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Fisheries Biology of Non-Indigenous Sardine, *Sardinella gibbosa*, in the Mediterranean Sea Front Damietta Region, Egypt

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ABSTRACT

The recent establishment of *Sardinella gibbosa*, a non-indigenous clupeid, in the eastern Mediterranean Sea—specifically along the Damietta coastline of Egypt—raises important questions concerning its population dynamics and potential ecological implications. This study presents a comprehensive evaluation of the species' biological parameters based on 595 specimens collected between April 2023 and February 2024. Length-weight relationships revealed negative allometric growth ($b< 3$), accompanied by statistically significant sexual dimorphism in both length–weight relationships and condition indices. Growth modeling, employing the von Bertalanffy growth function, yielded higher asymptotic lengths in females (21.1cm) compared to males (20.2cm), with growth performance indices (Φ') indicative of moderate somatic growth rates ($\Phi' \approx 2.24$ and 2.26 for female and male, respectively). The reproductive assessment revealed a female-biased sex ratio and a length at first maturity (Lm) that closely approximated the estimated length at first capture (Lc), suggesting potential exposure to growth overfishing. Mortality and exploitation rates suggested that the stock is approaching its optimal harvest level. These findings provide essential baseline data to support the development of evidence-based management and conservation strategies for this recently established species in Mediterranean fisheries.

INTRODUCTION

Oceans and seas provide essential ecosystem services, including food provision, oxygen production, economic support through fisheries and maritime industries, as well as recreational and cultural value, all of which are critical to human well-being and global sustainability. The Mediterranean Sea is among the most affected marine environments globally in terms of biological change, particularly regarding the number and persistence of non-indigenous species, as well as the unprecedented rate at which they are introduced **(Zenetos, 2009; Costello *et al.*, 2010; Zenetos, 2010)**. The Mediterranean Sea supports a diverse marine biota, much of which is believed to have originated from the Atlantic Ocean and Indo-Pacific regions, highlighting the basin's high susceptibility to species introductions and biogeographic exchange **(Bariche, 2012)**. Among the native pelagic fauna, sardines represent a functionally significant group, acting as key mediators of energy transfer from lower to higher trophic levels within the marine food web. Their abundance and wide distribution make them central to ecosystem dynamics, particularly in linking planktonic productivity to predatory fish and seabirds. Furthermore, sardines constitute the foundation of economically vital fisheries throughout the Mediterranean, playing a critical role in sustaining regional economies and ensuring food security for coastal populations **(Villegas-Hernández *et al.*, 2014)**. *Sardinella gibbosa*, commonly referred to as the goldstripe sardinella, is a small pelagic clupeid broadly distributed across the tropical and subtropical coastal waters of the Indo-West Pacific **(Whitehead, 1985)**. Its native range extends from the western Indian Ocean—including the Arabian Sea and the Persian Gulf—through northern Australia and eastward into the western Pacific, reaching as far north as southern Japan **(Whitehead, 1985; Thomas *et al.*, 2014; Hata & Motomura, 2021)**. The species occupies a functionally significant trophic position, serving as a key forage resource for piscivorous predators and making a substantial contribution to the biomass and energy transfer within coastal pelagic food webs. It also underpins the productivity of numerous artisanal and commercial fisheries throughout its native range. Notwithstanding its ecological and economic importance, the taxonomic status of *S. gibbosa* has historically been confounded by substantial morphological overlap with other members of the genus *Sardinella*. Addressing this ambiguity, **Stern *et al.* (2016)** conducted a systematic taxonomic reassessment using meristic and morphometric analyses, thereby establishing robust diagnostic criteria for distinguishing *S. gibbosa* from sympatric congeners across the Indo-West Pacific. The species' recent documentation in the Red Sea and subsequent detection in the eastern Mediterranean—presumably via lessepsian migration through the Suez Canal—suggests an ongoing range expansion, with implications for native biodiversity and fishery dynamics in the recipient ecosystems **(Stern *et al.*, 2015; Fortič *et al.*, 2023)**. As a dominant component of small pelagic fish communities, *S. gibbosa* plays a critical ecological role and remains a principal target in Southeast Asian fisheries, where it constitutes a considerable fraction of pelagic catch volume **(FAO, 2011; Palomares & Pauly, 2023)**.

Despite its significance, the biological and ecological understanding of *S. gibbosa* remains limited in several regions of its distribution. Fundamental aspects such as growth parameters, size structure, and reproductive biology are either outdated or regionally unstudied. Such gaps in knowledge hinder the development of effective fishery management strategies, especially given the growing pressure on coastal resources due to overfishing and environmental changes **(Froese & Pauly, 2023)**. Studies on related *Sardinella* species have demonstrated that their growth and population dynamics are highly sensitive to environmental factors such as temperature, salinity, and food availability **(Pauly & Ingles 1981; Cheung *et al.* 2013)**. However, species-specific, localized data are necessary to inform sustainable exploitation policies. Understanding the growth patterns and life history traits of *S. gibbosa* is critical for determining appropriate management measures, such as size limits, fishing seasons, and stock assessments. This study aimed to examine the length distribution and to estimate growth parameters of *S. gibbosa* in the Egyptian Mediterranean coastline, providing biological characteristics to inform regional fishery management strategies and promote the sustainable use of this new valuable resource.

MATERIALS AND METHODS

1. Area of study

The study was conducted on the coastal area of Mediterranean Sea in front of Damietta region. The area of study spans 170 km east of Alexandria and 50km west of Port Said at 31° 29' - 31° 33' N and 31° 46' - 31° 57' E (Fig. 1). The water depth gradually increases toward the open sea, reaching approximately 30m, with coastline extending along a roughly 20-kilometer. Damietta region is a crucial fishing area, accounting for approximately 36.1 % of the total fish catch from Egypt's Mediterranean fisheries, with a total landed catch of 18,642 tons, more than 9% are sardine in 2022 **(LFRPDA, 2022)**. The small-scale fisheries support coastal communities by providing thousands of jobs and serve as a vital cornerstone for livelihoods and food security in the region **(Pinello *et al.*, 2020; Samy-Kamal, 2021)**.

