Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(4): 1275 – 1291 (2025)
www.ejabf.journals.ekb.eg

Application of Length-Based, Data-Limited Stock Assessment Methods to European Anchovy, *Engraulis encrasicolus* (Linnaeus, 1758) in the Egyptian Mediterranean Water

Adham El Ebrashi*, Reda M. Fahim and Hatem H. Mahmoud
College of Fisheries and Aquaculture Technology - Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt

***Corresponding Author: a.ebrashi@aast.edu**

ARTICLE INFO

Article History:
Received: May 30, 2025
Accepted: July 12, 2025
Online: July 21, 2025

Keywords:
Engraulis encrasicolus,
Egyptian Mediterranean,
Length-based assessments,
Length-based spawning Potential ratio,
Data-limited fisheries

ABSTRACT

The European anchovy (*Engraulis encrasicolus*) is an economically crucial and ecologically relevant species in the southeastern Mediterranean waters; however, limited information is available regarding its stock status. This study presents the first comprehensive stock assessment of anchovy populations in the Egyptian Mediterranean, based on biological data collected from 2022 to 2024. Growth parameters were estimated using length-frequency distribution analysis. A widely used model for data-poor fisheries, the length-based spawning potential ratio (LBSPR) model, was applied to assess stock status. The growth model revealed the following parameters: asymptotic length ($L\infty$) of 135 mm; growth coefficient (k) of 0.44 $year^{-1}$; theoretical length at age zero (t_0) of –0.489 years; and natural mortality coefficient (M) of 0.93. The LBSPR model indicated that, over the two-year data collection period, the fishing mortality to natural mortality ratio (F/M) ranged from 1.67 to 3.30. The length at 50% and 95% selectivity (SL_{50} and SL_{95}) showed an increasing trend over the years, from 75.08 to 75.93 mm and from 88.69 to 89.93 mm, respectively. Moreover, the Spawning Potential Ratio (SPR) ranged from 0.18 to 0.24, indicating an overexploited state of the stock. Therefore, the implementation of an effective management plan is strongly recommended to ensure the sustainability of the stock at acceptable levels.

INTRODUCTION

Small pelagic species (e.g., anchovies, sardines) dominate mid-trophic levels in many marine ecosystems, influencing environmental dynamics through both top-down and bottom-up control of plankton populations while supporting higher predators **(Cury *et al.*, 2000)**. Their high turnover rates and shoaling behavior further enhance their ecological importance **(Bakun, 1996)**. Because of their ecological role, they are vital for managing fisheries using an ecosystem-based approach **(Pikitch *et al.*, 2014)**.

The European anchovy, *Engraulis encrasicolus*, is one of the most environmentally, economically, and socially important marine species in the Mediterranean Sea, Black Sea,

and Atlantic region **(Palomera *et al.*, 2007; Morello & Arneri, 2009; FAO, 2016)**. Alongside sardines (*Sardina pilchardus*), European anchovies account for approximately 34% of small pelagic landings across the General Fisheries Commission for the Mediterranean (GFCM) area, and 14.2% of the total landed catch in the eastern Mediterranean, amounting to 342,000 tonnes **(SOMFI, 2022)**.

In the Southeastern Mediterranean waters of Egypt, the European anchovy contributes approximately 10% of the total catch from Egyptian fisheries **(GAFRD, 2021)**. Landings have shown significant interannual variability, increasing from 2,003 tonnes in 2011 to 3,641 tonnes in 2014, followed by a decline to 2,657 tonnes in 2016. A subsequent increase brought landings up to 4,962 tonnes in 2020.

