ASSESSING THE POPULATION PARAMETERS OF EUROPEAN ANCHOVY, *ENGRAULIS ENCRASICOLUS* (LINNAEUS, 1758) IN ALGERIAN EAST COAST (SOUTHWESTERN MEDITERRANEAN SEA)

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Abstract. In this study, the stock of European anchovy, *Engraulis encrasicolus* (Linnaeus, 1758) caught off the eastern coast of Algeria was evaluated by the TropFishR package in R because it modernizes traditional stock assessment methods by simplifying their application with advanced statistical approaches. Between September 2022 and August 2023, 2455 individuals were caught. The growth parameters $L\infty$, K, and Φ' were estimated as 18.48 cm, 0.36 yr^{-1}, and 2.08, respectively. The overall population experienced positive allometric growth. The mortality rates for total (Z), natural (M), and fishing (F) were estimated as 2.09, 0.39, and 1.70 yr^{-1}, respectively. The exploitation rate (E) was estimated to be 0.81, with a length of 13.29 cm at first capture (Lc50). The yield-per-recruit analysis found that the current exploitation rate and fishing mortality were lower than the maximum sustainable exploitation rate (E_{max} = 1.24) and fishing mortality for maximum sustainable yield (F_{max} = 2.59 yr^{-1}), respectively. In this context, the stock of *E. encrasicolus* from the El Tarf coastline (eastern Algeria) was found to be stable, indicating sustainable fishing practices. Continuous monitoring of fishing effort and rigorous enforcement of regulations regarding mesh size and biological rest will guarantee the sustainability of species management.
Keywords: *Engraulidae, exploitation, biological reference points, TropFishR, Algeria*

Introduction

The ongoing increase in fishing pressure on fish stocks, despite their ability to self-renew, has been identified as the primary cause of decline in fish resource abundance and poses the greatest threat to the sustainable development of fishing activities. According to estimates from the Food and Agriculture Organization (FAO) for 2022, nearly 35.5% of global marine fish stocks are overexploited, 53.3% are exploited at the maximum sustainable level, and 7.2% are underexploited. In the Mediterranean (FAO fishing area No. 37), the situation is even worse, with 63.4% of fish stocks exploited at unsustainable levels. Small pelagic fish are among the most affected marine species, accounting for more than half of total annual fishing catches (FAO, 2022). Algeria, as part of the Mediterranean basin, is no exception, with small pelagic fish accounting for approximately 80% of national fishery production, which is estimated to be nearly 112000 tons (MPPH, 2023).

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Small pelagic fish have significant fishery potential in Algeria, both socially and economically, as evidenced by their low cost and high landings. The European anchovy, *Engraulis encrasicolus* (Linnaeus, 1758), and the sardine, *Sardina pilchardus* (Walbaum, 1792), are especially popular in markets (MPPH, 2023). However, anchovy production has discontinuous distribution and stock fluctuations, resulting in market scarcity during certain periods. According to the Ministry of Fisheries and Fishing Products, the exploitable biomass of anchovy landings was evaluated and ranked fifth over the last decade, accounting for 3% of total small pelagic catches in 2022. Sardine ranked first (26%), followed by round sardinella (25%), horse mackerel (17%), and bogue (5%).

Due to its economic importance, *E. encrasicolus* has been studied extensively in various Mediterranean and Atlantic regions. These studies have focused on various topics, including morphological, biological, and reproductive characteristics, age and growth characteristics, and population genetics. Notable works include those by Fage (1920), Erkoyuncu and Ozdamar (1989), Lisovenko and Andrianov (1996), Samsun et al. (2004), Gaamour et al. (2004), Sinovcic and Zorica (2006), Kada et al. (2009), Tsikliras et al. (2010), Somarakis et al. (2012), Saglam and Saglam (2013), Bacha et al. (2014), Ouattara et al. (2015), Basilone et al. (2015), Amponsah et al. (2016), Ciloglu and Sahin (2022), El-Betar et al. (2023), and Taylan (2024).

In Algeria, researchers have studied *E. encrasicolus* from various aspects. Bacha et al. (2010) studied dietary habits along the western coast, while Djabali and Hemida (1989) looked into reproductive characteristics in the central region. On the eastern coast, research was conducted in the Gulf of Béjaïa (Bacha and Amara, 2012) on growth and diet, in the Gulf of Skikda (Mezedjeri et al., 2013) on reproduction, along the coast of El Kala (Ladaimia et al., 2016) on reproduction, and in the Gulf of Annaba (Benchikh et al., 2018) on age and growth. However, no studies have been conducted to assess the population stock of this species, one of Algeria’s most important small pelagic species. This study aims to address this deficiency by improving and conserving this resource, ultimately striving to formulate sustainable management recommendations for the species based on findings derived from the TropFishR package in the software ‘R’, which integrates various contemporary stock assessment methodologies tailored for fisheries evaluation utilizing length frequency (LFQ) data.

Material and methods

Study area and sampling

Between September 2022 and August 2023, samples were collected monthly from commercial fishing inputs in the wilaya of El Tarf, which is located on the southwestern Mediterranean coast at the extreme east of the Algerian littoral, between the wilaya of Annaba and the Tunisian border. The province has a 120-kilometer-long coastline that stretches from Annaba (36°50’40.85 “N and 7°50’8.17 “E) in the west to Tunisia (36°56’30.32 “N and 8°38’30.60 “E) in the east (*Fig. 1*). Anchovies were captured throughout the year using purse seine nets (mesh size 8 mm) and artificial light. The current regulations imposed no temporal restrictions. A total of 2455 fish were brought to the laboratory to be weighed (total weight “TW”, to the nearest 0.01 g), measured (total length “TL”, to the nearest 0.1 cm), and identified by sex.