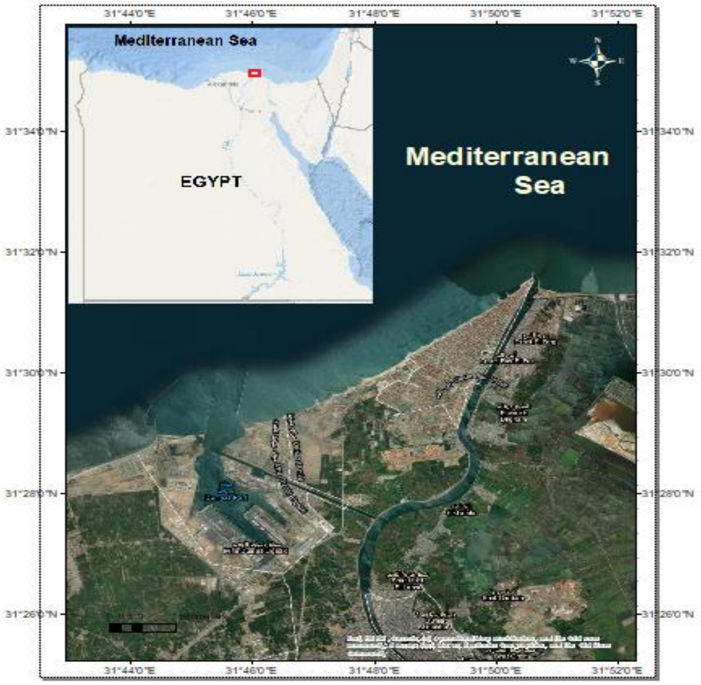

Fig. 1. The map of Egypt showing the location of the castellated area of Damietta region

2. Samples collection

Specimens of *S. gibbosa* were collected from the Damietta region on the northern coast of Egypt between April, 2023 to February, 2024. Sampling was monthly conducted from traditional artisanal fishing gear, including gill nets and purse seines, operated by local fishers in pelagic zones, to minimize bias in size and sex representation **(Froese, 2006)**. During the period of Study, a total of 595 individuals were collected and transported on ice to the laboratory for analysis. Samples were categorized as male (M), female (F), or combined sexes (C) based on gonad morphology **(West, 1990)**.

3. Morphometric measurements

In the laboratory, total length (TL), standard length (SL), forked length (FL), and head length (HL) of each fish were measured to the nearest 0.1cm using a digital caliper (Fig. 1). The total body weight (TW), gutted weight (GW), and gonad weight were recorded to the nearest 0.001g using an electronic balance **(Helfman *et al.*, 2009)**. Sex determination was conducted through the examination of gonad external features and macroscopic analysis **(Murua *et al.*, 2003)**. Damaged or incomplete specimens were excluded from the analysis. Relationships between TL and weight (TW, GW) were modeled using a power equation:

$$W = a\,L^{b}$$

Where, W = weight, L = TL, a = scaling coefficient, and b = allometric exponent **(Ricker, 1973)**.

For SL, FL, and HL, linear relationships were tested:

$$Y = a + bL$$

Where, Y = dependent variable (SL, FL, HL). Ordinary least squares (OLS) regression was applied **(Zar, 2010)**.

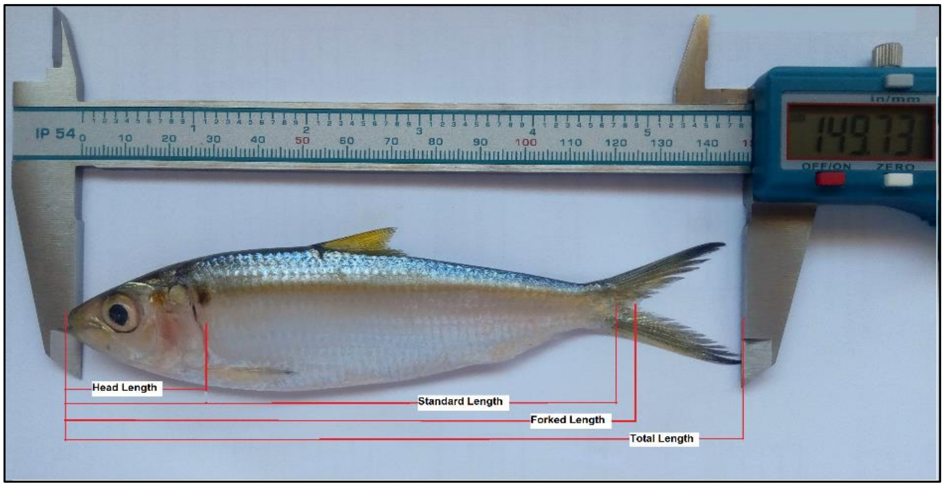

Fig. 1. Morphometric measurements of *Sardinella gibbosa* under study

4. Condition factor calculations

Two condition indices were computed:

- Absolute condition factor **(**K_c**) =** W x 100/ TL^3 **(Ricker, 1975)**.
- Relative condition factor **(**K_r**)** = Weight observed/ weight calculated **(Le Cren, 1951)**.

5. Length-frequency analysis and growth estimation

Length-frequency data were grouped into 1.0cm class intervals and were analyzed using the FiSAT II software package **(Gayanilo *et al.*, 2005)**. The von Bertalanffy growth function (VBGF) was applied to estimate growth parameters, including the asymptotic length (L_∞) and growth coefficient (K), using the ELEFAN I routine. The growth performance index (Φ') was calculated to compare growth parameters with other species.

The VBGF is expressed as:

$L_t = L_\infty \, (1 - e^{-K(t-t0)})$

Where, $\mathbf{L_t}$ is the length at age **t**; $\mathbf{L_\infty}$ is the asymptotic length; **K** is the growth coefficient; and $\mathbf{t_0}$ is the hypothetical age at which length is zero.

6. Reproductive biology

Sex ratio is the proportion of males to females in a population, typically expressed as M: F or as the percentage of males or females. Length at first maturity (L_m) is estimated from an accumulation (ogive) curve, the idea is to plot the cumulative proportion of mature individuals against length classes **(King, 2007)**.

