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Stock assessment of the lessepsian Reticulated leatherjacket *Stephanolepis diaspros* (Fraser-Brunner, 1940) in the Gulf of Gabès (Eastern Mediterranean Sea)

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Abstract

Assessing population dynamics is essential for the effective management of fish stocks. In this context, the current study examined key parameters: growth, mortality, and recruitment of *Stephanolepis diaspros* in the Gulf of Gabès, utilizing the FiSAT II (FAO-ICLARM Stock Assessment Tools) software (version 1.2.2) for analysis. The specimens were collected from monthly sampling of *S. diaspros* along the continental shelf of the Gulf of Gabès, between the parallel 35°N and the Libyan border, mainly at depths between 0 and 40 m and by collecting monthly samples from Sfax fishing harbour. A total of 1116 individuals were collected from August 2015 to February 2017. Most were small, ranging in size from 3.7 to 23.7 cm, and weighing 1.05 to 235.3 g respectively. Von Bertalanffy growth was deployed to determine the growth parameters of this alien fish. The asymptotic length is $L\infty = 37\ cm$, with a growth performance $\phi' = 2.628$, justifying the moderate growth rate $K = 0.31\ yr^{-1}$. Theoretical age $(t_0 = -1.976\ yr^{-1})$ and longevity or maximum age $(t_{max} = 9.664\ yr^{-1})$ were determined. Battacharya's method incorporated in the FISAT II software was applied to identify the different age groups (cohorts) and the mean length of each group. Age and Growth Plotting the decomposition of the length frequency distribution clarified four age groups with a dominance of the group II.

Natural mortality for this alien species $(M = 0.66\ yr^{-1})$ is lower than fishing mortality $(F = 2.81\ yr^{-1})$. The exploitation rate $(E = 0.81)$ is higher than the critical value $(E = 0.5)$. These results suggest that this species is overexploited in the Gulf of Gabès and the size of first capture $(L_c = 11.95\ cm)$ is lower than the size of first maturity $(L_m = 21.4\ cm)$ also, a condition that can disturb the stock.

Analysis of relative yield per recruit (Y'/R) indicates that the exploitation rate exceeds $E_{max}\,(0.557)$ and $E_{0.5}\,(0.308)$, thereby confirming overfishing. To ensure sustainable and rational management of this species, it is advised to decrease the exploitation rate from 0.81 to 0.308, representing a 49.8% reduction. The current research on the population dynamics of *S. diaspros* and emphasizes the importance of proactive measures to protect pelagic fish populations and maintain sustainable fishery resources. All parameters in the study of stock assessment of this species $(Z, M, F, L\infty, E, E_{max}, E_{0.5}, L_c, L_m)$ shows significant differences between males and females.

No prior studies or assessments were available concerning fish stock evaluation, making these results the first data on the overall status of this species in the Mediterranean Sea.

Keywords: *Stephanolepis diaspros*; Eastern Mediterranean Sea; Growth; Mortality; Exploitation; Yield per recruit

Introduction

The Mediterranean Sea is a globally recognized biodiversity hotspot, hosting approximately 17000 marine species, many of which are endemic. However, this semi-enclosed basin is undergoing significant ecological transformations due to various anthropogenic pressures, including habitat degradation, overfishing, pollution, and climate change. Among these challenges, the introduction of alien species through Lessepsian migration has emerged as a key driver of change, particularly in the eastern Mediterranean Sea. Lessepsian migration refers to the movement of marine organisms from the Red Sea into the Mediterranean via the Suez Canal, which has acted as a corridor for bioinvasions since its opening in 1869. This phenomenon has introduced nearly 1000 alien species to the Mediterranean, with many establishing themselves as dominant components of local ecosystems [1,2].

The *Monacanthidae* family, commonly known as filefishes, is closely related to the Balistidae family, and the two are often grouped together. Monacanthidae includes around 95 species, most of which are found in tropical regions. Of these, only one species, the reticulated leatherjacket *(Stephanolepis diaspros)*, originally from the Red Sea, has been reported in the Mediterranean Sea [3].

The Reticulated leatherjacket, *Stephanolepis diaspros* Fraser Brunner, 1940 is among the earliest Lessepsian settlers in the Mediterranean [4,5]. This specie is characterized by its compressed lateral body and rough skin. It inhabits inshore in sandy and rocky habitats in vegetation usually at depths not exceeding 20 meters [3,5]. Common sizes of *S. diaspros* range from 7 to 15 cm, with the maximum as 30.5 cm [6]. They feed on phytobenthos and small rock-dwelling organisms, especially small benthic invertebrates, mainly crustaceans, foraminifers, gastropods, ostracods, sea urchins [3,7,8]. Young individuals feed also in open water areas with sandy and muddy substrates [9].

S. diaspros is distributed in Arabian and in Red Sea (Randall 1995) [9], and entered the Mediterranean Sea through Suez Canal, such as other lessepsian migrant species [10]. Since the first record off Palestine [11], this demersal fish has now become common in several Mediterranean regions, where it appears to have successfully adapted to local conditions [9]. Thus, a sustainable population was successfully established in Turkish seas, for instance [12,13]. Also, it reached Gulf of Palermo, Sicily [14], the Adriatic Sea [15], and Maltese waters [16].

In the Tunisian coast, characterized by a warm and oligotrophic waters, *S. diaspros* was first recorded by Chakroun [17] in the Gulf of Gabѐs, furtherly, reported by Bradaï [18], Bradaï et al. [19] and Zouari-Ktari et al. [7,20,21] in the area. Northward, this species was recorded by Bdioui et al. [22] in a brackish area, the Bizerte Lagoon and by Ben Amor and Capapé [23] in Tabarka (northern Tunisia) and constituted the northernmost record of *S. diaspros* in the region and the westernmost in the Mediterranean Sea.

The presence and the establishment of a population of *S. diaspros* in the Gulf of Gabѐs raise both ecological and economic concerns. Ecologically, it competes with native species for resources and may alter local food webs. Economically, it has become an incidental catch in regional fisheries and represents an additional resource for some coastal communities [2,6].

This rapid expansion of *S. diaspros* in the Gulf of Gabѐs, raises important questions about its potential ecological impact and its population dynamics within this vulnerable ecosystem. Its increasing commercial exploitation calls for a better understanding of its biology, particularly its growth and population structure, in order to support sustainable management. Despite its growing significance, there is limited information on its biological traits and population dynamics in Tunisian waters except the both works of Zouari-Ktari et al. [7,21].

The present study aims to address this gap by estimating growth parameters and analyzing the population structure of *S. diaspros* in the Gulf of Gabѐs based on length-frequency data using the tools provided by the FISAT II software. Understanding these aspects is crucial for assessing its ecological impact and for informing management strategies in this rapidly changing ecosystem and potential fisheries implications. Such information is very important in Tunisian fisheries management strategies.

Despite the increasing presence of *S. diaspros* in the Mediterranean Sea, research has predominantly focused on its biological aspects, such as reproduction and diet. Studies have documented its reproductive biology in regions like the Gulf of Gabѐs [21] and the Gulf of Suez [24], as well as its feeding habits [7]. The study by El-Ganainy and Sabra [25] is the only work that addresses age, growth, mortality, and yield per recruit in the Gulf of Suez. Thus, comprehensive stock assessments of *S. diaspros* populations are notably lacking in both the Mediterranean and its native range in the Red Sea and Indo-pacific Ocean. This gap in knowledge hinders effective management and conservation strategies for the species, underscoring the need for further research into its population dynamics and stock status.

The present study represents the first comprehensive investigation into the growth, population dynamics, and stock assessment of *S. diaspros* in the Mediterranean region. By addressing this critical knowledge gap, the research aims to provide essential data for the sustainable management and conservation of this species, which has become increasingly significant in local fisheries.

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Materials and Methods

Sampling Site study area

The Gulf of Gabės spans approximately from 33° to 35.5°N in latitude and from 9.5° to 12.5°E in longitude, known as the Lesser Syrtis, is located in the south-eastern part of Tunisia, along the eastern Mediterranean coast (Figure 1). It is characterized by its wide continental shelf, one of the most extensive in the Mediterranean Sea, which can reach up to 80 kilometers in width and is bounded by the Kerkennah Islands to the northeast and Djerba Island to the southeast. This shallow marine area is influenced by semi-diurnal tides. Thus, it is one of the few areas in the Mediterranean with a significant tidal range and presents a high level of ecological productivity, making it an important fishing ground for both artisanal and industrial fisheries. It has a high primary productivity due to nutrient inputs from sediment resuspension (driven by tidal currents), freshwater discharges (e.g., from the Wadi Akarit and Wadi Gabės) and upwelling events along the Kerkenah Islands [26,27].