While anchovy fisheries and population structures in the northern and western Mediterranean have been intensively studied **(Pertierra & Lleonart, 1996; Palomera *et al.*, 2007)**, research in Egyptian waters remains limited. Existing studies include biological investigations in Lake Timsah and the Great Bitter Lake in the Suez Canal **(Sharaf *et al.*, 2009)**, population structure analysis in Lake Manzalah **(El-Betar *et al.*, 2023)**, and an examination of food and feeding habits in *E. encrasicolus* along the Port Said coast **(El-Beltagy *et al.*, 2022)**. Although *E. encrasicolus* holds significant importance in the Egyptian Mediterranean, critical knowledge gaps persist regarding age structure, growth parameters, stock status, spatial distribution, and the relationships between geographical and ecological factors.

The lack of sufficient, high-quality stock data—such as lifespan parameters, historical catch time-series, CPUE, and age structure—makes it challenging to assess fish stocks effectively, particularly in data-poor fisheries **(Costello *et al.*, 2012; Froese *et al.*, 2012; Hordyk *et al.*, 2015a)**. However, recent methodological advances have enabled robust assessments under data-limited conditions **(Carruthers and Hordyk, 2018; Chong *et al.*, 2020)**. Length-frequency catch data, being relatively cost-effective and simple to obtain, is widely used for such assessments **(Pilling *et al.*, 2009; Hordyk *et al.*, 2015a; Mildenberger *et al.*, 2017)**. The TropFishR R package is a valuable analytical tool for processing these data, providing various fish population assessment methods tailored for data-constrained fisheries **(Mildenberger *et al.*, 2017)**. Within this framework, several length-based approaches have been developed to estimate biological parameters and assess stock status. Among these, the length-based spawning potential ratio (LBSPR) is considered one of the most effective methods for reliable stock assessments **(ICES, 2015)**.

Therefore, the current study aimed to investigate the biology, population dynamics, and stock status of *E. encrasicolus* in the Egyptian Mediterranean using best practices for managing data-limited fisheries.

MATERIALS AND METHODS

1. Study region

A data collection framework was implemented on a monthly basis from October 2022 to September 2024. A total of 26,941 specimens were collected from five commercial fish landing sites along the Egyptian Mediterranean coast (Fig. 1). For each specimen, the following data were recorded: total length (TL), total weight (TW), gonad weight (Gon.W), and gutted weight (GW). In addition, sex and maturity stage were determined.