Gonado-somatic index (GSI) is a measure of the relative investment of a fish in gonadal tissue compared to its total body mass. It is widely used to assess reproductive status, spawning season, and gonadal development in fish populations.

$GSI = W_g / Wt \times 100$

Where, W_g= gonad weight **(**g**)** and Wt = total body weight **(**g**)**; gutted body weight is often used to exclude gut content effects **(King, 2007)**.

7. Estimation of mortality rates

Total mortality (Z) was estimated using the length-converted catch curve method **(Pauly, 1984)**. Natural mortality (M) was computed using Pauly's empirical formula, which incorporates water temperature, K, and L∞:

$\text{Log}\,(M) = -0.0066 - 0.279\log(L_\infty) + 0.6543\log(K) + 0.4634\log(T)$

Where, T is the mean annual water temperature in °C; it was measured and its average set at 20.8°C for the period of study. Fishing mortality (F) was estimated as F=Z−M, and the exploitation rate (E) was calculated as E= F/Z.

8. Length at first capture (L_c) and first maturity

Length at first capture (L_c) was estimated from the probability of capture routine in FiSAT II by fitting a logistic curve to the ascending limb of the length-converted catch curve **(Gayanilo *et al.*, 2005)**.

9. Statistical analysis

Parameter estimation: the regression coefficients (a, b) and coefficient of determination (R^2) were calculated to assess model fit **(Sokal & Rohlf, 1995)**. Slopes (b) and intercepts (a) between sexes in length-weight relationship were compared using analysis of covariance at α=0.05 **(Quinn & Keough, 2002)**.

RESULTS

1. Length-weight relationships and morphometric study

A morphometric assessment of *Sardinella gibbosa* specimens collected from the Mediterranean Sea off the Damietta coast was conducted to investigate growth patterns, sexual dimorphism, and body condition. A total of 595 individuals (182 males, 378 females, and 35 immature), ranging from 10.2 to 19.4cm for total length and from 8.6 to 50.6g for total weight, were examined to quantify length–weight and length–length relationships across sexes. The measured morphometric parameters included total length (TL), standard length (SL), forked length (FL), head length (HL), total weight (TW), and gutted weight (GW). Power and linear regression equations were used to model these relationships in order to assess allometric growth and body proportions.

The total length–total weight relationships (LWRs) were best described by the power function:

Total length – Total weight relationship (LWR)

Total length- total weight relations are represented by power equations:

$W=0.0168\ L^{2.733}$ (R^2=0.873) …. for combined sexes (Fig. 3a),

$W=0.0131\ L^{2.810}$ (R^2=0.861) … for females, and

$W=0.0124\ L^{2.788}$ (R^2=0.849) …. for males.

ANOVA analysis indicated a significant sex-related difference in intercepts ($P = 2.23 \times 10^{-5}$), with females being heavier than males at a given length.

Total length–gutted weight (LGWR)

Total length- total weight relations are represented by power equations:

$W_g=0.0141\ L^{2.780}$ **(**$R^2=0.878$**)** … for combined sexes (Fig. 3b),

$W_g=0.0247\ L^{2.758}$ ($R^2=0.808$) … for females, and

$W_g=0.0155\ L^{2.748}$ ($R^2=0.854$) …. for males.

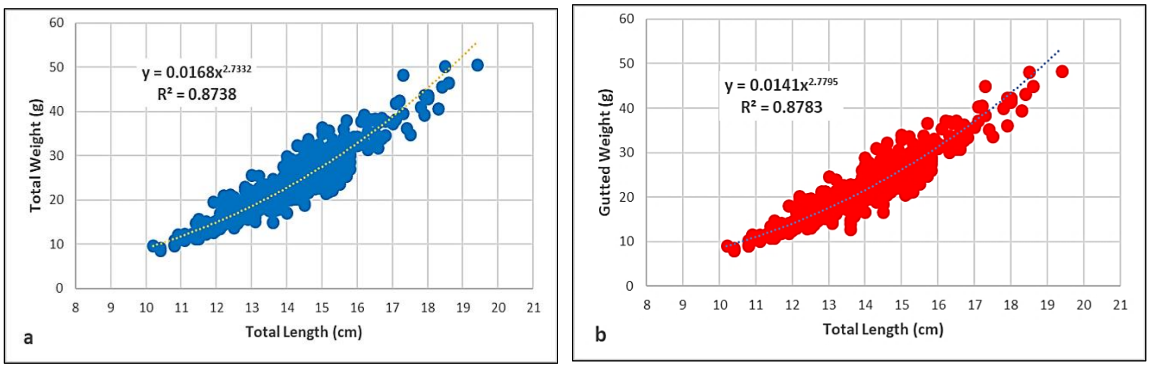

Fig. 3. Length-weight relationships of *S. gobbisa* combined sexes from Mediterranean Sea front Damietta region during the period of study; a, LWR and b, LGWR relationships.

Total length–standard length (TL-SL)

Total length- standard length relations are represented by linear equations:

$SL=-0.387+0.843TL$ **(**$R^2=0.939$**)** … for combined sexes (Fig. 4a),

$SL=-0.663+0.861TL$ ($R^2=0.934$) … for females, and

$SL=-0.399+0.844TL$ ($R^2=0.909$) … for males.

Total length–fork length (TL–FL)

Total length- forked length relations are represented by linear equations:

$FL=-0.072+0.885TL$ ($R^2=0.947$) … for combined sexes (Fig. 4b),

$FL=-0.183+0.892TL$ ($R^2=0.943$) … for females, and

$FL=-0.082+0.888TL$ ($R^2=0.917$) … for males.

Total length–head length (TL–HL)

Total length- head length relations are represented by linear equations:

$HL=0.662+0.166TL$ ($R^2=0.772$) … for combined sexes (Fig. 4c),

$a=0.669+0.165$ ($R^2=0.869$) … for females, and

= 0.6001+0.171 **(**R^2= 0.787**)** … for males.