The Gulf is known for its diverse habitats, including seagrass beds *(Posidonia oceanica)*, sandy and muddy bottoms, and coastal lagoons, which support a rich marine biodiversity. The Gulf also acts as a nursery and spawning ground for migratory species such as cephalopods, turtles, and sharks, many of which are listed as endangered by the IUCN [27-32]. However, the region is also subjected to various anthropogenic pressures, such as overfishing, pollution, and habitat degradation, which threaten its ecological balance.

Due to its unique environmental conditions and strategic geographical position, the Gulf of Gabès has become a favourable site for the establishment and expansion of Lessepsian species, including *S. diaspros*, whose presence may influence local biodiversity and fisheries dynamics. The present study focuses on this area to evaluate the growth patterns and population structure of this invasive filefish species.

Specimens sampling and measurements

Monthly sampling of *S. diaspros* was carried out in pelagic trawlers, along the continental shelf of the Gulf of Gabès, mainly at depths ranged 0 and 40 m as well as through monthly collecting samples from Sfax fishing harbour. Fishes were taken from the net, identified to species, segregated by sex and then frozen for laboratory examination. In the laboratory, the total length (TL) of each specimen collected was measured to the nearest 1 mm using an ichtyometer and the total weight was also recorded to the nearest 0.01 g using an electronic balance.

Growth and Exploitation Parameters

Growth parameters

The analysis of population parameters was conducted based on length frequency distribution using the FAO-ICLARM Stock Assessment Tools (FISAT II) software package (version 1.2.2) [33]. It is one of the most widely used models for growth studies in fisheries biology. Bhattacharya's method [34] incorporated in FISAT II software was applied to identify age classes (cohorts) within the population and determine the mean length of each class. The Asymptotic length $(L\infty)$ and the growth coefficient (K) of the Von Bertalanffy Growth Formula (VBGF) were estimated using the ELEFAN-I according to Pauly and Morgan [35]. Then, the VBGF was fitted to estimates of length-at-age expressed by the following equation:

$$LT = L_{\infty}\left[1 - e^{-k(t-t_0)}\right]$$

Where: TL: mean fish length at age t (cm), L_{∞} : asymptotic length (cm) at which growth is zero, K: growth rate $\left(yr^{-1}\right)$, t_0: the theoretical age at which the fish has zero size [33].

The theoretical age $\left(t_0\right)$ was calculated according to the following relationship elaborated by [36]:

$$Log_{10}\left(-t0\right) = -0.392 - 0.275 \times Log_{10} L_{\infty} - 1.038 \times Log_{10} K$$

The von Bertalanffy Growth Function (VBGF) was fitted to the length frequency data to estimate the asymptotic length $\left(L_{\infty}\right)$ and the growth coefficient (K).

The estimated values of $\left(L_{\infty}\right)$ and k were used to determine the growth performance index (ϕ') and growth inflection point age $\left(t_{tp}\right)$ using the following formulae of Pauly [37]:

$$\phi' = LogK + 2 \times LogL\infty$$

$$T\max = t_0 - \frac{1}{k} Log 0,05$$

$$t_{tp} = \frac{Lnb}{k} + t_0$$

The growth performance index (ϕ') was computed to compare with other population.

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Age and growth

Age estimation was performed for *S. diaspros* in the Gulf of Gabės using an age-length key. The age-length key was developed based on the length-frequency distribution of the sampled individuals and applied to the entire population as well as separately for males and females. To construct this key, we utilized the FISAT software, which is a widely used tool in fisheries biology for analyzing fish population dynamics. FISAT allows for the efficient estimation of growth parameters and age structures based on length-frequency data. By assigning individuals to age groups according to their total length, we were able to determine the age composition of the population. This method provided valuable insights into the growth dynamics, reproductive potential, and age structure of this invasive species, essential for its management and understanding of its ecological impact in the Gulf of Gabės.

Mortality, Exploitation, and Survival

The total instantaneous mortality rate (Z) was calculated using a length-converted catch curve method incorporated in FiSAT II software as described by Pauly [37] and expressed as:

$$Ln\left(\frac{N}{\Delta t}\right) = Zt_0 + c$$

Where N is the number of samples in different length groups; Δt is the time required for the corresponding body length group to go from the lower limit to the upper limit; $Ln = (N/\Delta t)$ is the number of deaths in the population N at time t and c is the intercept.

Natural mortality (M) was estimated according to Pauly [38] as:

$$Log_{10}M = \left[-0.0066 - 0.279 \times Log_{10}L\infty + 0.6543 \times Log_{10}K + 0.4634Log_{10}T\right]$$

Where: $(L\infty)$ and (K) are Von Bertalanffy parameters and (T) is average annual surface temperature. According to data obtained from relevant local authorities, T is 19.5 °C.

A number of relationships exist between the total (Z), natural (M) and fishing (F) mortality coefficients, as well as with the exploitation rate $(E): Z = M + F$; When two of the mortality parameters are known, the third is automatically deduced. Fishing mortality $(F) = Z - M$ and The exploitation rate $(E) = F / Z$ [39].

Following Gulland work on the exploitation rate (E) of a fishery resource, when E < 0.5, the stock is said to be underexploited, when E > 0.5 the stock is overexploited, and when E = 0.5 or F = M, the stock is optimally exploited [39].

The survival rate (S) are represented by the formula [40]

$$S = e^{-z}$$

where e is Euler's number.

Recruitment and First-Capture Size

Recruitment refers to the addition of new individuals to a harvestable stock and plays a crucial role in shaping fish population dynamics [41]. Thus, recruitment is the arrival of the youngest age group of individuals, called recruits, into the fishery each year for the first time [42].

These individuals are characterized by a size known as the recruitment size in the fishery (L_c or L_{50}), corresponding to the size at which the fish becomes exploitable, that is, likely to be encountered in fishing gear. Several stocks show considerable interannual variations in the number of recruits. It is therefore important to take this into account in stock dynamics assessments. Monthly recruitment patterns were calculated from the length frequency data series. For this purpose, the program incorporated in FISAT II [43] was used. The monthly recruitment estimates were generated following the procedure described by Dadzie et al. [44].

The ogive selection method proves that the probability of a fish being caught is correlated with its length. On this basis, the length at which 50% of the catch retains by the fishing (L_{50}) (length at first capture) was estimated from the catch curve analysis (probability of capture by length) incorporated in the FISAT II, according to Pauly [45,46]. In addition, the lengths associated with the 25th and 75th percentiles of catches were established at cumulative probabilities of 25% and 75%, respectively. Length at first sexual maturity (L_m) was obtained according to Froese and Binohlan [47] as follow:

$$Log_{10}M = \left[-0.0066 - 0.279 \times Log_{10}L\infty + 0.6543 \times Log_{10}K + 0.4634Log_{10}T\right]$$

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The optimal length of capture $\left(L_{opt}\right)$ is the length at optimum yield. It is determined for a given cohort according to the equation of Beverton [48]:

$$L_{opt} = L_{\infty} * \left[\frac{2}{3 + \frac{M}{K}} \right]$$

L_{∞} and K are function of Von Bertalanffy growth, while the value of M depends on the natural mortality rate. The recruitment period for *S. diaspros* in the Gulf of Gabès was determined using FiSAT II (recruitment patterns method), based on individual size frequency data.

Relative yield-per-recruit (Y'/R) and relative biomass-per-recruit (B'/R): Beverton and Holt Y'/R analysis

Y'/R (Relative Yield per Recruit) estimates the expected catch (in weight) per recruit, considering growth and mortality rates. Lower values suggest that each recruit contributes less to the fishery, potentially due to high mortality or early capture. B'/R (Relative Biomass per Recruit) reflects the average biomass each recruit contributes to the stock over its lifetime. Values below 1 indicate that the biomass per recruit is reduced compared to an unfished population, often due to fishing pressure.

The knife edge approach implemented in the FiSAT II software was applied for the Beverton and Holt analysis to generate plots of the relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) against as functions of the exploitation rate [49,50]. The analysis determined the maximum allowable exploitation rate $\left(E_{\max}\right)$ that yields the highest relative yield-per-recruit (MSY =Maximum Sustainable Yield).

Additionally, $E_{0.1}$, the exploitation rate at which the marginal increase in relative yield-per-recruit reaches 10% of its virgin stock, and $E_{0.5}$, the exploitation rate corresponding to 50% of the unexploited relative biomass per recruit (B/R) (TRP = target reference point), were calculated. Yield contours were created to illustrate the yield isopleths, enabling an assessment of the impacts of changes in exploitation rate $E_{\max}$ and the critical length ratio $(L_c = L_{50} / L_{\infty})$ on yield.