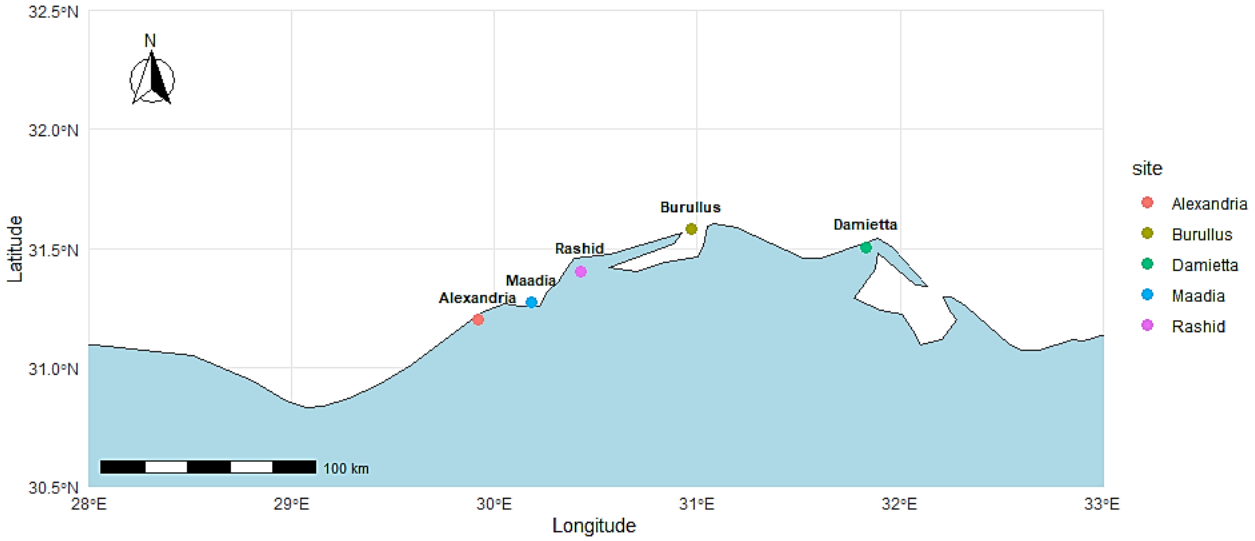

Fig. 1. Egyptian Mediterranean Coast, including the five sampled landing sites

2. Length-weight relationship

Following **Le Cren (1951)**, the relationship between length and weight was analyzed using a power function expressed as:

$$W = aL^b$$

Where, L denotes the total length of the specimen in millimeters (mm), W represents the total weight in grams (g), a is the intercept related to the condition factor, and b is the allometric growth exponent.

3. Estimation of growth, mortality, and maturity parameters

To estimate growth parameters, the study employed the Genetic Algorithm (GA) optimization method available through the ELEFAN_GA function in the R package *TropFishR* **(Mildenberger *et al.*, 2017)**. This approach facilitates the estimation of key parameters such as the asymptotic length ($L\infty$) and the growth coefficient (K) by fitting the von Bertalanffy Growth Function (vBGF) to length-frequency data **(von Bertalanffy, 1938)**. Compared to traditional methods, the GA-based ELEFAN approach improves

model performance by thoroughly exploring a wide parameter space and minimizing the risk of convergence to local optima.

Sexual maturity was determined using macroscopic grading throughout the spawning period. The length at 50% maturity (L_{50}) was estimated using logistic regression. To quantify uncertainty, the data were bootstrapped 1,000 times, generating distributions of the logistic regression parameters and maturity probabilities across the observed length range. The 95% confidence intervals for L_{50} and L_{95} were calculated using the 2.5th and 97.5th percentiles of the bootstrap estimates, while median values were used as point estimates. The logistic model applied was:

$P = 1 / [1 + e^{-r(L-L_{50})}]$ (King, 1995)

Natural mortality (M) was estimated using Gislason's empirical formula **(Gislason *et al.*, 2010)**.

4. Length-based spawning potential ratio (LBSPR)

The LBSPR method **(Hordyk *et al.*, 2015a, 2015b, 2016)** was employed to assess stock status. This method is regarded as one of the most robust length-based approaches for evaluating data-limited fisheries **(ICES, 2015)**. LBSPR was used to estimate the spawning potential ratio (SPR) reference point, based on the observed length composition of the catch, following the methodology described in **Hordyk *et al.* (2016)**.

RESULTS

1. Length-weight Relationship

The observed total weight (*W*) in the present study ranged from 0.15 to 13.35g. Moreover, the total length (*TL*) varied between 37 to 129mm. The Length-weight relationship for the sexes combined, graphically represented in Fig. (2), was determined by the power equation: $W= 0.0000001 * TL^{3.3806}$,

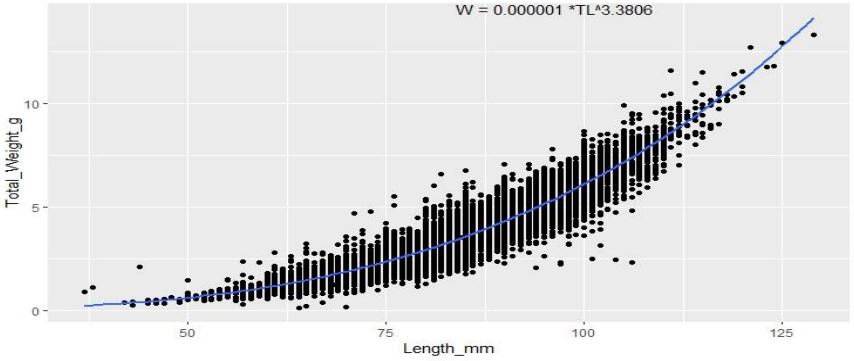

Fig. 2. Length-weight relationship of the *Engraulis encrasicolus* in the Egyptian Mediterranean

2. Growth, death rates, and maturation indicators

The von Bertalanffy growth variables, as estimated with ELEFAN-GA, were as follows: asymptotic length (L_∞) was 135mm, growth coefficient (K) was 0.44 year^{-1}, and the value of (t_0) was -0.489 year, as shown in Fig. (3). Natural mortality (M) estimated by Gislason method was 0.93. Length at 50% and 95% maturity (L_{50} and L_{95}) were 76 and 82mm respectively (Fig. 4).