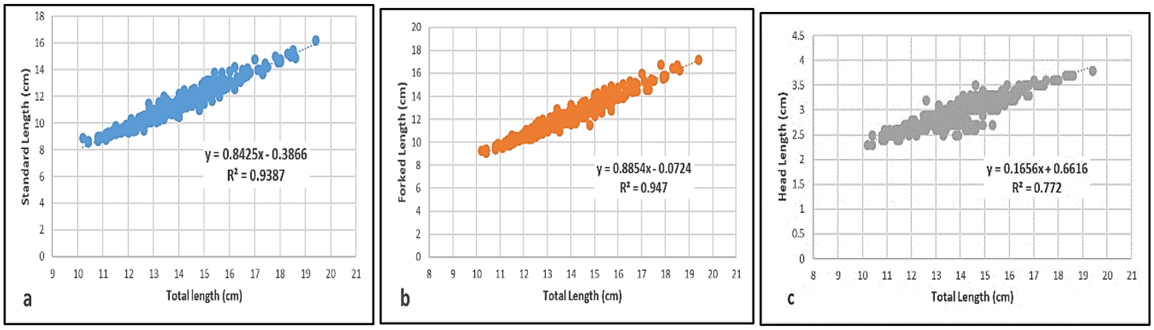

Fig. 4. Total length-standard length **(a)**, total length-forked length **(b)**, and total length-head length **(c)** relationships of *S. gibbosa* combined sexes during the period of study

Absolute condition factor (Kc)

The absolute condition factor (Kc) was used to evaluate the somatic condition of *S. gibbosa* in relation to body size and monthly variation along the Damietta coast. As shown in Fig. (5a), Kc values declined progressively with increasing total length across all groups. The mean Kc was 0.813 ± 0.055 for combined sexes, 0.838 ± 0.081 for females, and 0.782 ± 0.070 for males within the 10– 19cm length range. Female individuals exhibited higher conditions at smaller sizes, peaking at approximately 0.997 at 11cm and maintaining elevated values relative to both males and combined up to ~14cm. Males showed a steeper decline, with Kc values decreasing from 0.882 at 12cm to a minimum of 0.681 at 18cm. These trends suggest that smaller fish are relatively "plumper" (higher Kc) in better physiological conditions, whereas larger individuals exhibit a more elongated morphology with reduced conditions (lower Kc).

Seasonal patterns in absolute condition factor (Kc) are presented in Fig. (5b). Female fish consistently displayed higher Kc values than males throughout most months. For example, in June, female Kc peaked at 0.867, compared to 0.810 in males. The highest mean Kc was observed in April (0.966), followed by a notable decline in May (0.785) and July (0.790).

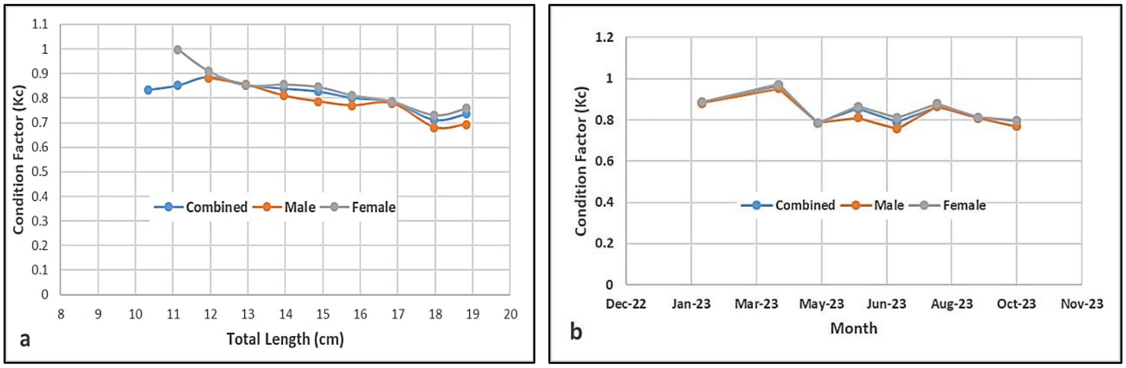

Fig. 5. Absolute condition factor **(**Kc**)** of *S. gibbosa* from Damietta region according to fish size **(**a**)** and according to month **(**b**)** during the period of study

Relative condition factor (Kr):

As illustrated in Fig. (6a), the relative condition factor (Kr) for combined sexes remained close to unity across length classes (mean = 0.980 ± 0.037), peaking at 1.023 around 12cm, then gradually declining to 0.917 at 18cm. Female fish exhibited consistently higher Kr values across the size range (mean = 1.060 ± 0.030), maintaining values above 1 at nearly all lengths, with a maximum of 1.110 at 11cm and a minimum of 1.025 at 18cm. This trend suggests that females are generally in a better-than-average condition relative to the expected length-weight relationship. In contrast, males showed more variable conditions (mean = 1.007 ± 0.026), fluctuating slightly above and below 1.0, with values ranging from 0.958 at 18cm to 1.052 at 17cm. The steeper decline in male condition may indicate earlier energy reallocation toward reproductive efforts, such as gonad development or territorial activity, whereas females appear to invest more in somatic reserves to support oogenesis. The sharp drop in both Kr and absolute condition factor (Kc) at larger sizes (~17– 18cm) across sexes may represent a life-history threshold associated with reproductive maturation or a shift in energy allocation strategy. Seasonal patterns shown in Fig. (6b) further emphasize this disparity. Female Kr values remained consistently above those of males throughout most months. For example, in June, females reached a Kr of 1.096 compared to 1.007 in males. The highest condition was observed in March, followed by a marked decrease during the spawning season (May–June), suggesting reproductive investment impacts the condition. These ongoing differences between sexes likely arise from variations in biological functions and reproductive demands—females generally tend to store more energy to support the development and production of eggs.