Virtual population analysis (VPA)

The previously determined growth and mortality parameters $\left(L_{\infty}, K, t_o, M, F, a, and\ b\right)$ were used as input data for the Virtual Population Analysis (VPA) performed following the methodology outlined by Gayanilo et al. [33].

Results

Length-Frequency Distribution

A total of 1116 specimens, with total lengths (TL) varying between 3.7 and 23.7 cm, were examined. The greatest number of specimens caught was between 11 and 14.9 cm (Figure 2), and the most common size is 12.5 for all specimens, 15.5 cm for males and 13.6 cm for females. The characteristics of this population were resumed in Table 1.

Growth and Exploitation Parameters

Growth parameters

The asymptotic length is the theoretical maximum length that individuals of this exotic species can reach in this fraction of Mediterranean Sea, in relation to the factors influencing their environment. The value of K corresponds to the speed at which these fish grow to reach this greatest length locally. The asymptotic length obtained is 37 cm. The growth rate obtained K for this species is 0.31 yr^{-1}, length-based index of growth performance (ϕ' = 2.628), theoretical age $\left(t_0 = 1.976\ yr^{-1}\right)$ and longevity or maximum age in the Gulf of Gabès $\left(t_{\max} = 9.84\ yr^{-1}\right)$. The largest growth inflection point age $\left(t_{tp}\right)$ was detected for males (6.157) because they have an important value of growth rate (Table 2). The von Bertalanffy growth curve used to determine these parameters is shown in Figure 3. The comparison of the growth parameters between all sample, males and females are presented in Table 2. The representation of growth curve is provided in Figure 3. The blue growth curves are superimposed on black size frequency distributions of the samples. Each blue curve illustrates the progression of a cohort or age class that appeared successively (on the same date).

Age and Growth

Plotting the decomposition of the length frequency distribution (Figure 4) clarified four age groups; I, II, III and IV; for all sample, males and females of the lessepsian specie *S. diaspros* in the Gulf of Gabès. Group III was predominantly represented among males (62.6 %), whereas Group II was more prevalent among combined sexes and females (67.26 %) (Table 3).

The estimated mean length at age allowed us to plot length-at-age curves for the entire sample and for males and females separately (Figure 5).

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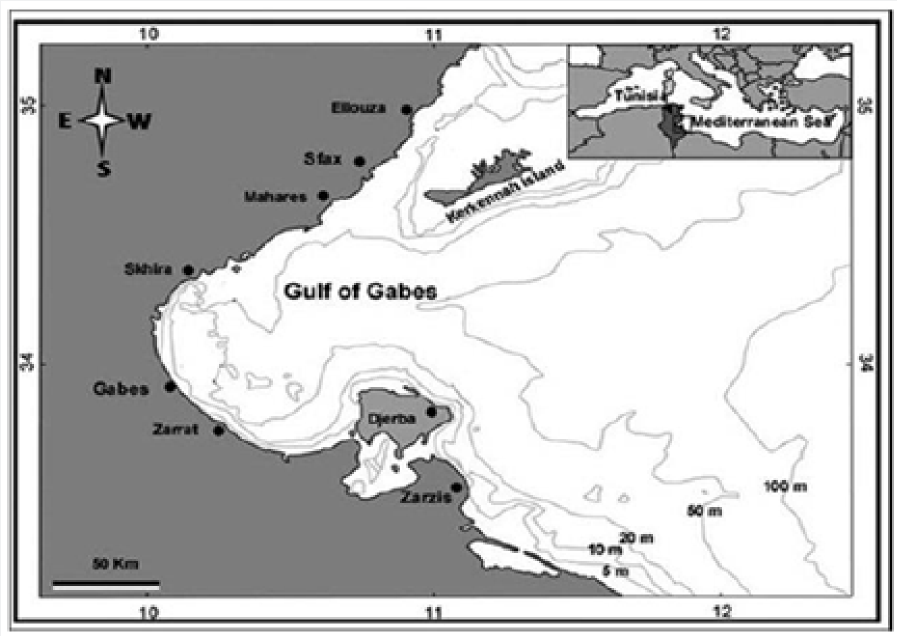

Figure 1: Map of the Gulf of Gabès and his location in the Mediterranean Sea.

Table 1: Characteristics of the population of *S. diaspros* in the Gulf of Gabės.

Sex	N	TL Range (cm)	Mode (cm)	σ^2	S.D.	Q1	Q2	Q3
M+F	1116	3.7-23.7	12.5	9.61	3.1	11.4	13.4	15.5
M	571	6.5-23.7	15.5	34.04	5.83	13	15.1	17.1
F	459	7.8-19.1	13.6	4.23	2.06	10.9	12.2	13.6

σ^2: variance; S.D.: standard deviation, Q1 (First Quartile): the 25th percentile. It marks the value below which 25% of the data fall; Q2 (Second Quartile or Median): This is the 50th percentile. It divides the data set into two equal halves; Q3 (Third Quartile): This is the 75th percentile. It marks the value below which 75% of the data fall.

Table 2: Parameters of the Length weight relationship (a and b), Von Bertalanfy growth parameters (L_∞, K, t_0), index of growth performance ϕ›, tmax and t_{tp} of *S. diaspros* from the Gulf of Gabės.

Growth Parameters	M+F	Males	Females
N	1116	571	459
a	0.043	0.035	0.036
b	2.684	2.755	2.75
L_∞ (cm)	37	28.5	22.65
K	0.31	0.8	0.36
t_0	1.976	4.92	2.016
ϕ'	2.628	2.813	2.26
t_{max}	9.84	8.67	8.63
t_{tp}	4.135	6.157	4.05

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Table 3: Age-length Key of *S. diaspros* (all sample, males and females) in the Gulf of Gabės obtained by Bhattacharya's method. S.D.: standard deviation, S.I.: separation index, n.a.: not affiched.

Group	Computed Mean	S.D.	Population	S.I.	Frequency (%)
All samples					
1	9.61	2.230	183.22	n.a.	16.12
2	13.69	2.320	852.23	1.920	75
3	17.00	1.930	92.82	1.880	8.16
4	21.00	1.910	8.01	2.020	0.7
Males					
1	8	0.950	8.00	n.a.	1.31
2	11.54	1.490	124.00	2.900	20.42
3	15.31	1.880	380.00	2.240	62.6
4	18.39	1.670	95.00	1.740	15.65
Females					
1	9.16	0.7	56.19	n.a.	11.08
2	11.83	1.480	341.05	2.100	67.26
3	14.21	0.950	88.31	1.990	17.41
4	17.23	1.200	21.45	2.110	4.23

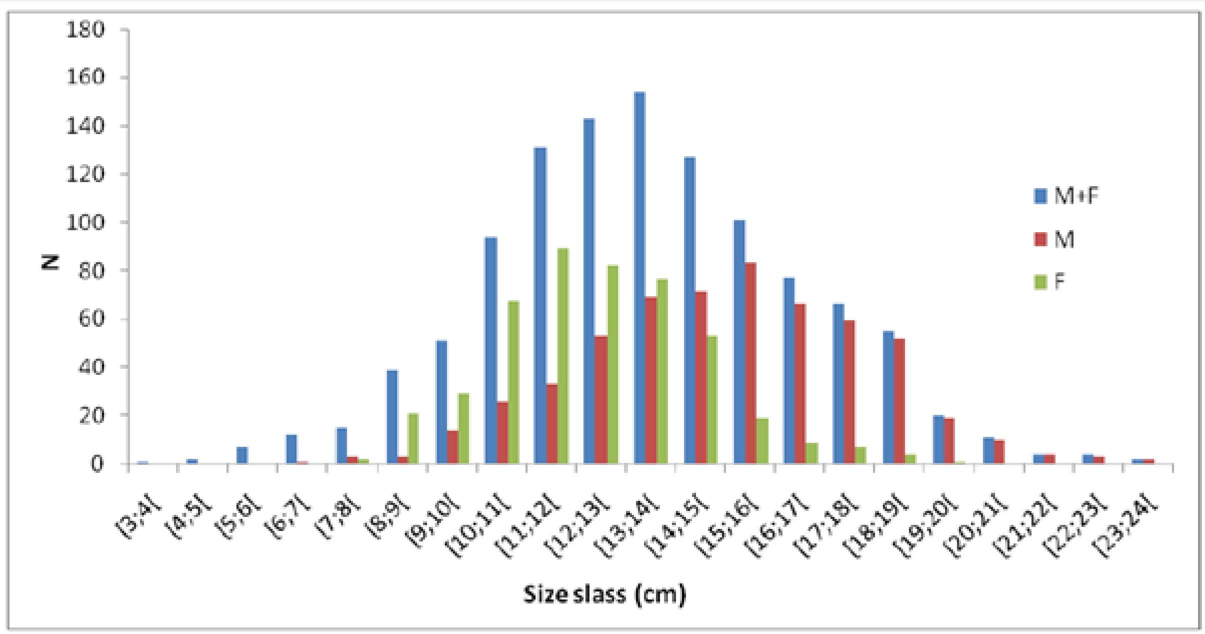

Figure 2: Length-frequency histograms of *S. diaspros* in the Gulf of Gabès.