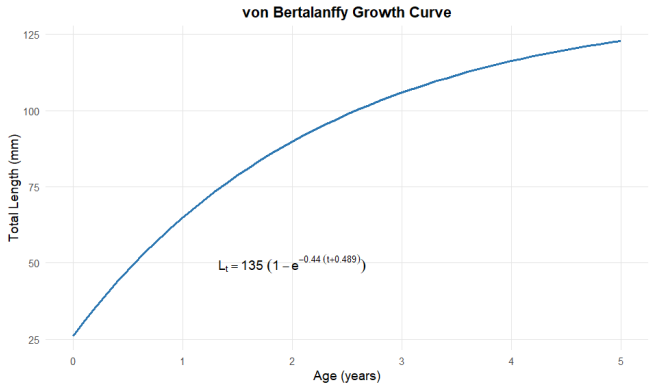

Fig. 3. von Bertalanffy growth curve of *E. encrasicolus* caught from the Egyptian Mediterranean

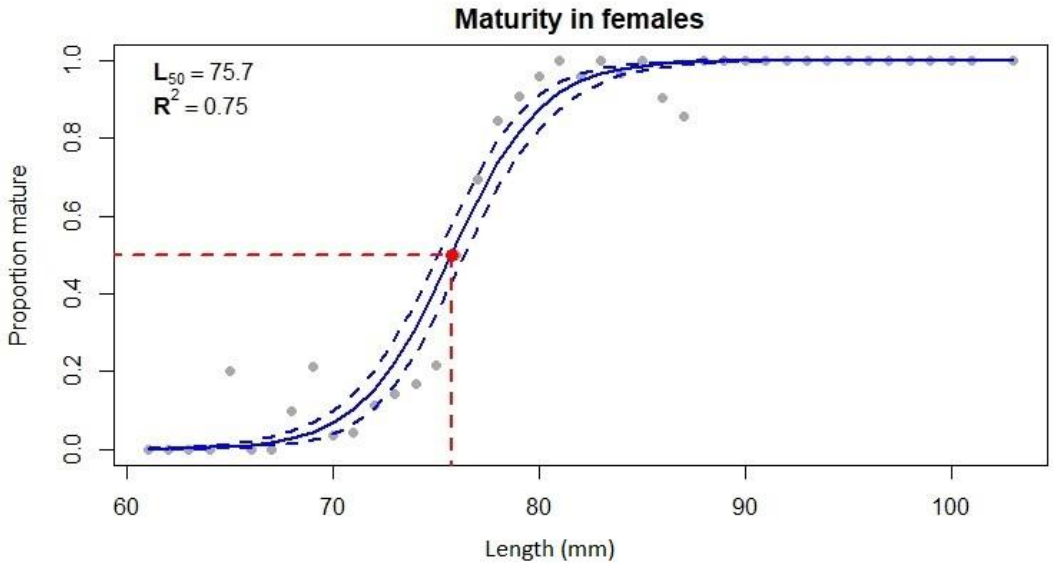

Fig. 4. Length at first sexual maturity of European anchovy in the Egyptian Mediterranean