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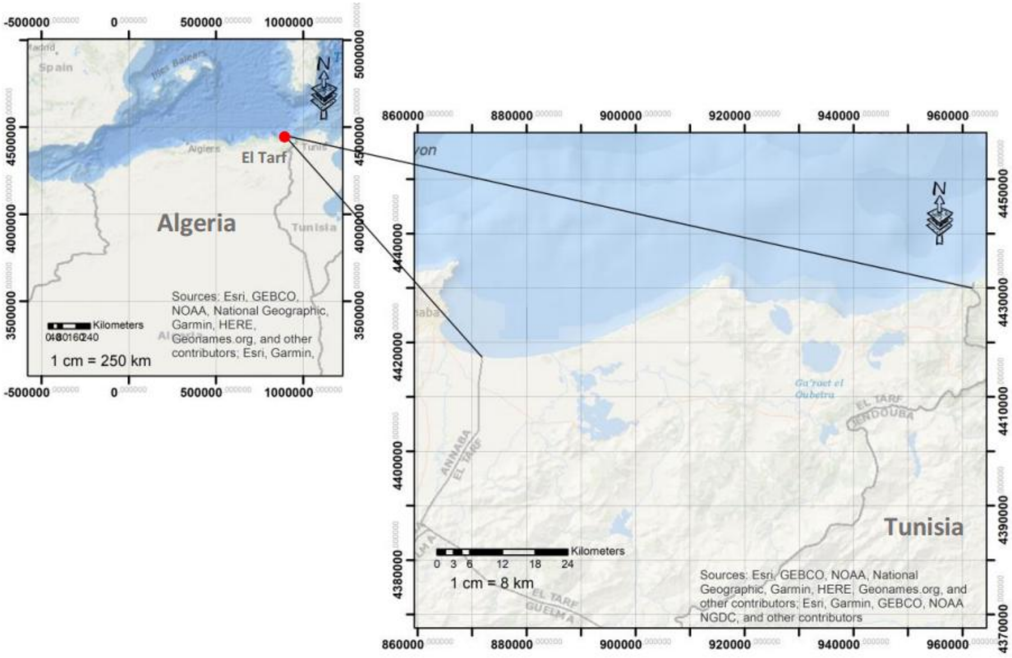

Figure 1. *Location of the study area*

Growth parameters

The von Bertalanffy Growth Function (VBGF) was used to determine growth parameters. The growth rate (K) and asymptotic length (L∞) were estimated using the simulated annealing (SA) option of the Electronic Length Frequency Analysis (ELEFAN), as described by Taylor and Mildenberger (2017). Using these parameters (L∞ and K), we calculated the growth performance index with Pauly and Munro's (1984) formula:

$$\Phi' = 2\mathrm{Log}_{10}\,\mathrm{L}\infty + \mathrm{Log}_{10}\,\mathrm{K} \qquad \text{(Eq.1)}$$

Additionally, the theoretical age at length zero (t_0) was determined using Pauly's (1979) equation:

$$\mathrm{Log}_{10}(-\mathrm{t0}) = -0.3922 - 0.2752\,\mathrm{Log}_{10}\,\mathrm{L}\infty - 1.038\mathrm{Log}_{10}\,\mathrm{K} \qquad \text{(Eq.2)}$$

Length-weight relationships

The length-weight relationship was assessed using Ricker's (1973) equation:

$$\mathrm{TW} = \mathrm{a}\,\mathrm{TL}^{\mathrm{b}} \qquad \text{(Eq.3)}$$

where, a is the intercept of the regression and b is the growth coefficient. The b value was compared to $b_0 = 3$ at an α = 5% significance level using the Student's t-test to determine the growth pattern of the population (Dagnelie, 1975).

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Mortality and exploitation rates

The length-converted catch curve method was used to calculate the instantaneous rate of total mortality (Z) (Pauly, 1984). The natural mortality coefficient (M) was estimated using the method of Djabali et al. (1994), which has the following formula:

$$\mathrm{Log_{10}M} = -0.0278 - 0.1172 \times \mathrm{Log_{10}}\, L\infty + 0.5092 \times \mathrm{Log_{10}}\, K \quad \text{(Eq.4)}$$

Based on the growth and mortality of 56 Mediterranean fish stocks, where k and L_∞ are the von Bertalanffy constants.

The fishing mortality coefficient (F) was calculated using Pauly's (1980) relationship:

$$F = Z - M \quad \text{(Eq.5)}$$

The exploitation rate (E) was obtained using Gulland's (1971) formula:

$$E = F / Z \quad \text{(Eq.6)}$$

The stock is in equilibrium when E = 0.5. It is under-exploited when E < 0.5 and overexploited when E > 0.5 (Gulland, 1971; Pauly, 1985).

Length at first capture (Lc_{50})

The length at first capture Lc_{50}, the length at which half of the fish of that size are susceptible to capture, was estimated from a linearized catch curve and a selectivity ogive analysis (Pauly, 1987). This method allowed for the calculation of capture lengths with probabilities of 50%, 75%, and 95% (Pauly, 1987).

Estimated stock size

Jones' (1984) length-converted cohort analysis, which estimated stock size, is a revision of Pope's virtual population analysis (VPA) for length data integrated into TropFishR. This cohort analysis (CA) requires parameters a and b of the length-weight relationship, the estimated value of F, and the mortality rate per terminal fishery that was considered the exploitation rate (Taylor and Mildenberger, 2017).