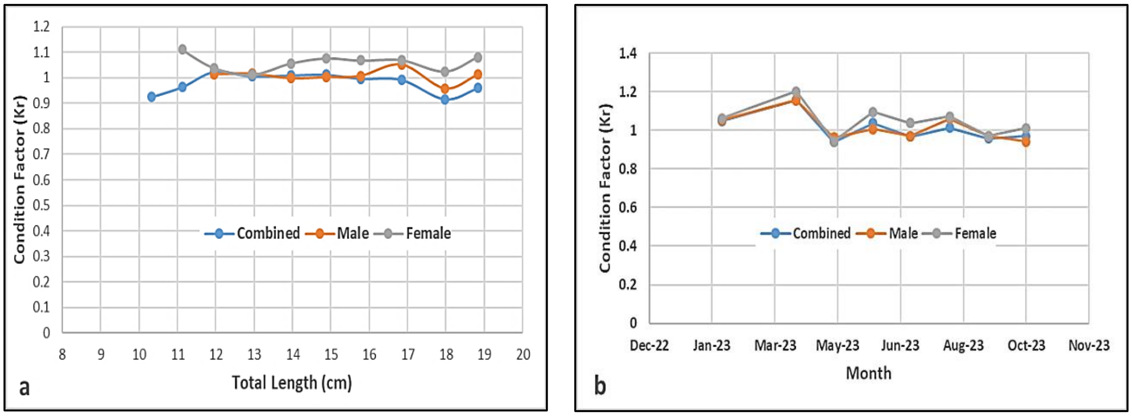

Fig. 6. Relative condition factor **(**Kr**)** of *S. gibbosa* from Damietta region according to fish size **(a)** and according to month **(b)** during the period of study

2. Growth parameters

Growth parameters of *S. gibbosa* were estimated from length–frequency data of 595 individuals, comprising 182 males, 388 females, and 25 unsexed (thread) specimens, using the ELEFAN I routine. The asymptotic length (L∞) was higher in females (21.1 cm) than in males (20.2cm), indicating a greater potential maximum size in females. In contrast, males exhibited a faster growth rate, with a von Bertalanffy growth coefficient (K) of 0.445 yr^{-1}, compared to 0.376 yr^{-1} in females. The theoretical age at zero length (t_0) was slightly earlier in males (–0.411 years) than in females (–0.483 years).

When sexes were pooled, the combined estimates fell between the two, with $L\infty$ = 20.8cm, K = 0.399 yr^{-1}, and t_0 = –0.456 years. The growth performance index (Φ'), which integrates $L\infty$ and K into a composite measure of growth efficiency, was the highest in males (Φ' = 2.259), followed by the combined sample (Φ' = 2.237), and the lowest in females (Φ' = 2.224). These results suggest that males achieve relatively faster growth in relation to their asymptotic size (Table 1).

Table 1. Growth parameters of *S. gibbosa* from the coastal area of Damietta during the period of study

Parameter	Symbol	Male	Female	Combined sexes
Fish number	No.	595	182	378
Minimum length **(**cm**)**	$L_{min.}$	11.5	11.4	10.2
Maximum length **(**cm**)**	$L_{max.}$	19.4	18.6	19.4
Average length **(**cm**)**	$L_{av.}$	13.97	14.13	13.91
Standard Deviation	SD	±1.429	±1.244	±1.324
Asymptotic maximum length **(**cm**)**	L_{∞}	20.2	21.1	20.8
Growth rate coefficient	K	0.445	0.376	0.399
Hypothetical age at zero length **(**y**)**	t_o	-0.411	-0.483	-0.456
Growth performance	Ө	2.259	2.224	2.237

3. Reproduction biology

Sex ratio

A total of 595 individuals of *S. gibbosa* were examined for sex determination based on macroscopic gonadal inspection. Of these, 570 individuals were mature, comprising 182 males and 388 females. The overall sex ratio was significantly female-biased, with an approximate male-to-female ratio of 1:2.13. Seasonal fluctuations in sex composition were evident. In winter, the sex ratio was approximately 1:1.8 (male: female), shifting to near parity in spring (1:1), and becoming increasingly female-dominated in summer (1:2.2) and autumn (1:4.6) (Fig. 7a). These seasonal differences suggest possible sex-specific variations in reproductive activity or catchability linked to environmental alerts.

Length-based frequency analysis revealed a consistent female bias across nearly all size classes ranging from 11.0 cm to 19.0 cm (Fig. 7b). This pattern was particularly pronounced in intermediate classes associated with peak reproductive activity. For example, in the 14.0cm group, 115 females were recorded compared to 47 males; similar trends were observed in the 13.0cm (94 vs. 63) and 15.0cm (60 vs. 28) groups. Although some younger size classes (e.g., 12.0cm) approached more balanced proportions (~1:2), the divergence became more apparent in reproductively active cohorts. Larger size classes (≥16.0cm), though sparsely represented, continued to exhibit a female-skewed composition.

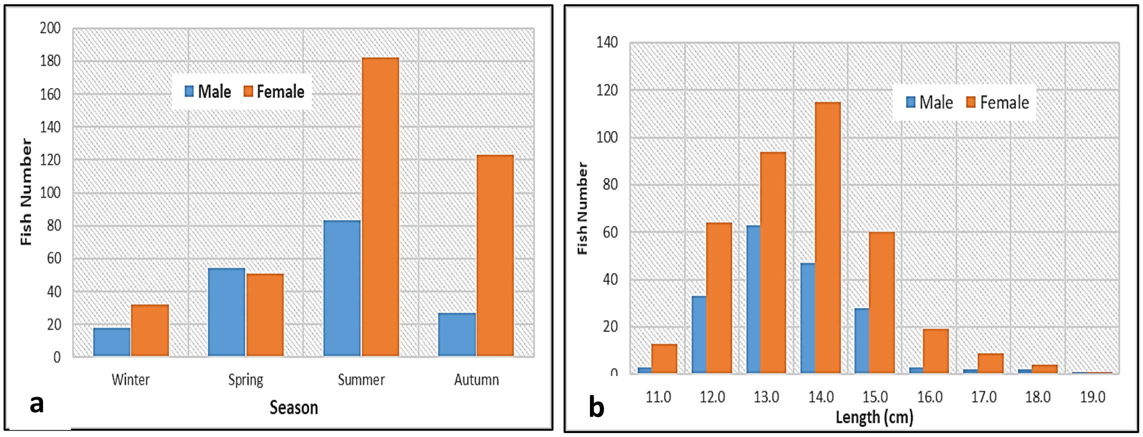

Fig. 2. Sex ratio of *S. gibbosa* in the Mediterranean coast of Damietta region during the period of study; according to season (a) and according to length (b)

Length at first maturity (L_m)

Reproductive dynamics of the studied species were evaluated through estimates of length at first maturity (L_m) and seasonal variation in the gonadal-somatic index (GSI). The L_m, derived from the cumulative frequency distribution of mature individuals, was estimated at 12.4cm for males, 13.1cm for females, and 12.7cm for the combined sexes (Fig. 8), indicating that females attain maturity at slightly larger sizes.