3. Length-based spawning potential ratio

The LBSPR model successfully fits the length-frequency data of *E. encrasicolus* in Egyptian Mediterranean waters (Fig. 5). Model outputs revealed critical indicators of stock status (Table 1). Curves of selectivity and curves of maturity, *F/M*, and *SPR* results are shown in Figs. (6) and (7).lLength at 50% selectivity (SL_{50}) was 75.08-75.93mm, and length at 95% selectivity (SL_{95}) was 88.69-89.93mm. The estimated values of F/M from the length frequency data were 1.67 and 3.30 for the two sampled years, showing higher rates than the threshold F/M=1. In addition, values of SPR were 0.18 and 0.24, which are lower than the target reference point of SPR 0.40. Both values of F/M and SPR revealed overexploitation of the stock, while maturity and selectivity at length curves showed increasing fishing effort on smaller sizes than larger ones.

Table 1. Main outputs of LBSPR

Year	SL_{50}	SL_{95}	SPR	F/M
2023	75.08	88.69	0.18	1.67
2024	75.93	89.93	0.24	3.30

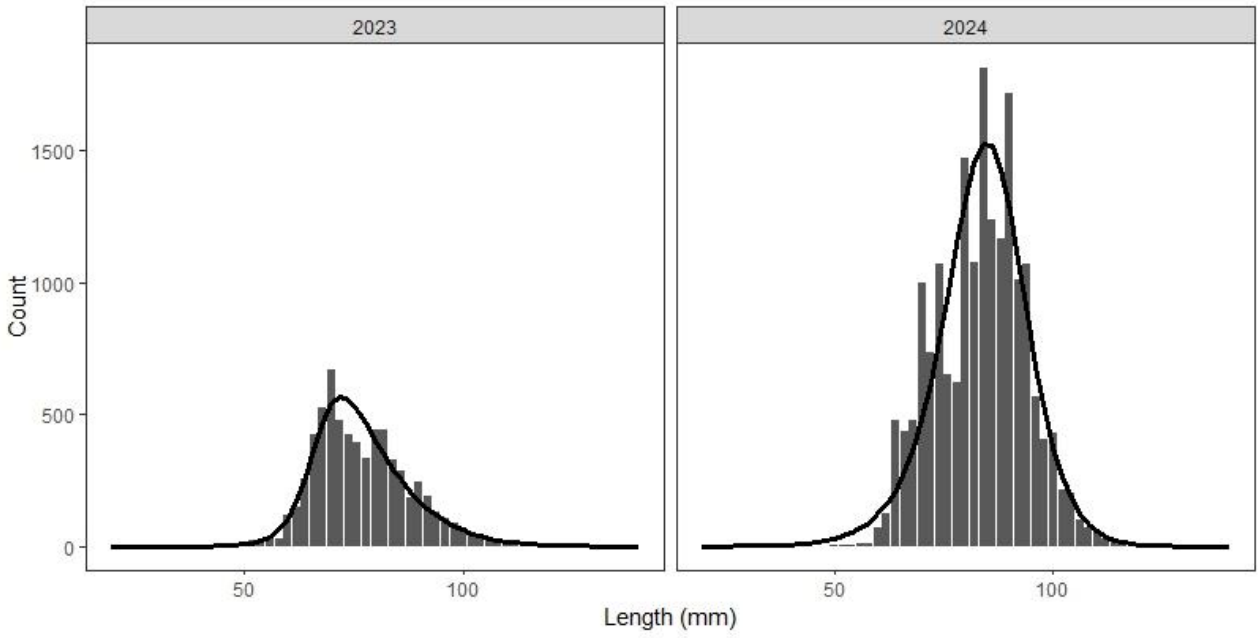

Fig. 5. LBSPR model fit to the observed length-frequency data (LFD) of *E. encrasicolus*. The black bars represent the observed LFD, while the black line shows the model-predicted length distribution