Relative yield per recruit (YPR)

The Thompson and Bell model provided the biological reference levels required to determine input control measures, such as reducing fishing effort. To estimate yield and biomass trajectories in the study, fishing mortality was assessed by varying the parameter F in this model. The biological reference levels were F_{max} (fishing mortality for maximum sustainable yield), $F_{0.5}$ (fishing mortality reducing the population to 50% of unfished biomass), and $F_{0.1}$ (fishing mortality reducing the marginal yield per recruit gain at an arbitrary rate of 10% compared to F = 0) (Taylor and Mildenberger, 2017). The yield-per-recruit isopleth diagram was used to evaluate the impact of variations in fishing mortality and selectivity ($Lc = Lc_{50}/L_\infty$).

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Data analyses

The TropFishR package of the statistical software 'R' (version 4.4.1) (Mildenberger et al., 2017) was used to determine the population parameters of the species *E. encrasicolus* from length-frequency (LFQ) data. TropFishR incorporates enhanced versions of all functions from FAO-ICLARM's Fish Stock Assessment Tools II (FiSAT II) (Gayanilo et al., 2005). The package includes updated versions of the Electronic Length Frequency Analysis (ELEFAN) method (Pauly 1980), which is used to estimate growth parameters. It also includes new optimization techniques (Taylor and Mildenberger, 2017), non-linear selectivity models, and a wide range of fisheries analysis methods that estimate mortality rates, length-to-catch, virtual population analysis (VPA) and biological reference points.

Results

Length-frequency distribution

Between September 2022 and August 2023, a total of 2455 *E. encrasicolus* (1173 females, 1039 males, and 243 undetermined) were collected from commercial landings. The total length (TL) of the population ranged from 8 to 17.4 cm, while the total weight (TW) varied from 2.5 to 32.47 g. Females measured between 8.4 and 17.4 cm TL ($3.5 \leq TW \leq 32.47$ g), while males measured between 8.5 and 16.8 cm TL ($2.5 \leq TW \leq 30.37$ g). The frequency distribution was established with 0.5 cm classes. Individuals measuring 13 to 16 cm accounted for 50% of the catches (*Fig. 2*).

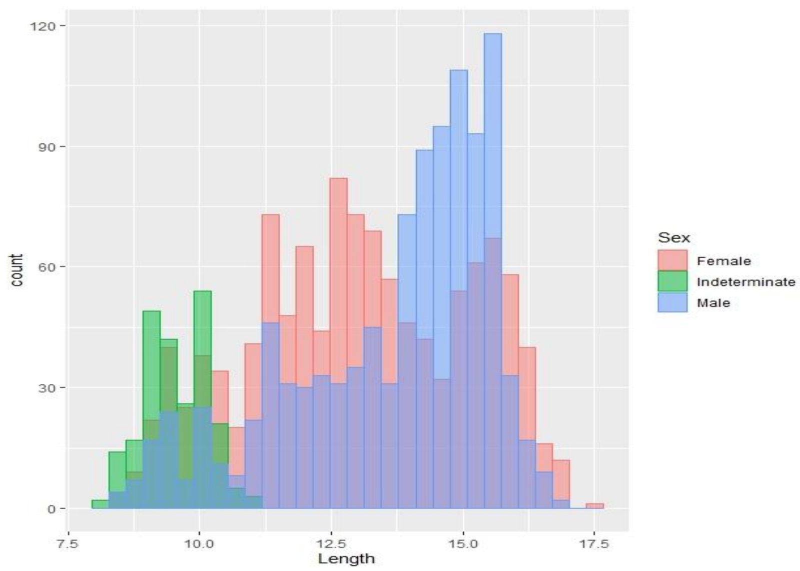

Figure 2. *Size frequency distribution of E. encrasicolus caught along the eastern Algerian coast from September 2022 to August 2023*

Growth parameters

The ELEFAN_SA algorithm was applied to the length-frequency data of *E. encrasicolus* to determine growth parameters. $L\infty$ and K were estimated to be 19.49 cm and 0.33 yr^{-1} for females, 18.65 cm and 0.28 yr^{-1} for males, and 18.48 cm and 0.36 yr^{-1}

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for the overall population, respectively. *Table 1* shows the other growth parameters estimated using ELEFAN_SA, while *Figure 3* depicts the restructured length-frequency distribution overlaid with the growth curves.

Table 1. *Growth parameters gained with the ELEFAN_SA algorithm*

Sex group	L∞ (cm)	K (yr^{-1})	t_0 (yr)	t_{anchor}	t_s	C	Φ′	Rn score
Female	19.49	0.33	-0.565	0.63	0.52	0.73	2.104	0.36
Male	18.65	0.28	-0.679	0.30	0.25	0.34	2.002	0.22
Tot pop	18.48	0.36	-0.540	0.16	0.82	0.97	2.089	0.27

Tot pop: Total population; L∞: Asymptotic length; K: Growth coefficient; t_{anchor}: Defined the percentage of the year in which the growth curve crosses the zero-point length; t_s: Summer point of oscillation; C: Intensity of seasonality; Rn: Goodness of fit index; Φ′: Growth performance index; t_0: Theoretical age at length zero (derived from the growth parameters L_∞ and K)