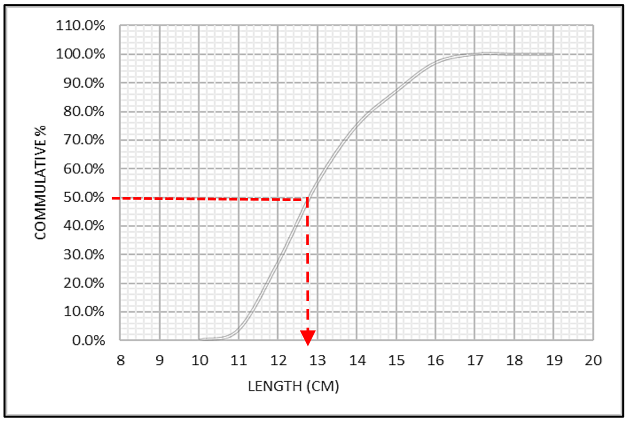

Fig. 3. Commutative curve for L_m estimation of *S. gibbosa* combined sexes from Damietta region during the period of study

Gonado-somatic index

Seasonal reproductive activity, assessed using GSI (gonad weight as a percentage of total body weight), showed pronounced fluctuations across the year (Fig. 9). Peak GSI values were observed in spring, averaging 3.588 ± 1.474 for males, 4.416 ± 1.625 for females, and 4.089 ± 1.615 for combined sexes, indicating elevated gonadal development and active spawning. Conversely, the lowest reproductive investment occurred in winter, with GSI values declining to 0.314 ± 0.138 in males, 0.363 ± 0.207 in females, and 0.346 ± 0.185 in combined sexes. These findings emphasize a distinct seasonal reproductive cycle characterized by spring spawning and reproductive inactivity during the winter months.

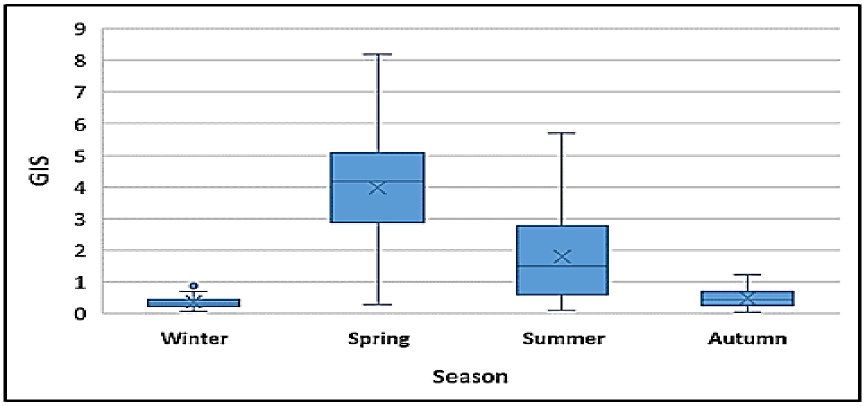

Fig. 9. Seasonal variation of the gonado-somatic index (GSI) of *S. gibbosa* from Damietta region during the period of study

4. Population structure

The population structure of *S. gibbosa* was evaluated through length-frequency analysis, mortality estimates, and capture selectivity parameters. Distinct sex-specific trends were observed, reflecting differential responses to both natural and fishing-related pressures. As shown in Table (2), natural mortality (M) is slightly higher in males (1.02 y^{-1}) than in females (0.91 y^{-1}), with a combined estimate of 0.95 y^{-1}. This pattern may indicate increased exposure of males to natural mortality factors such as predation or environmental stressors. Fishing mortality (F) was also marginally greater in males (0.98 y^{-1}) than in females (0.92 y^{-1}), while the total population exhibited a lower fishing mortality of 0.82 y^{-1}. Total mortality (Z), which combines natural and fishing sources, followed a similar pattern: 2.00 y^{-1} in males, 1.82 y^{-1} in females, and 1.76 y^{-1} for the. combined population (Fig. 10). This suggests that males are subject to higher overall mortality pressures.

Table 2. The population structure of *S. gibboza* in the Mediterranean Sea front Damietta region during the period of study

Parameter	Symbol	Male	Female	All samples
Natural mortality (y^{-1})	M	1.02	0.91	0.95
Fishing mortality (y^{-1})	F	0.98	0.92	0.82
Total mortality (y^{-1})	Z	2.00	1.82	1.76
Exploitation ratio	E	0.49	0.5	0.46
Length at first capture (cm)	L_c	12.5	13.0	12.7

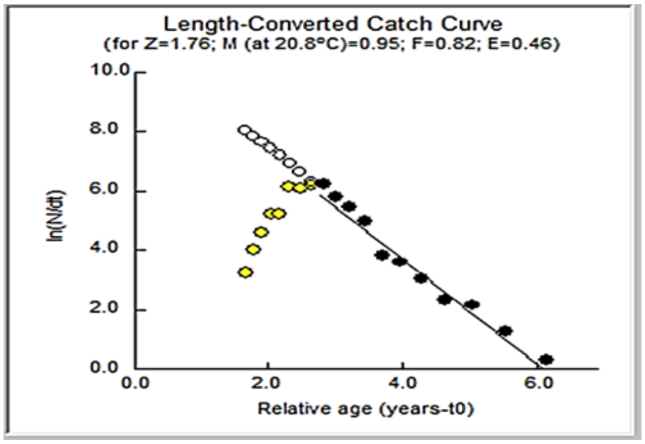

Fig. 10. Total mortality estimation using the length-converted catch curve for *S. gibboza* combined sexes from Damietta region during the period of study