Mortality, Exploitation, and Survival

Three instantaneous mortality rates for *S. diaspros* populations can be calculate: The total instantaneous mortality (Z) can be estimated using the L-converted catch curve method in FiSAT II software. Length-based catches with extrapolated data points are represented in Figure 6. The points represent the natural logarithm of the numbers per age class. The white points represent the theoretical values that should be considered. The yellow points are not considered because they are either too close to or too far from the asymptotic length. The black points are those used for the least squares calculation of the linear regression. These black points are used for the estimation of total mortality.

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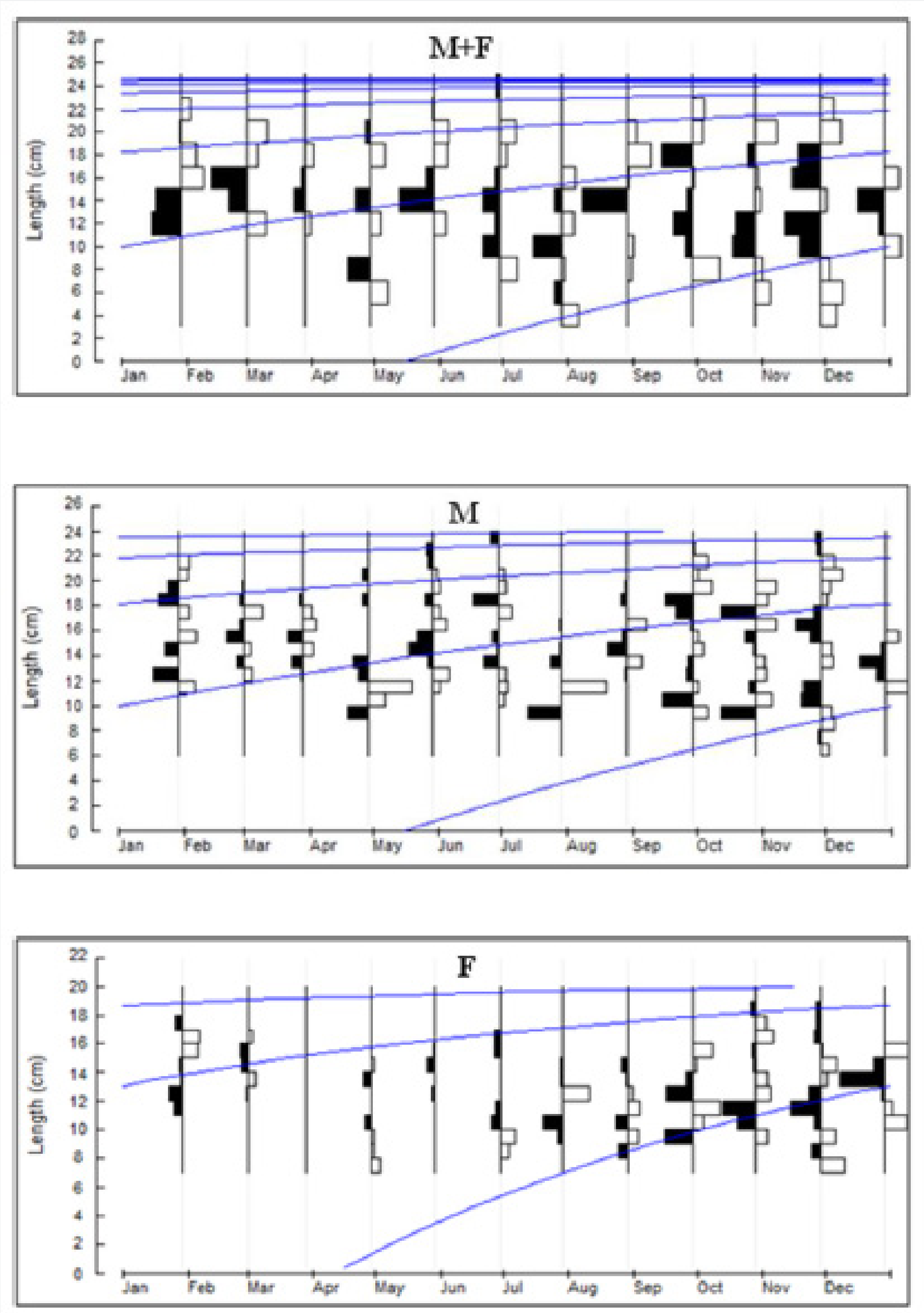

Figure 3: Growth curve of *S. diaspros* from the Gulf of Gabès.

The slope of the line produced by the formula $LnN / \Delta t = -3.47t + 13.091$ for all sample, $LnN / \Delta t = -2.46t + 7.428$ for males and In $N / \Delta t = -1.81t + 10.102$ for females represents the estimated values of Z (Table 4). The values obtained with a mean surface temperature of 19.5°C are total mortality (Z), natural mortality (M), fishing mortality (F) and exploitation rate (E) in the Gulf of Gabès marine waters. The exploitation rate (E) for all sample, males and females are respectively 0.81, 0.46 and 0.54) (Figure 6, Table 4).

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Table 4: Data obtained from the FiSAT software, including the values of Z (total mortality), F (fishing mortality), M (natural mortality), and E (exploitation rate), L_{25}, L_{50}, L_{75}, L_{op} and L_m. The intercept and the slope of the line produced by the formula In N/□t of *S. diaspros* from the Gulf of Gabės.

	M+F	Males	Females
Z	3.47	2.46	1.81
M	0.66	1.32	0.84
F	2.81	1.14	0.97
E	0.81	0.46	0.54
S	0.0311	0.0854	0.1636
L_{25}	10.9	8.04	11.95
$L_{50} = L_c$	11.95	8.86	13.77
L_{75}	13.01	9.68	15.6
Z/K	11.19	3.075	5.028
Intercept (a)	13.091	7.428	10.102
Slope (b)	-3.474	-2.456	-1.806
R	-0.9996	-0.9994	-0.9907
r^2	0.992	0.9989	0.9814
L_{op}	21. 64	18.4	12.74
L_m	21.42	16.91	13.76

Table 5: Exploitation parameters of *S. diaspros* (all samples, males and females) of the Gulf of Gabės obtained by the knife edge selection hypothesis in the B-H dynamic equation.

	M+F	Males	Females
M/K	2.13	1.65	2.33
L_c/L_∞	0.32	0.31	0.608
Y'/R	0.011	0.033	0.021
B'/R	0.032	0.223	0.357
E	0.81	0.46	0.54
$E_{0.1}$	0.466	0.451	1
$E_{0.5}$	0.308	0.307	0.404
E_{max}	0.557	0.528	1

Table 6: A comparison of VBGP for *S. diaspros* from the Gulf of Gabės and the Gulf of Suez.

	Gulf of Gabės	Gulf of Suez
L∞ (cm)	37	27.83
K	0.31	0.35
t_0 (year^{-1})	-1.976	-0.499

Table 7: A comparison of the mean estimated lengths at age for *S. diaspros* from the Gulf of Gabės and the Gulf of Suez.

	Gulf of Gabės		Gulf of Suez			
	Battacharya method		Battacharya method		Age reading	
Age group	Mean length	%	Mean length	%	Mean length	%
0	-	-	9	8.67	8.9	11.63
1	9.61	16.12	14.89	65.47	13.65	42.72
2	13.69	75	18.17	19.21	18.74	32.9
3	17.00	8.16	22.00	5.95	23.06	11.45
4	21.00	0.7	25.55	0.68	25.65	1.27

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Table 8: A comparison of the mortality and the exploitation parameters of *S. diaspros* from the Gulf of Gabės and the Gulf of Suez.