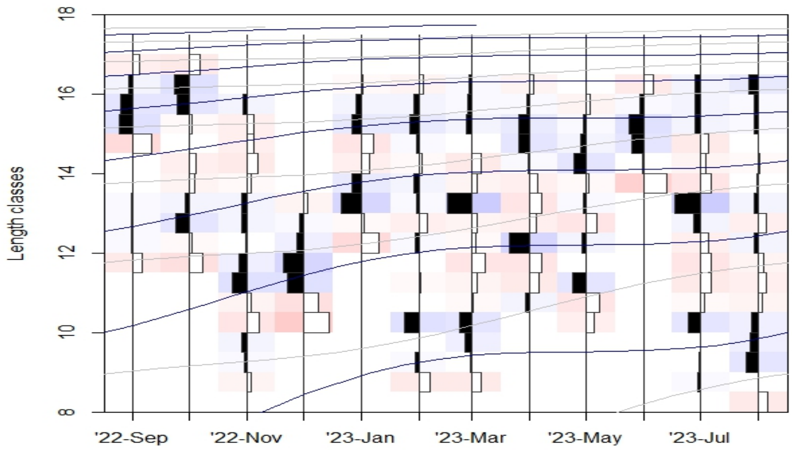

Figure 3. *Graphical fit of the estimated growth curve of the total population plotted using the length frequency data (ELEFAN_SA)*

Length-weight relationships

The length-weight relationships were determined as follows: TW = 0.029 $TL^{3.280}$ (R2 = 0.956) for females; TW = 0.027 $TL^{3.300}$ (R2 = 0.959) for males; and TW = 0.026 $TL^{3.310}$ (R2 = 0.965) for the total population. The entire population showed a positive allometric growth type (+). *Table 2* contains the parameters of the length-weight relationship model, and *Figure 4* depicts the graph for different groups with similar growth types (overlapping regression lines).

Table 2. *Length-weight relationship model parameters of E. encrasicolus*

Sex	a	b	95% CI of b	R^2	Allometry type
Female	0.029	3.280	3.24 - 3.32	0.956	Positive
Male	0.027	3.300	3.26 - 3.34	0.959	Positive
Tot pop	0.026	3.310	3.29 - 3.34	0.965	Positive

b: Growth allometry coefficient; a: Constant (These values (a and b) were used as input parameters for performance analysis per recruit in TropFishR); CI: confidence interval; R^2: Determination coefficient; $p < 0.001$ for all regressions

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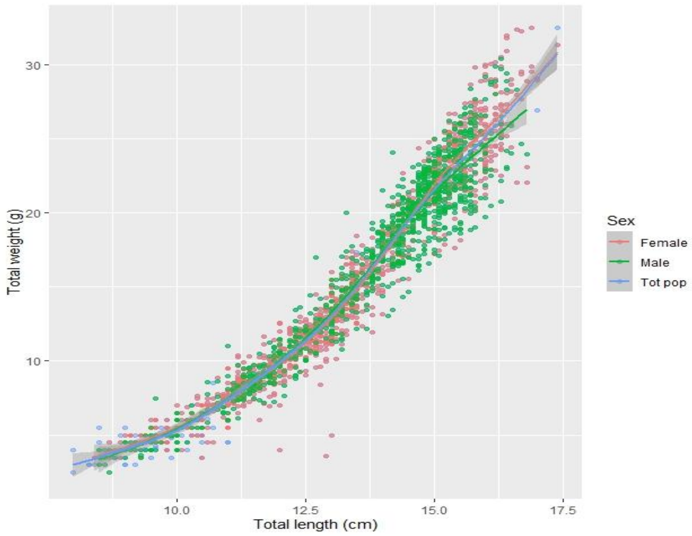

Figure 4. *Length-weight relationship graph of E. encrasicolus (red points represent females, green points represent males, and blue points represent the total population; red, green, and blue lines show the regression line for females, males, and the total population, respectively; grey areas describe the 95% CIs of regression lines)*

Mortality and exploitation rates

Due to indiscriminate harvesting, effective management strategies cannot be applied differently to males and females. As a result, the stock assessment of the European anchovy, *E. encrasicolus*, from Algeria's eastern coast (El Tarf coastline) was conducted using data from all sampled individuals. The linearized length-converted catch curve was used to estimate instantaneous total mortality (Z), as illustrated in *Table 3* and *Figure 5*. The total mortality rate (Z) was 2.09 ± 0.44 yr^{-1}. Natural mortality (M), according to Djabali et al. (1993) and consequently fishing mortality (F) were estimated at 0.39 yr^{-1} and 1.70 yr^{-1}, respectively. The current exploitation rate (E) was 0.81.

Table 3. *Mortality, exploitation rates and biological reference points of the E. encrasicolus on the Eastern Algerian coast*

Parameters	Total population
Total Mortality (Z)	2.09 yr^{-1}
Natural Mortality (M)	0.39 yr^{-1}
Fishing Mortality (F)	1.70 yr^{-1}
F_{max}	2.59 yr^{-1}
$F_{0.1}$	0.71 yr^{-1}
$F_{0.5}$	0.81 yr^{-1}
Current Exploitation (E)	0.81
E_{max}	1.24
$E_{0.1}$	0.34
$E_{0.5}$	0.38
Length at first capture (Lc_{50})	13.29 cm
Age at first capture (t_{50})	3.56 yr

F_{max}: Fishing mortality for maximum sustainable yield; $F_{0.1}$: Fishing mortality reducing the marginal yield per recruit gain at an arbitrary rate of 10% compared to F = 0; $F_{0.5}$: Fishing mortality to fish the stock at 50% of the virgin biomass; E_{max}: Exploitation rate producing maximum yield; $E_{0.1}$: Exploitation rate at which the marginal increase in relative yield-per-recruit is 10% of its virgin stock; $E_{0.5}$: Exploitation rate under which the stock is reduced to 50% its virgin biomass

