TARGET REFERENCE POINTS FOR MANAGING DEEP-WATER PINK SHRIMP *PARAPENEAUS LONGIROSTRIS* (LUCA, 1846) ALONG THE EASTERN ALGERIAN COAST

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Abstract. This study represents the first investigation into the population dynamics and management of deep-water pink shrimp, *Parapeneaus longirostris* along the eastern Algerian coast. Over a 15-month period from November 2022 to January 2024, a total of 899 individuals were collected monthly from commercial bottom trawlers landing in the Gulf of Annaba. The FiSAT II software was used for analysis. Estimated growth parameters were the followings: $CL_\infty = 47.25$ mm, $K = 0.59$ yr^{-1}, and $t_0 = -0.24$ y, yielding a growth performance index (ϕ') of 3.12. The relationship between carapace length (CL) and total weight (TW) indicated negative allometric growth. Total (Z), natural (M), and fishing (F) mortality rates were calculated at 3.21 yr^{-1}, 0.90 yr^{-1}, and 2.31 yr^{-1} respectively, with the current exploitation rate (E) recorded at 0.72. The length at first capture (CLc_{50}) was determined to be 15.30 mm. Analysis of the relative yield per recruit (Y/R) indicated that the current exploitation rate exceeds both E_{max} and $E_{0.5}$ (0.53 and 0.31 respectively), underscoring the overexploitation of the *P. longirostris* population in the study area, as confirmed by the quadrant rule. To ensure sustainable management of this resource, the current exploitation rate should be reduced by 57% from 0.72 to 0.31.
Keywords: *exploitation rate, growth parameters, Gulf of Annaba, Penaeidae, relative yield per recruit*

Introduction

The assessment of marine resources is a critical step toward achieving sustainable and responsible development and management. This process involves estimating the current state of stocks and predicting their progression under various operating conditions. It is critical to include the spatial and seasonal aspects of fishing activity in order to accurately estimate fishing effort and produce credible stock assessments and realistic projection models for successful management (Vermard et al., 2008).

Algeria's coastline spans over 1620 km, with approximately 10 million hectares designated for fishing. These coastal waters present a highly diverse potential for exploitable fisheries, which are crucial for supplying seafood products to the population. The country boasts 44 fishing ports that serve as pivotal landing and trading hubs for numerous fish species, including crustaceans. Among these, shrimps are particularly notable, often referred to as "pink gold" due to their status as the world's most traded seafood product. Their abundance, nutritional value, and exquisite flavor contribute significantly to their market appeal.

Parapeneaus longirostris, known as the deep-water pink shrimp (Luca, 1846), is a benthic organism with a broad geographical distribution. It is found in the Atlantic

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(Holthuis, 1980; Ribiero-Cascalho and Arrobas, 1987; Pérez-Farfante and Kensley, 1997; Sobrino et al., 2005; Gonzalez et al., 2019; Pires et al., 2021) and throughout the Mediterranean basin and adjacent seas (Ragonese et al., 2006; Rodríguez et al., 2009; Kapiris et al., 2013; Awadh and Aksissou, 2020; İhsanoğlu et al., 2020; Ciloglu and Ates, 2022; Perdichizzi et al., 2022). Despite its socio-economic importance and commercial value in Algeria, research on this species is scarce, with current data being fragmentary and focusing mainly on biology and ecology. The most recent studies are carried out by Bekadja et al. (2009) in the west of the Algerian coast, and by Nouar and Maurin (2001) and Fellah et al. (2021) in the central region. However, no studies have been undertaken in the eastern coastal region, particularly in the Gulf of Annaba. Consequently, the aim of this study is to assess the population dynamics of *P. longirostris* in this area and to recommend appropriate management measures to ensure the sustainable development of the fishery.

Material and methods

Study area and sample collection

This study was conducted in the Gulf of Annaba, which is located on the western Mediterranean coast in the easternmost part of Algeria. The Gulf is bordered to the west by Cape of Guard (36°38' N - 7°16' E) and to the east by Cape Rosa (36°68' N - 8°15' E), encompassing a coastline of approximately 21.5 miles (40 km) (*Fig. 1*).