Parameters	Gulf of Gabės	Gulf of Suez
Z	3.47	1.88
M	0.66	0.702
F	2.81	1.178
E	0.81	0.627
M/K	2.13	2.006
Lc	11.95	8.5
$E_{0.1}$	0.466	0.457
$E_{0.5}$	0.308	0.305
E_{max}	0.557	0.541

Recruitment and First-Capture Size

The potential length of 50% of the population being captured was estimated as 11.95 cm for all sample, 8.86 cm for males and 13.77 cm for females (Figure 7). The length at first sexual maturity (L_m) was found to be 21.4 cm for all sample, 16.91 cm for males and 13.76 cm for females, in addition to 21.64 cm for the optimum length (L_{op}) for all sample, 18.4 cm for males and 12.74 cm for females, which generate the maximum sustainable yield (Figure 7, Table 4).

The recruitment histogram for *S. diaspros* shows continuous recruitment throughout the year (Figure 8), with a significant peak in the months of June-July for all sample and males but females show 2 peaks in June-July and another in October.

Relative yield-per-recruit (Y'/R) and relative biomass-per-recruit (B'/R): Beverton and Holt Y'/R analysis

These exploitation rate of *S. diaspros* were obtained by the knife edge selection hypothesis in the B-H dynamic equation. The Y'/R and B'/R values were evaluated according to L_c / L_∞ and M / K. The analytical model of relative yield per recruit was applied to clarify the current and optimal status of *S. diaspros* stock in the Gulf of Gabės (Table 5). The value of relative yield per recruit (Y'/R) was 0.011 for all samples, 0.033 for males and 0.021 for females and the value of relative biomass-per-recruit (B'/R) was 0.032 for both sexes, 0.223 for males and 0.357 for females. The values of $E_{0.1}$, $E_{0.5}$ and $E_{\max}$ were resumed in Table 5. The peak relative yield per recruit (Y'/R) occurred at Emax, signifying the maximum sustainable yield (MSY). The findings demonstrate that the exploitation rate (E = 0.81) surpasses the threshold that would yield the maximum relative yield per recruit $\left(E_{\max} \text{ or } MSY = 0.557\right)$ and E0.5 for all samples (Figures 9 & 10).

Virtual population analysis

Virtual population analysis (VPA) provides valuable information on the proportion of survivors and the losses attributed to both natural mortality and fishing activities which are assessed by plotting various length groups against fishing mortality. In the present study, survival rates and natural mortality decreased as body length increased were observed for both males and females (Figure 11). The highest catch rates were recorded in the length groups of 10 to 18 cm for combined sexes, between 11.5 and 18.5 cm for males and between lengths classes 10.5 to 14.5 cm for females.

Fishing mortality also increased after a length of 8 cm, 9.5 cm and 7.5 cm for combined sexes, males and females respectively and attained a peak at a mid-length of 18 cm for all samples and 18.5 for males. For females we find two peaks in mid length 14.5 and 18.5 cm.

Discussion

The growth pattern, exploitation level, recruitment capacity, and mortality are among the key factors influencing fish population dynamics. Aside from the study by El-Ganainy and Sabra [25], which remains the only comprehensive research to date on the population dynamics of this species in the Gulf of Suez, no prior studies or assessments have been conducted on this parameter for the alien fish *S. diaspros* in the Red Sea or in the Mediterranean Sea. As such, the present findings represent the first available data on the overall status of this species in the study area.

S. diaspros, commonly referred to as filefish, is a pelagic species abundant along the coastline of the Gulf de Gabès. It is harvested year-round but no holds considerable financial significance in Tunisian's markets. Despite not being widely recognized as a food fish, it shows significant potential as an alien species. This makes the study of its population dynamics and related characteristics tend to be imperative, forming the basis for the current research focus.

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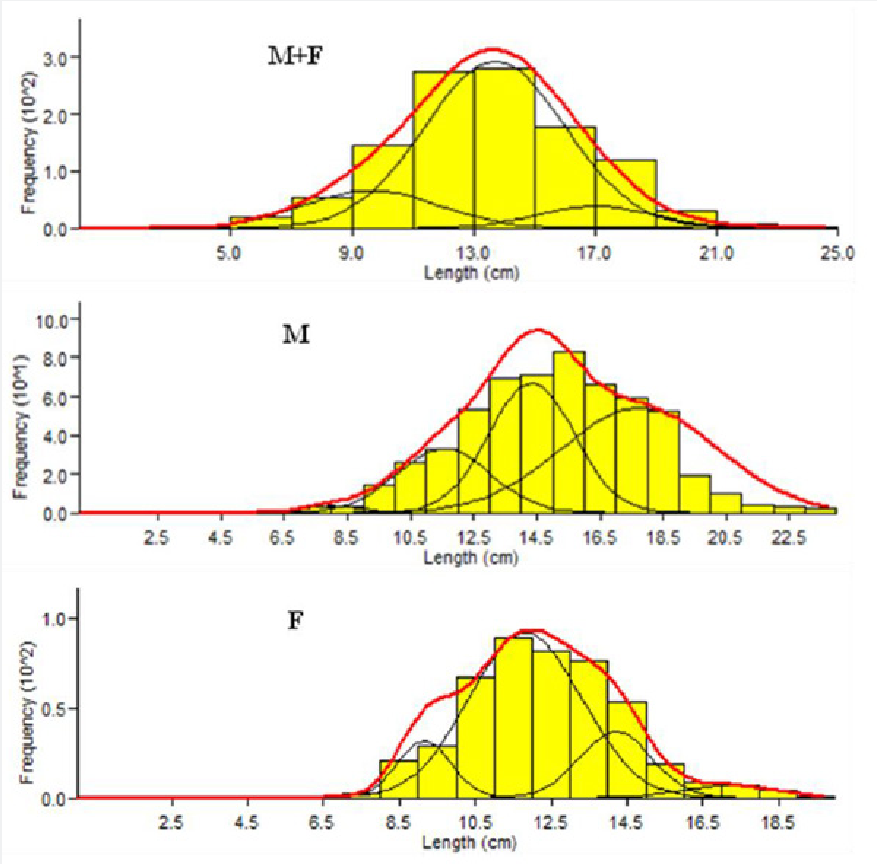

Figure 4: Bhattacharya plot for the decomposition of the length frequency distribution of *S. diaspros* from the Gulf of Gabès.

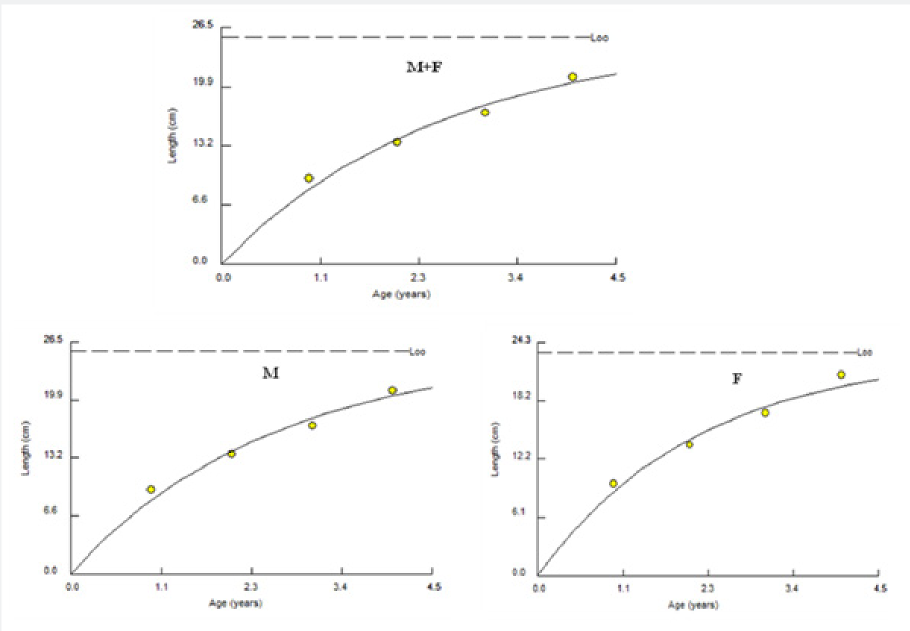

Figure 5: Analysis of length at age estimated for *S. diaspros* in the Gulf of Gabès by FISAT II.