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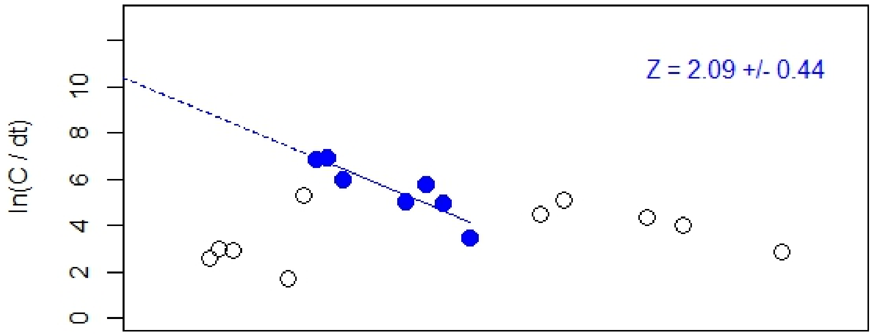

Figure 5. *Linearized length-converted catch curve for the estimated total mortality (Z) of E. encrasicolus on the eastern coast of Algeria*

Length at first capture (Lc_{50})

The length at first capture (Lc_{50}) was 13.29 cm, or approximately 3.56 yr (*Fig. 6* and *Table 3*). The lengths where the probability of capture was 75% (Lc_{75}) and 95% (Lc_{95}) were 13.81 cm and 14.56 cm, respectively, with ages of t_{75} = 3.86 yr and t_{95} = 4.35 yr.

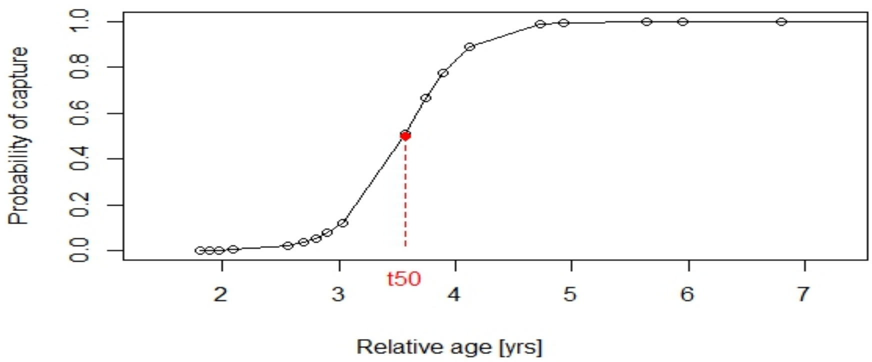

Figure 6. *The logarithm of catch per length interval against relative age*

Estimated stock size

According to Jones' cohort analysis (CA), fishing mortality affects all size classes of *E. encrasicolus*, and the majority of this species was caught between 13 and 16 cm, with a peak fishing mortality (F) observed at mid-length of 16.25 cm. Natural losses were highest among individuals ranging in length from 8 to 10.75 cm. The number of surviving individuals in the stock decreased as fishing pressure increased (*Fig. 7*).

Relative yield per recruit (YPR)

The plot of relative yield per recruit versus exploitation ratio revealed that the indices for E_{max} $E_{0.5}$ and $E_{0.1}$ were 1.24, 0.38, and 0.34, respectively. The current E value (0.81) is higher than Gulland's (1969) optimal level (E = 0.5), as well as the rates $E_{0.5}$ and $E_{0.1}$, but it is lower than the E_{max} rate (*Table 3*). According to *Figure 8a*, the sustainable yield indices were F_{max} = 2.59 yr^{-1}, $F_{0.5}$ = 0.81 yr^{-1}, and $F_{0.1}$ = 0.71 yr^{-1}. This shows that the current fishing mortality (F=1.70 yr^{-1}) is lower than the fishing mortality for maximum sustainable yield (F_{max}=2.59 yr^{-1}) but still higher than $F_{0.1}$ and $F_{0.5}$, confirming the exploitation ratio indication. As a result, the fishing of the *E. encrasicolus* stock off

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Algeria's eastern coast is stable and sustainable, as fishing pressure on this species is not at its extreme (*Table 3*). The exploration of the impact of different exploitation rates and Lc values on yield per recruit reveals a stable state (Blackheads represent the current fishing regime) (*Fig. 8b*).

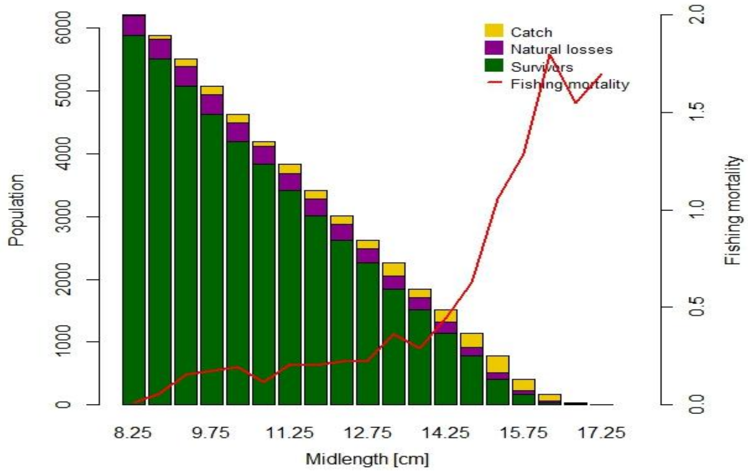

Figure 7. *Jones' cohort analysis (CA) of E. encrasicolus fishery with fishing mortality rate by length classes and resulting reconstructed population structure (survivors, natural losses and catch) in numbers per length class*