Fishing mortality (F) was estimated from the length-converted catch curve constructed for the combined population. The regression applied to the descending portion of the log-transformed length-frequency distribution produced an estimate of $Z = 1.76$ yr^{-1} and $F = 0.82$ yr^{-1} for all samples. When examined by sex, fishing mortality was higher in males (0.98 yr^{-1}) than in females (0.92 yr^{-1}), suggesting that males may be more heavily exploited or more exposed to fishing activity. The lower F observed in females may indicate spatial or behavioral avoidance of fishing grounds, or it may reflect reduced gear vulnerability or sex-selective catchability **(Sparre & Venema, 1998)**. The exploitation ratio ($E = F/Z$), which reflects the proportion of total mortality attributable to fishing, was 0.49 for males, 0.50 for females, and 0.46 for the overall population. The current exploitation levels appear to be approaching but not exceeding optimal levels for both sexes. However, the values also suggest that continued monitoring is essential, as even small increases in fishing pressure could push the population beyond sustainable thresholds, especially for a species with moderate natural mortality.

The length at first capture (L_c) was estimated at 12.7 cm for the combined population, as derived from the logistic probability of the capture curve (Fig. 11). Sex-specific values indicated a slightly lower L_c for males (12.5 cm) and a higher value for females (13.0 cm). When compared to the length at first sexual maturity (L_m)—12.4 cm for males, 13.1 cm for females, and 12.7 cm for the pooled sample—these results indicate that individuals are generally entering the fishery at or shortly after achieving reproductive maturity. This timing, wherein individuals are typically captured shortly after attaining sexual maturity, is considered ecologically beneficial, as it allows for at least one reproductive event before removal. Such conditions help maintain the stock's reproductive capacity and support its demographic stability under the prevailing exploitation regime.

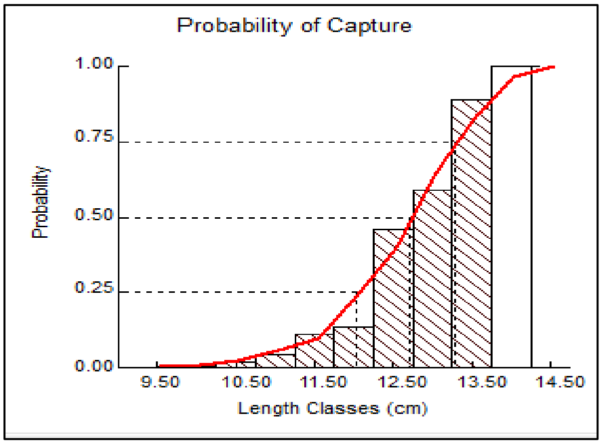

Fig. 11. Length at first capture of *S. gibbosa* combined sexes from Damietta region during the period of study

DISCUSSION

Growth, reproductive dynamics, and population structure are central to understanding fish biology and effective resource management **(Wotton, 1998; Froese, 2006; King, 2007)**. Together, these parameters allow for the assessment of population status and potential responses to environmental and fishing pressures. The growth and condition of sardines exhibit spatial and temporal variability, influenced by factors such as food availability, temperature, and population density. Sardines are opportunistic feeders, primarily consuming phytoplankton and zooplankton **(Sinovčić *et al.*, 2004)**. Their diet composition can vary depending on location and season, reflecting the availability of different prey items **(Conover, 1992)**. In the present study, *b*-value ranges from 2.73–2.81, indicating negative allometry **(**weight increases slower than the cube of length**)**. These results agree with the finding of **Ghosh *et al.* (2012)** in West Bay in Bangal and that of **Nguyen *et al.* (2016)** in Ham Thuan Nam. This aligns with streamlined body shapes in pelagic fish to reduce drag **(Froese, 2006)**. The ANOVA results demonstrated a highly significant difference in intercepts between sexes ($P = 2.23 \times 10^{-5}$). LWR in females exhibit higher *b*- value for (b=2.81) compared to males (b=2.79), suggesting males prioritize somatic growth. Conversely, females show higher R-values (R=0.849), indicating less variability in their weight-length relationship **(Quinn & Keough, 2002)**. For LGWR, males have a higher intercept (a=0.0247) but lower b (2.758), implying larger gutted weights at smaller sizes but slower scaling. Negative allometry (b<3) reflects energy allocation to locomotion over mass, common in pelagic species **(Helfman *et al.*, 2009)**. Sexual differences in scaling may relate to reproductive strategies, such as females investing in gonad development over somatic growth **(Murua *et al.*, 2003)**.

Regression slopes of TL with morphometric lengths are <1 (e.g., b=0.843 for SL), confirming these traits scale proportionally but slower than TL. Negative values (e.g., a=−0.387a=−0.387 for SL) are mathematical artifacts, highlighting that linear models are valid only within observed TL ranges **(Ricker, 1973)**. Females show steeper slopes for FL (b=0.892) compared to males (b=0.888), suggesting proportionally longer bodies at larger sizes. Linear relationships with high R-values **(**R=0.93–0.95 for SL/FL**)** validate their use for predicting body proportions (Table 3). The weaker fit for HL (R=0.77–0.87) may reflect greater variability in head morphology due to feeding adaptations **(Zar, 2010)**.