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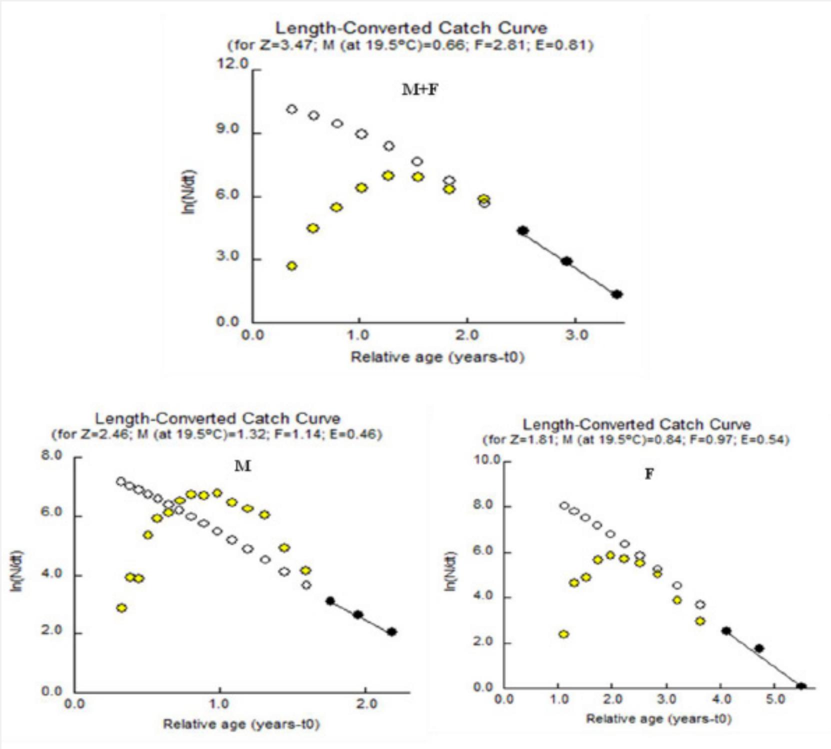

Figure 6: Length converted catch curve based on length composition of *S. diaspros* from the Gulf of Gabès.

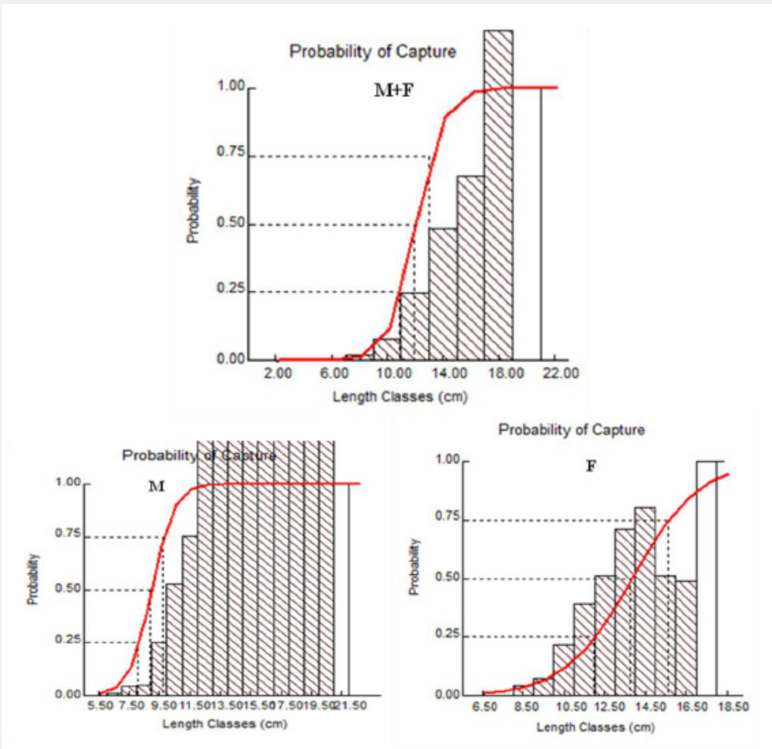

Figure 7: Selectivity curves showing the probability of catching of *S. diaspros* in the Gulf of Gabès.

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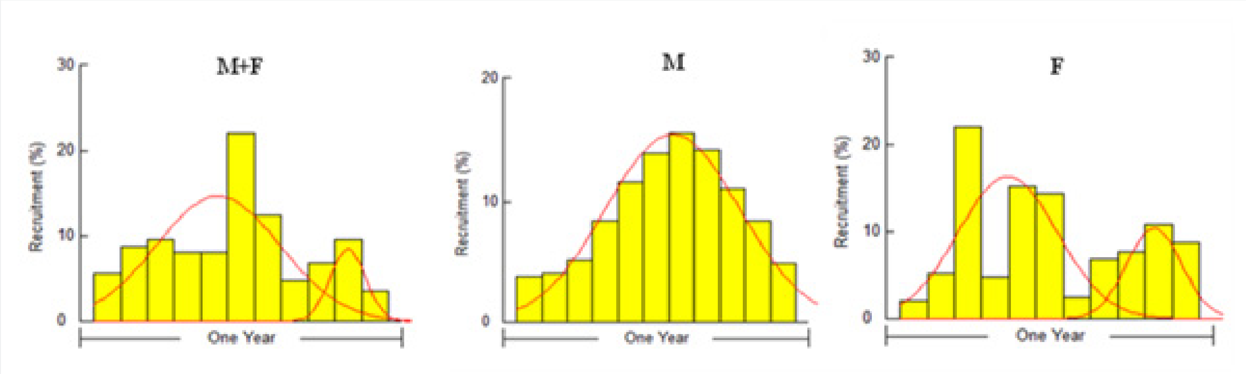

Figure 8: Recruitment patterns of *S. diaspros* from the Gulf of Gabès.

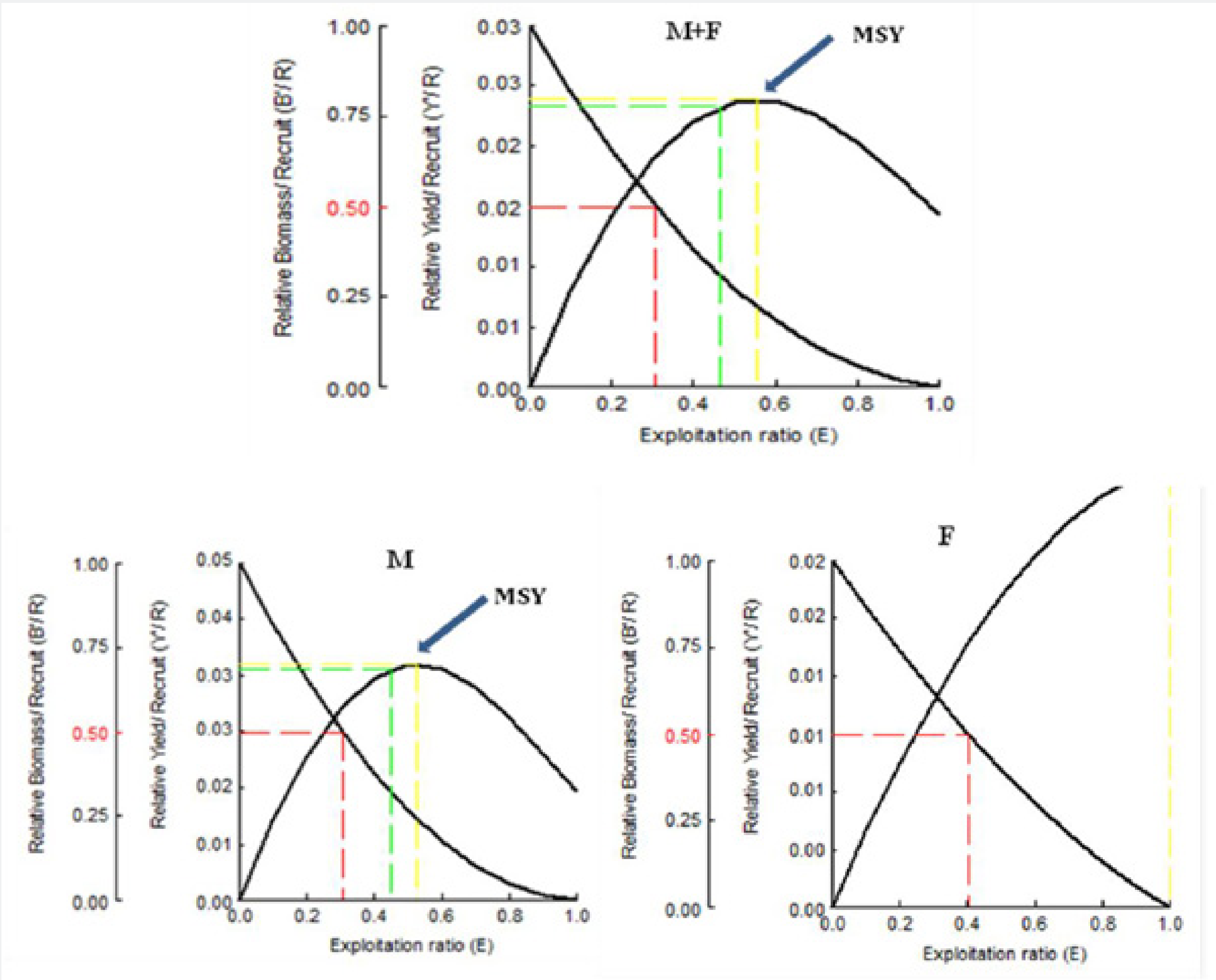

Figure 9: Two-dimensional analysis for Y′/R and B′/R of *S. diaspros* in the Gulf of Gabès (Beverton and Holt analysis).