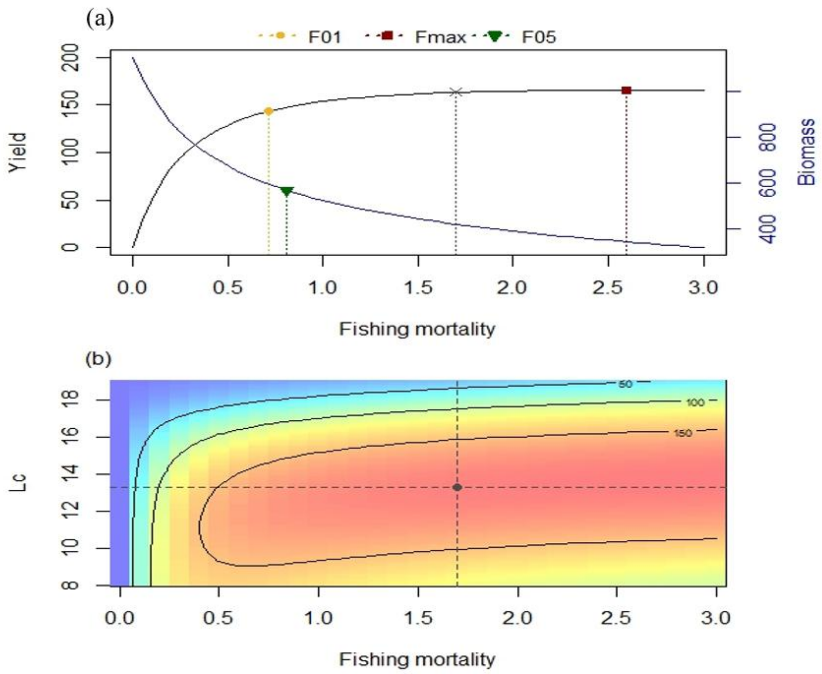

Figure 8. *Thompson and Bell model: a) Curves of yield and biomass per recruit plot of E. encrasicolus on the Est Algerian coast. The black dot represents yield and biomass under the current fishing pressure (F=1.70 yr^{-1}). The yellow, red and green lines represent fishing mortality that reduces the marginal gain in yield per recruit to an arbitrary 10% of that at F = 0 ($F_{0.1}$=0.71 yr^{-1}), maximum allowable fishing mortality (F_{max} = 2.59 yr^{-1}) and fishing mortality with a 50% reduction related to the virgin biomass ($F_{0.5}$ = 0.81 yr^{-1}). b) Exploration of the impact of different exploitation rates and Lc values on the relative yield per recruit*

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Discussion

Because there is limited information on the population dynamics of *E. encrasicolus* in Algerian marine waters, the results of the current study's findings will serve as a reference basis for the sustainable management of this species. Between September 2022 and August 2023, a total of 2455 individuals (1173 females, 1039 males, and 243 undetermined) were collected from commercial landings in wilaya of El Tarf (Eastern Algerian coastline). Females outnumbered males, which reassures us about the reproductive potential of the stock. Numerous authors who have studied small pelagic species have reported this dominance (Khemiri and Gaamour, 2009; Mezedjeri et al., 2013; Ladaimia et al., 2016; Dahel et al., 2016; Benchikh et al., 2018). Females' numerical superiority can be attributed to a variety of factors, including greater longevity, rapid growth (early ovary development), increased vulnerability to fishing gear, and different migratory movements than males (Khemiri and Gaamour, 2009).

The total length (TL) of the entire population ranged between 8 and 17.4 cm, which is consistent with the findings of Benchikh et al. (2018) and Mustac et al. (2020), who discovered 6.9-17.7 cm and 10-17.5 cm, respectively. However, it differs from those obtained in Italy by Basilone et al. (2000), Tunisia by Khemiri et al. (2007), Morocco by Kada et al. (2009), Algeria by Bacha et al. (2010), Côte d'Ivoire by Ouattara et al. (2015), Ghana by Amponsah et al. (2016), and Egypt by El-Betar et al. (2023) (*Table 4*). Differences in sampling methods or sample size could explain the variations in values found across the Mediterranean and Atlantic.

Estimating body growth is critical for understanding populations and ecosystems, and it forms the basis for all analytical stock assessment methods in fisheries science. Modal progression analysis, a length-based method, has been used to estimate fish body growth since the beginning of fisheries science (Schwamborn et al., 2019). *E. encrasicolus* length-frequency data collected in the coastal waters of Eastern Algeria were used to calculate growth parameters using ELEFAN (Electronic Length Frequency Analysis), a widely used method for fitting a growth curve to length-frequency distribution (LFD) data (Schwamborn et al., 2019). ELEFAN with simulated annealing (ELEFAN_SA) and ELEFAN with a genetic algorithm (ELEFAN_GA) were applied to the length-frequency data in our study. However, ELEFAN_SA's results were deemed more appropriate for the dataset than those of ELEFAN_GA due to a higher Rn value (goodness-of-fit index). ELEFAN_SA employs simulated annealing ('S.A.'), a common probabilistic technique for approximating a global optimum (Xiang et al., 2013).

The European anchovy stock (*E. encrasicolus*) has an estimated asymptotic length ($L\infty$) of 18.48 cm and a growth rate (K) of 0.36 yr^{-1}. Branstetter's (1987) growth mode criteria indicate that a species grows slowly at $0.05 \leq K \leq 0.10$ yr^{-1}, intermediately at $0.10 \leq K \leq 0.20$ yr^{-1}, and rapidly at $0.2 \leq K \leq 0.50$ yr^{-1}. As a result, anchovies caught off the coast of El Tarf (Eastern Algeria) grow rapidly (0.36 yr^{-1}). Several authors have reported similar findings in various regions of the Mediterranean and Atlantic, including Samsun et al. (2004), Kada et al. (2009), Bacha et al. (2010), Amponsah et al. (2016), Benchikh et al. (2018), and El-Betar et al. (2023) (*Table 4*). The asymptotic length in females was estimated to be 19.49 cm, which was greater than that in males (18.65 cm). These lengths were achieved at rapid growth rates of 0.33 and 0.28 yr^{-1}, respectively, following the same growth pattern as the *E. encrasicolus* total population. *Table 4* shows that the $L\infty$ and K values in our study differ from those in other studies. The main causes of this situation could be the sampled individuals' maximum lengths and the techniques used in parameter optimization.

