mustafa *et al*., 2023)**, who determined a value of E greater than 0.5 (Table 6).

Table 6. Different values of some population indices according to different studies

Author	Location	Z (y^{-1})	M (y^{-1})	F (y^{-1})	E	Lc(cm)	Lm(cm)
Mehanna (2007)	Port Said	1.95	0.62	1.33	0.68	11.1	
Al-Zahaby *et al*. (2018)	Bardawil Lagoon	1.08	0.394	0.691	0.637	12.85	
Mokbel *et al*. (2020)	Bardawil Lagoon	0.792	0.153	0.554	0.803		
Desouky *et al*. (2021)	Abu Qir Bay, Alexandria	1.16	0.56	0.6	0.52	18.96	
Mustafa *et al*. (2023)	Bardawil Lagoon	0.794	0.23	0.56	0.71		
the present study	Alexandria	1.45	0.55	0.9	0.62	15.71	20.11

CONCLUSION

It could be concluded that the studied species in Alexandria fishing ground is heavily exploited. For the management purpose, the present level of exploitation rate should be decreased by about 30 - 40% in Alexandria to conserve an enough spawning biomass for recruitment. This can be attained by decreasing the fishing effort by at least 30% of its current level to protect the spawners. In addition, all profitable stocks exploited by trawling should be assessed to propose a realistic management plan for this multispecies fishery.

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