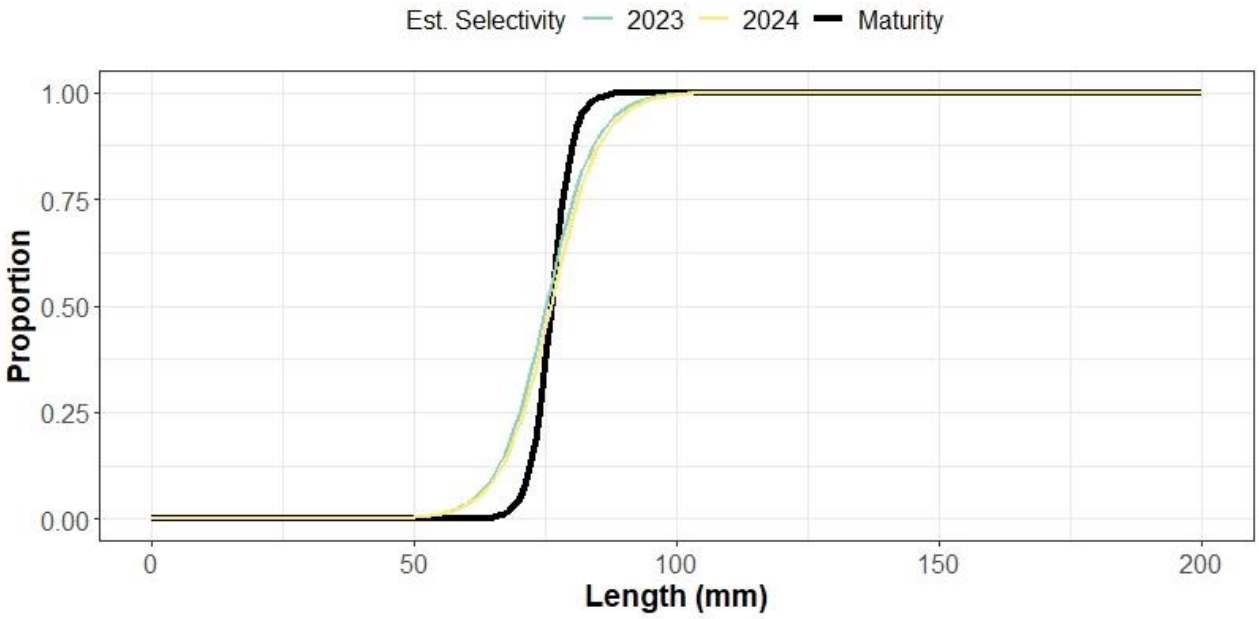

Fig. 6. Curves of maturity-at-length and selectivity-at-length

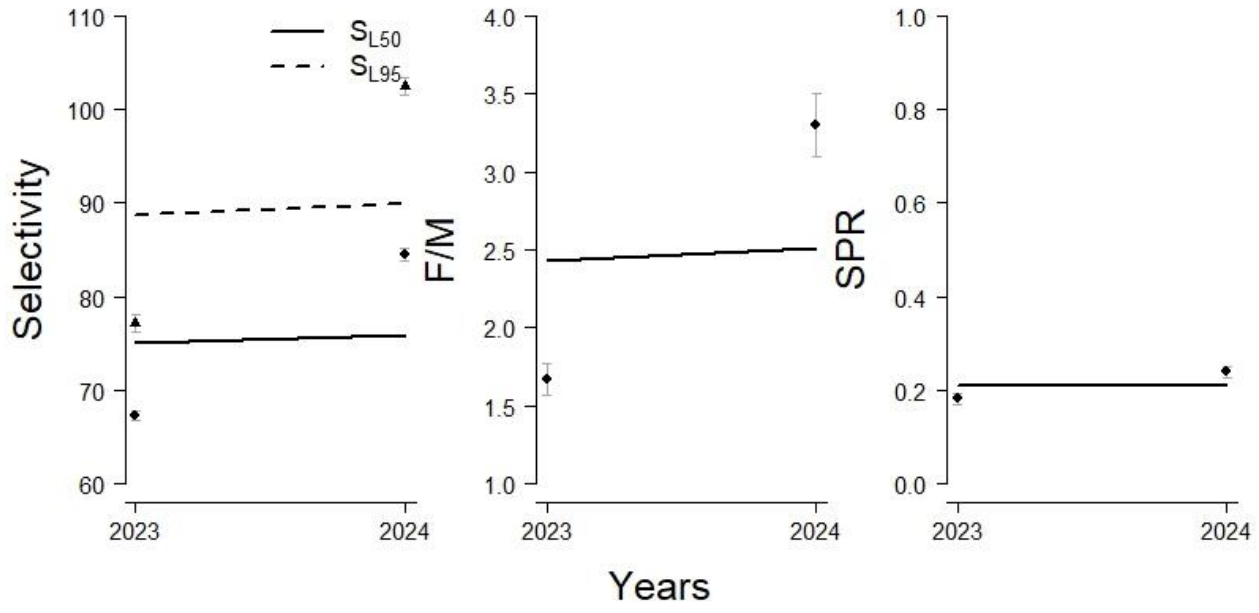

Fig. 7. Estimated SL_{50}, SL_{95}, F/M and SPR

DISCUSSION

Length-based models are commonly applied in data-limited situations to overcome the absence of age data **(Morgan, 1985; Parsamanesh *et al.*, 1998; Mahmoud *et al.*, 2024)**. The length–weight relationship analysis in the present study revealed positive allometric growth in European anchovy in Egyptian Mediterranean waters, with a b value significantly greater than 3.

Although limited, previous studies on anchovies in this region have reported varying length–weight relationships. **Abdallah (2002)** and **Ragheb *et al.* (2019)** recorded b values of 2.86 and 2.77, respectively, using trawl bycatch data—gear not typically suited for anchovy—indicating negative allometric growth. These discrepancies may be attributed to gear selectivity, sample size, and sampling methods, as reflected in the narrower length-frequency ranges compared to the present study.

More broadly, reported b values for anchovy in the Mediterranean and Black Sea vary widely—from 2.3 in the Central Black Sea **(Kalayci *et al.*, 2007)** to 3.82 in the North and North-Western Aegean Sea **(Karachle & Stergiou, 2008)**. These differences are likely driven by environmental variability, fishing pressure, population structure, and methodological factors.