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Table 4. *Growth parameters of E. encrasicolus obtained in different geographical regions*

Location	N	Method	LT (cm) Min- Max	L∞ (cm)	K (yr^{-1})	t_0 (yr)	φ'	a	b	Source
Atlantic										
Côte d'Ivoire	1400	Scales	4.4-11.8	19.99	1.03	-0.061	2.610	0.030	2.460 (-)	Ouattara et al. (2015)
Ghana	-	Frequency analysis FiSAT	3-11	11.03	0.58	-0.370	1.849	-	-	Amponsah et al. (2016)
Mediterranean										
Italy (Strait of Sicily)	11769	Otolith	6-16.5	18.6	0.30	-1.810	2.016	-	-	Basilone et al. (2000)
Turkish (Black Sea)	-	Frequency analysis FiSAT	6-15	17.07	0.28	-2.104	2.00	0.0076	2.910 (=)	Samsun et al. (2004)
Eastern Adriatic Sea (Croatia)	860	Otolith	10-17.5	18.36	0.32	-1.890	2.028	0.0037	3.201 (+)	Mustac et al. (2020)
Egypt (Lake Manzala)	1536	Frequency analysis FiSAT	4.2- 12.1	12.52	0.95	-0.162	2.170	-	-	El-Betar et al. (2023)
Morocco (Nador Lagoon)	350	Frequency analysis FiSAT	4.1-10	10.68	0.87	0.210	2.001	0.0035	3.224 (+)	Kada et al. (2009)
North Tunisian coast	343	Otolith	8-16.5	19.16	0.32	-1.680	2.028	-	-	Khemiri et al. (2007)
South Tunisian coast	607	Otolith	6.5-15.5	17.19	0.36	-1.010	2.069	-	-	Khemiri et al. (2007)
West of Algeria (Bay of Bénisaf)	324	Otolith	7-16.2	15.61	0.75	-1.320	2.260	-	-	Bacha et al. (2010)
East of Algeria (Gulf of Annaba)	4152	Frequency analysis FiSAT	6.9-17.7	17.89	0.60	-0.008	2.283	0.0033	3.221 (+)	Benchikh et al. (2018)
East of Algeria (Coast of El Tarf)	2455	Frequency analysis TropFishR	8-17.4	18.48	0.36	-0.540	2.089	0.0268	3.310 (+)	**Current study**

N: Nombre; LT: Total length; Max: Maximum length; Min: Minimum length; L∞: Asymptotic length; K: Growth coefficient; t_0: Theoretical age at length zero; (+): Positive allometry; (-): Negative allometry; (=): Isometric allometry

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For example, in FiSAT II studies, optimization can vary by user. TropFishR, on the other hand, uses advanced algorithms to eliminate user errors (Mildenberger et al., 2017). Pauly and Munro (1984) recommend using the growth performance index (Φ') to compare growth curves between populations of the same species or within the same family. The study found that the index (Φ' = 2.089) was comparable to other authors' results in the Mediterranean and Atlantic (*Table 4*). According to Rahman et al. (2016), species growth performance varies depending on the environment, number of species sampled, and size of the largest individual. The results of the present research represent the first stock estimates of *E. encrasicolus* ever obtained using TropFishR. As a result, the growth parameters estimated using ELEFAN_SA could not be compared to previous studies on *E. encrasicolus*. These growth parameters included the percentage of the year when the growth curve crossed the length at the zero point (tanchor = 0.16), the summer point of oscillation (ts = 0.82), the intensity of seasonality (C = 0.97), and the goodness of fit index (Rn = 0.27).

E. encrasicolus from the coast of El Tarf showed positive growth allometry (b > 3), indicating that weight increases proportionally faster than length, indicating good weight growth (*Table 4*). This result is consistent with the findings of Benchikh et al. (2018) in the Gulf of Annaba (Eastern Algerian coast). This observation was shared by Kada et al. (2009) in Morocco and Mustac et al. (2020) in Croatia. Ouattara et al. (2015) discovered negative growth allometry (b < 3) in Ivorian anchovies, while Samsun et al. (2004) reported isometric allometry (b = 3) in Turkey. Seasons, feeding behavior, competition, maturity, sex, and age can all contribute to regional concordances and divergences in results (Sparre et al., 1989; Sparre, 1992; Mommsen, 1998).

Due to indiscriminate harvesting, it is frequently impossible to apply separate management strategies for males and females in stock assessment models. As a result, most stock assessments require a single set of population characteristics (Santos et al., 2022). The total mortality (Z) for the anchovy *E. encrasicolus* caught along the eastern Algerian coast (El Tarf coastline) was estimated at 2.09 yr^{-1} using the linear catch curve (Pauly, 1984), while natural mortality (M) was 0.39 yr^{-1} using Djabali et al. (1994) method. Fishing mortality (F = 1.70 yr^{-1}) was significantly higher than natural mortality. As a result, the *E. encrasicolus* stock off the coast of El Tarf is more vulnerable to fishing gear than to natural marine causes, specifically environmental conditions (Amponsah et al., 2016). The Z coefficient value is close to that found by Benchikh et al. (2018) and Fedja and Bouaziz (2015) for the same species caught along the eastern Algerian coast, where the mortality rate Z was estimated at 2.31 and 2.63 yr^{-1}, respectively. It is also comparable to the rate discovered by Saglam and Saglam (2013) in the Black Sea of Turkey (Z = 2.84 yr^{-1}). However, it exceeds that of Samsun et al. (2004) in the same region of Turkey, who estimated Z at 1.60 yr^{-1}, while Amponsah et al. (2016) in Ghana and El-Betar et al. (2023) in Egypt discovered higher mortality coefficients of approximately 3.40 $yr^{-1}$and 3.71 yr^{-1}, respectively (*Table 5*). Total (Z) and natural (M) mortalities vary by geographical area (*Table 5*). The disparity in results can be explained by various factors, such as the fishing methods used, the intensity of pressure and the mesh size of the fishing gear, possible ecological differences between study areas, and the values of K and L_∞, which can also directly influence mortalities Z and M, and water temperature (Pauly, 1984, 1997). Ursin (1967) showed that natural mortality M could be influenced by physiological factors such as diseases and aging, environmental factors such as temperatures, currents, and salinities, and random factors such as predation.