Table 3. The morphometric relationship types, fit, and biological insight

Relationship	**Model Type**	**Key Sex Difference**	**Fit (R^2)**	**Biological Insight**
TL-TW	Power	Males: higher *b*, lower *a*	0.85–0.88	Negative allometry; sexual dimorphism
TL-GW	Power	Males: higher *a*, lower *b*	0.81–0.85	Gutted weight scales differently
TL-SL/TL-FL	Linear	Females: steeper slopes	0.91–0.94	Strong linearity; sex-specific growth
TL-HL	Linear	Females: better fit **(***R*=0.87**)**	0.77–0.87	Head length variability higher in males

The condition factor (K) provides a standardized way to assess fish “plumpness” by comparing observed weight to the theoretical weight predicted by the length–weight equation **(Le Cren, 1951)**. K values > (1) reflect good energy reserves, feeding success, or favorable environmental conditions. Kc and Kr remain the most widely applied indices in fisheries biology. Decline in K values with increasing length, consistent with many studies showing negative allometry (b < 3) in weight–length relationships which corresponds to ontogenetic shifts in energy allocation—from somatic growth toward reproduction **(Froese, 2006)**. The seasonal distribution of male and female individuals revealed significant fluctuations aligned with the reproductive dynamics of the species, which is presumed to spawn in spring **(Lowerre-Barbieri *et al*., 2011; Lloret *et al*., 2012)**. During spring, which corresponds with the peak spawning season, both sexes were well represented (54 males and 51 females), reflecting active reproductive participation and a high degree of sexual synchronicity, increasing their susceptibility to capture **(Hunter & Macewicz, 2003)**. The high presence of mature individuals in spring is indicative of reproductive readiness, consistent with studies showing elevated gonado-somatic indices and spawning activity during this season **(King, 2007; Rivera *et al.*, 2017)**. Dropping in male numbers compared to female in post-spawning may reflect a delayed migratory or dispersal behavior in females, possibly associated with energy recovery or continued reproductive investment **(Lloret *et al.*, 2012)**. The female length at maturity ($L_m = 13.1$ cm) is 56% of $L\infty$, which is close to the finding of **Rivera *et al.* (2017)** in Manila Bay and to that of **El-Betar and Osman (2021)** in the Red Sea. Under the given VB parameters, fish reach maturity by ~1.4 years, indicating early reproductive effort—a trait beneficial in fluctuating environments **(Froese & Pauly, 2023)**. Only modest sexual dimorphism is assessed in both asymptotic length (L_∞) and growth coefficient (K) **(von Bertalanffy, 1938)**. Females reach a slightly larger L_∞ (21.1 cm vs. 20.2 cm in males), but grow more slowly ($K = 0.376\ y^{-1}$ vs. $0.445\ y^{-1}$), whereas males show faster early-life growth but plateau at a smaller size. The negative theoretical age at zero length ($t_0 \approx -0.45$ y for all fish) is typical of species with rapid juvenile growth in warm waters (20.8 °C), suggesting that larvae recruit quickly into the size classes surveyed **(Pauly, 1980)**. The growth performance index (Φ') of ~2.24 for the pooled sample is comparable to other sub-tropical marine teleosts of similar life-history strategy, indicating a balance between somatic growth and longevity **(Froese & Pauly, 2024)**. This φ' is within the typical range for small pelagic fishes **(Pauly & Munro, 1984; Sanders *et al.*, 1984; Froese & Pauly, 2023)**. A moderate Φ' implies neither extreme "fast" nor "slow" growth, consistent with a species inhabiting relatively stable, warm shelf habitats where food availability is seasonally variable.

Natural mortality ($M \approx 0.95\ y^{-1}$) and total mortality ($Z \approx 1.76\ y^{-1}$) yield an exploitation ratio ($E = F/Z$) of ~0.46 for the combined sexes. This E is just below the classic "optimal" exploitation target of 0.5 for many tropical/sub-tropical stocks, implying the population may be approaching, but not yet exceeding, sustainable yield levels. However, the female exploitation ratio (0.50) exactly meets that threshold and warrants caution, as over-harvesting larger, more fecund females can depress spawning biomass disproportionately. According to **Gulland**'s **(1971)** recommendation, an exploitation rate of $E \approx 0.5$ indicates sustainable fishing pressure. Thus, current exploitation levels appear to be approaching but not exceeding optimal levels for both sexes. However, the values also suggest that continued monitoring is essential, as even small increases in fishing pressure could push the population beyond sustainable thresholds, especially for a species with moderate natural mortality.

Size-at-first-capture (L_c) and size-at-first-maturity (L_m) are crucial for recruitment-overfishing risk assessment. Our estimates show $L_c \approx 12.7$ cm and $L_m \approx 12.7$ cm for the pooled data, meaning fish are, on average, caught at the same size they mature. For females, L_c (13.0 cm) is marginally below L_m (13.1 cm), indicating that a substantial fraction of females can be harvested before contributing to the spawning stock **(Beverton & Holt, 1957)**. To safeguard recruitment, management should consider increasing the minimum landing size or mesh regulations so that the majority (>50 %) of individuals attain L_m before capture. This strategy has proven effective in sustaining snapper populations in Australia **(Dowling *et al.*, 2016)**.

CONCLUSION

The biological assessment of *S. gibbosa* in the Damietta region demonstrates its successful establishment as a non-indigenous species in the Mediterranean. The fish exhibits moderate growth rates, female-biased sex ratios, and reproductive maturity around 12.7–13.1 cm. Current exploitation rates (~0.46) suggest sustainable but near-threshold fishing pressure. The close proximity between the size at first maturity and the size at first capture raises concerns for long-term recruitment and stock replenishment. The species' growth traits and reproductive timing indicate early-life investment in reproduction, aligning with its success in newly colonized habitats. These findings underscore the importance of immediate, informed management interventions to ensure sustainable exploitation and conservation of this valuable resource.

RECOMMENDATION

From a fisheries management perspective, some measures should be considered;

- Increase minimum catch size to ensure individuals reach sexual maturity before harvest, especially females whose $L_c \approx L_m$.
- Restrict fishing during peak spawning periods **(**spring**)**, based on elevated GSI values, to allow for successful reproduction.
- Regulate gill net and purse seine mesh sizes to reduce juvenile capture and protect the spawning stock.
- Establish continuous biological and ecological surveys to monitor changes in population dynamics, exploitation, and recruitment.
- Educate fishers on sustainable practices and the importance of protecting reproductive stocks to support long-term fisheries health.
- Recognize the species as an emerging economic resource and incorporate it into Mediterranean fisheries governance frameworks.

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