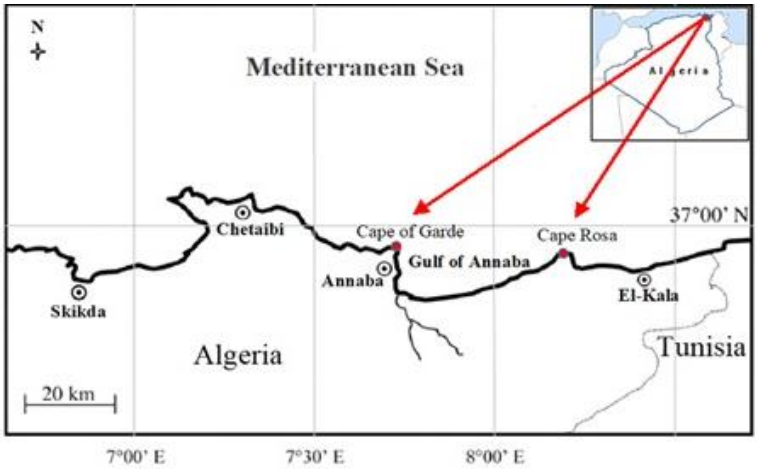

Figure 1. *Map of the sampling area*

Samples of 899 *P. longirostris* were systematically collected each month from commercial bottom trawler landings at the fishing port "La Grenouillère" in Annaba, from November 2022 to January 2024. Each specimen was randomly selected and sorted by sex. Total length (TL), measured in millimeters (mm) from the rostrum to the telson using a digital caliper with a precision of 0.01 mm and cephalothoracic length or carapace length (CL), measured from the supra-orbital notch to the posterior dorsal edge of the carapace, were recorded. Length measurements were categorized into 2 mm intervals for size frequency analysis. Additionally, total weight (TW) was recorded using a digital scale with an accuracy of 0.01 g.

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Growth parameters

Size frequency distribution analysis was used to estimate growth parameters for pink shrimp *P. longirostris* (combined sex) using the Von Bertalanffy technic (VBGF) and the ELEFAN I method (Pauly, 1987) module incorporated into the FiSAT II software (Gayanilo et al., 2005):

$$Lt = CL\infty\,[1 - e - K(t - t0)] \quad \text{(Eq.1)}$$

where, Lt = carapace length (mm) at time t, CL_∞= asymptotic carapace length, K= growth coefficient, t_0= theoretical age at length zero, e: basis of the natural log.

Parameter t_0 was calculated independently using Pauly's (1979) formula:

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

where, CL_∞= asymptotic carapace length, K= growth coefficient, t_0= theoretical age at length zero.

The growth performance to compare the growth rate of shrimp species with other published values was generated with Munro and Pauly's (1983) equation:

$$\phi' = 2\mathrm{Log}_{10}\,CL\infty + \mathrm{Log}_{10}\,K \quad \text{(Eq.3)}$$

where, ϕ'= growth performance, CL_∞= asymptotic carapace length, K= growth coefficient.

Length-weight relationship

The relationship between size and weight was determined by Froese's (2006) equation:

$$TW = a\,CL^b \quad \text{(Eq.4)}$$

where, TW = total weight, CL = carapace length, a = regression constant, b = allometry coefficient. The type of growth was defined using the Student t-test (Dagnelie, 1975).

Mortality and exploitation rates

The total mortality rate (Z) was estimated using the catch curve converted to length, while the natural mortality rate (M) was calculated using the Pauly method (1980):

$$\mathrm{Log}_{10}\,M = -0.0066 - 0.279\,\mathrm{Log}_{10}\,CL\infty + 0.6543\,\mathrm{Log}_{10}\,K + 0.4634\,\mathrm{Log}_{10}\,T \quad \text{(Eq.5)}$$

where, T is the mean annual temperature, estimated in the study area at 18°C.