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Table 5. *Various mortality and Exploitation rates estimated for E. encrasicolus from different locations*

Location	Z (y^{-1})	M (y^{-1})	F (y^{-1})	E	Source
Atlantic (Ghana)	3.40	1.59	1.81	0.53	Amponsah et al. (2016)
Turkish (Black Sea)	1.60	0.46	1.14	0.71	Samsun et al. (2004)
Turkish (Black Sea)	2.84	0.66	2.18	0.77	Saglam and Saglam (2013)
East coast of Algeria	2.63	0.61	2.02	0.76	Fedja and Bouaziz (2015)
East of Algeria (Annaba)	2.31	0.56	1.75	0.75	Benchikh et al. (2018)
Egypt (Lake Manzala)	3.71	1.46	2.25	0.60	El-Betar et al. (2023)
East of Algeria (El Tarf)	2.09	0.39	1.70	0.81	**Current study**

E = 0.5: balanced stock; E < 0.5: under-exploited stock and E > 0.5: over-exploited stock

The assessment of the *E. encrasicolus* stock status on the eastern Algerian coast, based on the exploitation rate (E=0.81), shows that its fishery is not operating at its optimum level (Gulland, 1971). Benchikh (2009) and Fedja and Bouaziz (2015) both made similar observations in the same study area. Similar findings were reported by Samsun et al. (2004) and Saglam and Saglam (2013) on Turkey's Black Sea, El-Betar et al. (2023) on Egypt's Lake Manzala, and Amponsah et al. (2016) on Ghana's Atlantic coast (*Table 5*). For rational management purposes, the exploitation rate should be equal to or less than 0.5 to keep the stock's spawning biomass intact.

The length at first capture in the current study (Lc_{50}=13.29 cm) was significantly greater than the Algerian Ministry of Fisheries and Aquaculture's minimum landing size for *E. encrasicolus*, which was set at 9 cm by Executive Decree No. 01-11 on July 3, 2011 (MPRH, 2012). This indicates that mature individuals accounted for the majority of the catches, with juveniles and immatures being spared. As a result, the impact on the stock's recruitment potential will be proportionately reduced. The critical length at capture (Lc), a ratio of the length at first capture to the asymptotic length (Lc_{50}/L_∞), estimated in the current study as 0.72 cm, was significantly higher than 0.5, indicating an abundance of adult individuals compared to juveniles (Pauly and Soriano, 1986). This observation could be attributed to the increased mesh size of fishing gear used along the coast of El Tarf to catch small pelagic species, which tends to increase the length at first capture. Therefore, fisheries managers in Algeria must consider revising the legal mesh sizes.

The Jones cohort analysis (CA) results support our assertions, which are that larger-sized fish have higher fishing mortality rates. Furthermore, the higher survival rate among smaller-sized individuals suggests that recruitment overfishing is unlikely to occur in this species' stock. The study found that *E. encrasicolus* from the coast of El Tarf has a higher fishing mortality rate (F = 1.70 yr^{-1}) than natural mortality (M = 0.39 yr^{-1}). This demonstrates that fishing, not natural mortality, is the primary cause of *E. encrasicolus* extinction. However, the fishing pressure on this species was not considered extreme, as it was lower than the required fishing mortality rate for Maximum Sustainable Yield (F_{max} = 2.59 yr^{-1}). The relative yield per recruit (YPR) analysis revealed that the Maximum Sustainable Yield (MSY) would be obtained at an exploitation rate of E_{max} =1.24. The E_{max} value exceeded the current estimated exploitation rate (E = 0.81), indicating stable and sustainable fishing. The conservation of fishery resources necessitates their sustainable exploitation, which must be managed in accordance with the maximum sustainable yield (MSY) principle (ICES, 2006). F_{Max} and E_{max} are biological reference limit points that should not be exceeded because they may jeopardize the stock's ability to self-renew.

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Conclusion

Understanding a species' biological characteristics is critical for making sound decisions and implementing effective management strategies. As a result, TropFishR allowed us to conduct biological analyses and model growth to assess the stock status of *E. encrasicolus* off the eastern Algerian coast using optimized ELEFAN_SA methods and length frequency (LFQ) data. The results showed that the fishing mortality rate (F) was higher than the natural mortality rate (M), and the exploitation rate (E) was greater than 0.5, indicating fishing pressure. However, this pressure was not considered extreme because it was lower than the fishing mortality rate required for maximum sustainable yield (F_{max}). To maintain a sustainable fishery and avoid the risk of stock collapse, we recommend observing biological rest periods in Algeria, which last from June 1 to September 30, enforcing strict mesh regulations, and monitoring fishing efforts (fishing mortality) by limiting landings. The implementation of these recommendations will ensure optimal and sustainable production while also ensuring the renewal of exploitable stocks.

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