Numerous studies have shown that growth parameters of European anchovy vary depending on geographic region and duration of study (Table 2). The present study reported relatively low asymptotic length and length at maturity, with a K value similar to that observed elsewhere. These differences in growth are closely linked to environmental conditions, which are major factors influencing fish growth. Sea surface temperature directly affects growth rates **(Pauly, 1980; Brunel & Dickey-Collas, 2010; Gursalan *et al.*, 2017)**, while fluctuations in environmental conditions may indirectly affect growth through changes in food availability **(Möllmann *et al.*, 2005)**.

According to **Basilone *et al.* (2017)**, fish size at a given age can vary between populations depending on ecological circumstances. Fishing also influences size structure: intense exploitation can lead to size shrinkage in some Mediterranean stocks **(Pauly *et al.*, 1998; Damalas *et al.*, 2015)**. **Leitão (2019)** highlighted fishing as a driver of size changes in fish populations, while **de Roos *et al.* (2006)** found that reduced length at maturity can be a natural adaptation to increased fishing pressure. Such changes affect reproductive capacity and recruitment due to the size-selective nature of fisheries **(Shin *et al.*, 2005; Tu *et al.*, 2018)**. Other studies report decreasing average catch length under sustained fishing effort **(Jennings *et al.*, 1999; Götz *et al.*, 2008)**.

The continued decline in Mediterranean anchovy populations appears to be associated with bottom-up regulatory effects, such as changes in plankton abundance and diversity **(Brosset *et al.*, 2016; Saraux *et al.*, 2019)**.