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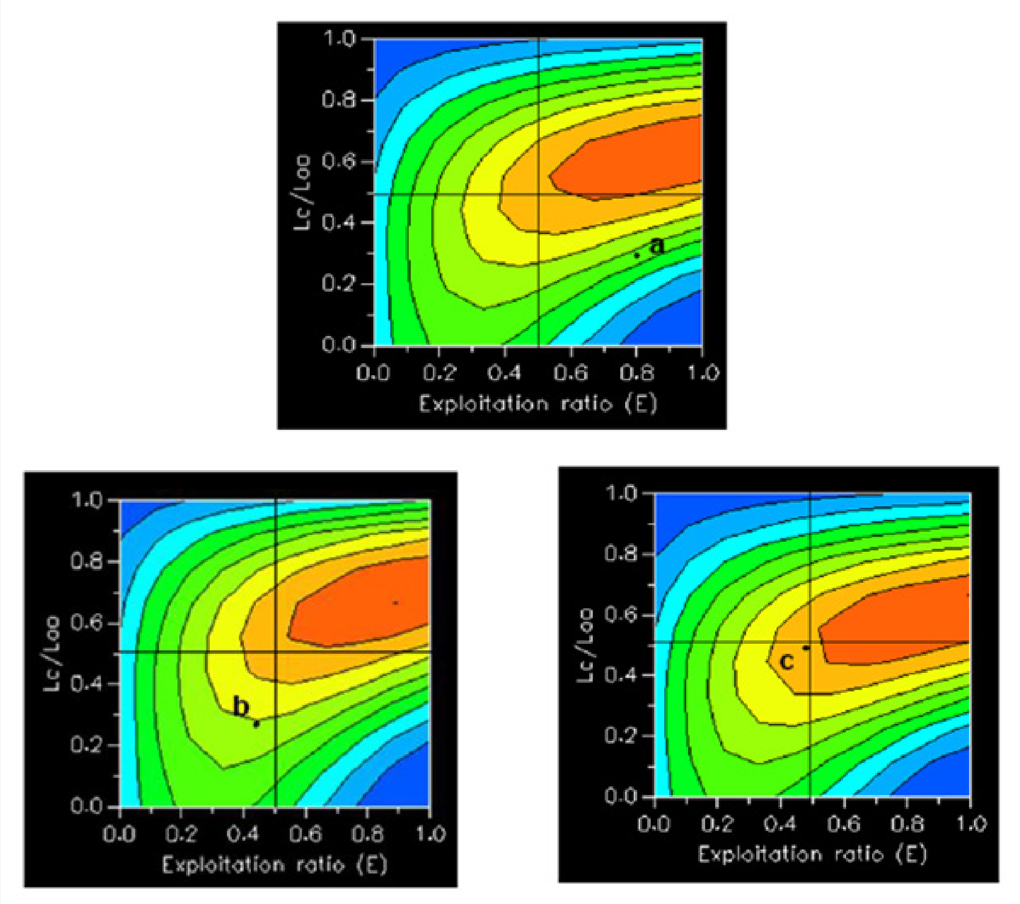

Figure 10: Relationship between relative yield per recruit, Y′/R; exploitation rate, E; and catchable size of *S. diaspros*. The lines in the figure are contour lines of Y′/R values. a, b and c represents the Y′/R value of the current state for all samples, males and females respectively.

Utilizing the length-frequency data, the current study provides inferences on the population of *S. diaspros* in the Gulf of Gabès. We have examined the fundamental elements necessary to formulate a rational and sustainable management strategy for this species stock. Among 1116 sampled individuals, with size frequency distribution from 3.7 to 23.7 cm, the overall sex ratio (SR = 0.87) indicated a significant disparity, favoring males. The proportion of females is 46.53% and the proportion of males is 53.47%. Kartas and Quignard [51] suggest that the physiological condition of fish and fluctuations in the quantity and quality of sex-specific food may account for variations in the sex ratio and the differential susceptibility of each sex to the employed fishing gear.

S. diaspros exhibits clear sexual dimorphism, with noticeable differences between males and females. In adult males, the second spine of the second dorsal fin is elongated, and the caudal peduncle often features several rows of horny patches. Additionally, males tend to be larger in body size compared to females. In this study, the average length of males was 15.03 m with the predominance of 15.5 cm, while that for females, the average length was 12.32 cm and predominance of 13.6 cm. The largest sizes were 23.7 cm and 19.1 cm for males and females respectively. El-Ganainy and Sabrah [25] found that the total length of *S. diaspros* ranged from 7 to 26.1 cm with an average of 14.59±3.61 cm. In their biological studies of the filefish *S. diaspros* from the Gulf of Suez (Egypt), El-Ganainy and Sabrah [24] reported that females were represented in small sizes (8.0 - 16.0 cm), while males largely outnumber females up to the length interval of 16.0 - 26.0 cm. They also found a monthly sex ratio of *S. diaspros* that showed a predominance of males over females nearly during all the fishing season, and in sizes larger than 16 cm.

Variations in sex composition among fish populations can be influenced by several factors, including differences in natural and fishing mortality rates between sexes, or seasonal segregation of males and females. This segregation may also result from differences in age and size at sexual maturity [52]. In the case of the filefish, the notably high proportion of males is likely due to the disappearance of females following spawning [53], as well as selective fishing practices that may disproportionately affect one sex.

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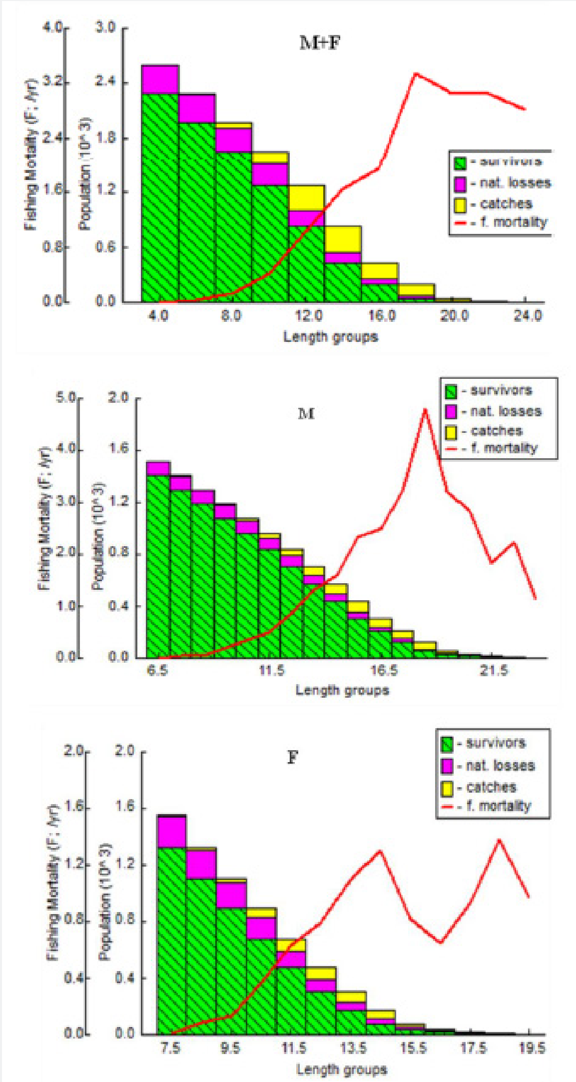

Figure 11: Virtual population analysis of *S. diaspros* in the Gulf of Gabès.

The growth performance index (ϕ') for the combined sexes was 2.62, with an asymptotic length $(L\infty)$ of 37 cm and a growth coefficient (K) of 0.31. This value reflects a moderate growth rate, typical of an invasive species adapting to a new environment. When considering the sexes separately, males exhibited a higher growth performance index of 2.813, with a smaller $L\infty$ of 28.5 cm and a significantly higher K value of 0.8, indicating a faster growth rate compared to females. In contrast, females showed a lower growth performance index of 2.26, with a smaller $L\infty$ of 22.65 cm and a K value of 0.36, indicating slower growth. The higher growth performance index for males suggests that they have a greater capacity for rapid growth, which may enhance their ability to adapt and proliferate in the new ecosystem. These differences in growth rates and performance indices between sexes are crucial for understanding the invasive potential of this species, highlighting its ability to thrive and potentially impact local biodiversity in the Gulf of Gabès.

The asymptotic length happens to be a vital factor for demarcating the mesh size limits of fishing gears [54]. The asymptotic length is considerably higher in the combined population compared to males and females separately, which can be attributed to the presence of numerous small-sized individuals of undetermined sex. Furthermore, this value is higher in males than in females, as previously mentioned, due to the generally greater length of males. This observation also explain the notably

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higher growth rate recorded in males $(K=0.80)$ compared to females $(K=0.33)$ and the combined population $(K=0.31)$.

The size distribution of a fish population can be influenced by several external factors, with fishing methods and water temperature playing particularly important roles [55]. These factors, along with the type of data models used in analysis, can ultimately affect estimates of growth rates and the maximum size that fish in the population are expected to reach [56].

The $L\infty$ value estimated in our study is considerably higher than that reported by El-Ganainy and Sabrah [25] $(L\infty = 27.8)$, while the K values in both studies remain relatively similar. A comparative summary of the Von Bertalanffy Growth Function (VBGP) parameters for the Gulf of Gabѐs and the Gulf of Suez is presented in Table 6.

The identification of four age groups (I to IV) in the length-frequency distribution of *S. diaspros* indicates a stable and continuous recruitment within the population in the Gulf of Gabѐs. This structure suggests successful establishment and adaptation of this Lessepsian migrant in the Mediterranean environment. The presence of multiple age classes reflects ongoing reproduction and survival across different cohorts, which is essential for maintaining population resilience. The dominance of Group II among males and Group III among females may reflect differences in growth rates, mortality, or maturation between sexes. Such age distribution patterns are crucial for understanding the population dynamics and for developing effective management strategies.

In the study conducted on *S. diaspros* from the Gulf of Suez, five age classes were identified using two complementary methods: the examination of growth rings on thin sections of the dorsal fin spine and the Bhattacharya method. The results indicated rapid growth during the first year of life, with individuals reaching nearly 50% of their estimated maximum length. In subsequent years, growth rate declined considerably. A comparison of the mean estimated lengths at age for *S. diaspros* from the Gulf of Gabѐs and the Gulf of Suez is presented in Table 7.

The total (Z), natural (M), and fishing (F) mortalities for *S. diaspros* along the coast of the Gulf of Gabѐs waters were estimated at 3.47, 0.66, and 2.81 yr^{-1}, respectively. In this case, the value of fishing mortality is very higher than natural mortality, for all samples but closed for males and females. Also, the exploitation rate (E) of our species is higher than the reference exploitation rate $(E = 0.5)$ which symbolize overexploitation and an anthropogenic action. This implies that the mortality of most of these fish is linked to fishing and not to predation or habitat and physicochemical characteristics. Human harvesting is therefore responsible for stock fluctuation in this ecosystem. According to Al-Nahdi et al. [57], the maximum level of exploitation of a resource is reached, when the exploitation rate is greater than or equal to 0.5, or when fishing mortality (F) is equal to or greater than natural mortality (M). It is therefore possible to affirm that this fish species, considered as by-catch is overexploited in the Gulf of Gabѐs. In addition, the Z/K ratio (11.19 for all sample, 3.075 for males and 5.028 for females) greater than 1 again confirms high fishing-related mortality. A Z/K ratio greater than 1 suggests that mortality surpasses growth, potentially indicating overexploitation. Conversely, a ratio less than 1 implies that growth outpaces mortality, which is characteristic of a healthy, growing population [58].

The opening catch, L_{50}, of *S. diaspros* was 11.95 cm. Specimens ≤ 11.95 cm can be considered a supplementary population. It's considered one of the most important premises for analyzing the relationship between the relative yield per recruit (Y'/R) and E. This is bound to lead to very intense exploitation of this resource, as many of the young individuals have no chance of reaching optimum growth size. As the size of first capture (L_c or L_{50}) is lower than the size of first maturity L_m, we can say that this is a case of biological overexploitation. A fishery focused on the spawning stock generally leads to such overexploitation.

The recruitment histogram for *S. diaspros* indicates year-round recruitment, with a marked peak in June–July for the overall population and males, while females display two distinct peaks: one in June–July and another in October. These months, included in the major upwelling, are thought to be favorable for young fish feeding, thanks to the planktonic proliferation during this period, whereas recruitment tends to be lowest during the winter months, likely due to the drop in water temperature [59]. The availability of food and favorable environmental conditions are among the key factors that can significantly influence fish recruitment [60-64].

According to Ktari-Zouari et al. [21], the gonadosomatic index (GSI) of female *S. diaspros* shows significant variation during the spawning season, which extends from July to December, with two noticeable peaks in July and October. The overall

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pattern of females GSI suggests a prolonged breeding period lasting from April to December, with fluctuations throughout. The development of ovaries and the growth of oocytes in fish may be influenced by changes in water temperature. Spawning season of *S. diaspros* typically begins in July, coinciding with rising summer temperatures, suggesting that temperature shifts may play a key role in triggering ovarian development in this alien species. Additionally, there appears to be a strong link between photoperiod and GSI, as both reach their highest levels at the end of spring and the start of summer [65,66]. Similar to females, the GSI values of males reached a peak in July [21].

The current Y'/R and B'/R values for *S. diaspros* in the Gulf of Gabès (0.011 and 0.032 for both sexes, 0.033 and 0.223 for males and 0.021 and 0.357 for females) indicate that the population, particularly males, is under significant fishing pressure, leading to reduced yield and biomass per recruit, potentially compromising the stock's sustainability. Implementing targeted management strategies is essential to ensure the long-term viability of the species and the fishery.

Also, the examination of Y'/R and B'/R indicates that the current exploitation level $\left(E = 0.81\right)$ substantially exceeds both E_{max} and $E_{0.5}$ (0.557 and 0.308, respectively). The reduction of exploitation rate should be occurred from 0.81 to 0.308 with a rate of 49.8% to ensure effective management and to sustain the spawning stock biomass. Similarly, El-Ganainy and Sabrah [25] reported an exploitation ratio that exceeded the level associated with the maximum relative yield per recruit $\left(E_{max}=0.541\right)$ by approximately 16%, indicating that fishing pressure in the Gulf of Suez had surpassed the critical threshold. Furthermore, they found that the estimated length at first capture $\left(L_c = 8.5\ cm\right)$ was very close to the length at first sexual maturity (9.0 cm) [24], suggesting that juvenile individuals are heavily targeted by the fishery. This early exploitation poses a serious threat to the stock dynamics of the species, as the removal of immature individuals can significantly reduce future yields. The high vulnerability of juvenile fish to trawl fishing highlights the urgent need for protective measures. Safeguarding juvenile fish, particularly through the periodic spatial closure of spawning and nursery grounds, is likely a key factor for ensuring the long-term sustainability of the resource. This could be effectively implemented by establishing marine reserves within the Gulf of Suez aimed at protecting the spawning stock biomass, followed by continuous monitoring to evaluate the effectiveness of such management strategies.

A comparison of the mortality and the exploitation parameters of *S. diaspros* from the Gulf of Gabès and the Gulf of Suez were resumed in Table 8.

The yield isopleths categorize the *S. diaspros* fishery in quadrant D for all population and in quadrant C for males and females separately [50], signifying the inclusion of juvenile fish in the landings throughout the study period (growth and recruitment overfishing).

Hard work must be done to reduce fishing effort in general and tighten control over landing sites and fishing ports to ensure compliance with the minimum allowable size of the catch. Thus, strengthen the monitoring and regulation of shallow fishing sites in order to better preserve our fishery resources and ensure the sustainability of marine ecosystems [67].

This finding is consistent with the results obtained from the virtual population analysis (VPA). Thus, Virtual population analysis provides valuable insights into the proportion of survivor and the losses resulting from both natural causes and fishing pressure. This is achieved by comparing different length groups against levels of fishing mortality. In the present study, the number of survivors and natural losses decreased as fish size increased. However, fishing-related mortality rose sharply beyond a length of 18 cm for the overall sample, 18.5 cm for both males and females, and showed an additional peak at 14.5 cm specifically for females. The highest catch rates were recorded in fish measuring between 10 and 18 cm overall, 11.5 to 18.5 cm for males, and 10.5 to 14.5 cm for females (Figure 11).

Therefore, we can note that the stock of *S. diaspros*, especially the females, caught off the Gulf of Gabès is overexploited and cannot achieve a sustainable fishing rate. This reflects a tendency to catch immature or maturing fish. Raising awareness among fishers about the negative impact of this practice could gradually change their behaviour and motivations.

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