The estimated natural mortality rate (M) was 0.93 year^{-1}, consistent with the high turnover rates typical of short-lived pelagic species like *E. encrasicolus*. This finding aligns with previous studies reporting similar mortality rates for anchovies in the Bay of

Biscay ($M \approx 0.9\ yr^{-1}$) **(Uriarte *et al.*, 2016)**, and in the southeastern Black Sea, where M ranged from 0.93 to 1.26 yr^{-1} over a decade **(Çiloğlu & Şahin, 2022)**. These similarities may reflect comparable environmental pressures across regions.

Additionally, the study found that *E. encrasicolus* in the Egyptian Mediterranean is experiencing overfishing and overexploitation. Spawning Potential Ratio (SPR) values ranged from 0.18 to 0.24, indicating that the current reproductive capacity of the population is only 18%–24% of its unfished potential. While a slight increase in SPR was observed over the two years, values remained below the accepted sustainability threshold. International fisheries guidelines generally recommend an SPR range of 30%–40% as the target, with 20% considered the lower limit. Falling below this reference point puts the stock at risk of recruitment failure **(Mace & Sissenwine, 1993)**.

The F/M ratio also showed that fishing mortality exceeds natural mortality, highlighting overfishing. Increasing F/M values suggest rising fishing pressure, which may further erode the reproductive potential of the population.

The selectivity curves displayed an S-shaped pattern, indicating that larger fish are more likely to be caught than smaller ones. Fig. (6) shows the estimated selectivity curves for 2023 and 2024, alongside the maturity ogive. While the gear predominantly targets fish around the length at 50% maturity (L_{50}), a significant proportion of immature individuals remain vulnerable to capture. This is evident from the leftward shift of the selectivity curve relative to the maturity curve. Although the gear is relatively size-selective, it does not fully exclude immature fish. Consequently, some individuals are caught before reaching reproductive maturity, negatively impacting spawning stock biomass and long-term recruitment.

A persistently low SPR indicates a reduced number of reproductive individuals, underscoring the urgent need for protective measures to conserve the spawning population. Similar observations have been made in other parts of the Mediterranean, where low SPR values have been associated with stock declines and diminished recruitment **(Tsikliras *et al.*, 2015)**.

Based on the results of this study, an effective management plan is recommended. Key measures should include reducing current fishing mortality and implementing size limits to protect immature individuals, thereby enhancing the spawning potential and ensuring long-term stock sustainability.

Table 2. Comparing the growth variables of European anchovy in various previous investigations

Area	L_∞	*K*	t_0	Source
Egyptian Mediterranean	13.5	0.44	-0.489	**Current Study**
Gulf of Cádiz	18.8	0.9	-	Bellido *et al.* (2000)
Central–northern Adriatic	19.4	0.57	-	Sinovčić (2000)
Central Ionian Sea	17.5	0.51	-	Machias *et al.* (2000)
Alboran Sea	18.8	0.34	-	CGPM (2000)
Strait of Sicily	18.6	0.3	-1.81	Basilone *et al.* (2000)
Black Sea	16.36	0.42	-1.35	Samsun *et al.* (2004)
South Tunisian coast	17.19	0.36	-1.010	Khemiri *et al.* (2007)
North Tunisian coast	19.16	0.32	-1.680	Khemiri *et al.* (2007)
Lagune de Nador	10.68	0.87	-0.21	Kada *et al.* (2009)
Benisaf	15.61	0.75	-1.32	Bacha *et al.* (2010)
Gulf of Annaba	17.89	0.6	-0.008	Nadira Benchikh *et al.* (2018)
Lake Manzala, Egypt	12.52	0.95	-0.162	El-Betar *et al.* (2023)

CONCLUSION

This study used length-based, data-limited methods to provide insights into the biology, growth, and stock status of *E. encrasicolus* in the Egyptian Mediterranean. The results revealed that the stock is currently in an overexploited state, with spawning potential ratios (SPR) falling below accepted biological reference points. The observed high F/M ratios and low SPR values reflect increased fishing pressure and reduced reproductive capacity of the stock. Applying the LBSPR model, combined with growth and maturity analyses, highlights the need for immediate management measures.

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