The fishing mortality rate (F) was calculated using the Pauly (1980) relationship:

$$F = Z - M \quad \text{(Eq.6)}$$

The exploitation rate (E) was calculated using the formula:

$$E = F / Z \quad \text{(Eq.7)}$$

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

Length at first capture

The ascending left arm of the length converted catch curve incorporated in FiSAT II tool was used to estimate the carapace length at the first capture (CLc_{50}) corresponding to the 50% cumulative probability, in addition to the capture carapace length (CLc_{25}) and (CLc_{75}) which corresponded to the cumulative probability at 25% and 75%, respectively.

Relative yield per recruit and relative biomass per recruit

The relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) were estimated by using the model of Beverton and Holt (1966) as modified by Pauly and Soriano (1986) and incorporated in the FiSAT software package. According to analysis, E_{max} implies exploitation rate producing maximum yield, $E_{0.1}$ suggests an exploitation rate at which the marginal increase of Y'/R is 10% of its virgin stock, with $E_{0.5}$ indicates the exploitation rate under which the stock is reduced to half its virgin biomass were computed using the Knife-edge option. The yield contours that characterize the yield isopleth were plotted to identify the impact on yield depending on changes in exploitation rate (E) and critical length ratio (CrL).

$$\mathrm{CrL} = \mathrm{CLc50}/\mathrm{CL}\infty \qquad \text{(Eq.8)}$$

where, CrL= critical length ratio, CLc_{50}= carapace length at the first capture, CL_∞= asymptotic carapace length.

Data analyses

The biological and dynamic parameters of the *P. longirostris* population were estimated using FAO-ICLARM(FiSAT II) stock assessment tools (Gayanilo et al., 2005).

Results

A total of 899 pink shrimp individuals were examined, comprising 594 females and 305 males. Analysis of samples of *P. longirostris* from both sexes revealed a range of 64 to 153 mm for total length (TL), 12 to 45 mm for carapace length (CL), and 2.6 to 15.6 g for total weight (TW). The distribution of carapace (CL) size frequencies of the collected specimens ranged from 12 to 45 mm (*Fig. 2*). For all catches, the highest frequencies were between 20 and 32 mm, with the largest size class between 26 and 28 mm (21.46%). Frequencies less than 14 mm and above 38 mm were insignificant.

The growth parameters estimated for *P. longirostris* using ELEFAN I were CL_∞= 47.25 mm, K = 0.59 y^{-1} and t_0 = -0.24 y. Thus, the Von Bertanlaffy equation was $Lt = 47.25\ [1 - e^{-0.59\ (t - (0.24))}]$ with a growth performance index of $\phi' = 3.12$. *Figures 3* and *4* show the reconstructed length-frequency data superimposed on the estimated growth curve and the K-scan routine for the best value of the von Bertalanffy growth function (VBGF).

The carapace length-to-total weight relationship of *P. longirostris* from the Gulf of Annaba (n=899) was calculated as follows: $TW = 0.001\ CL^{2.477}$, with a correlation coefficient: r = 0.827. Applying the student t-test, it was confirmed that b is less than 3,

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indicating slow growth by weight relative to carapace length (negative allometric growth).

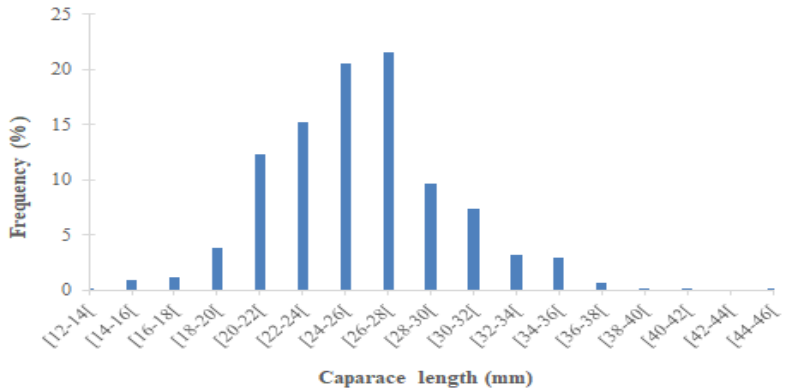

Figure 2. *The distribution of carapace size frequencies of the collected specimens*

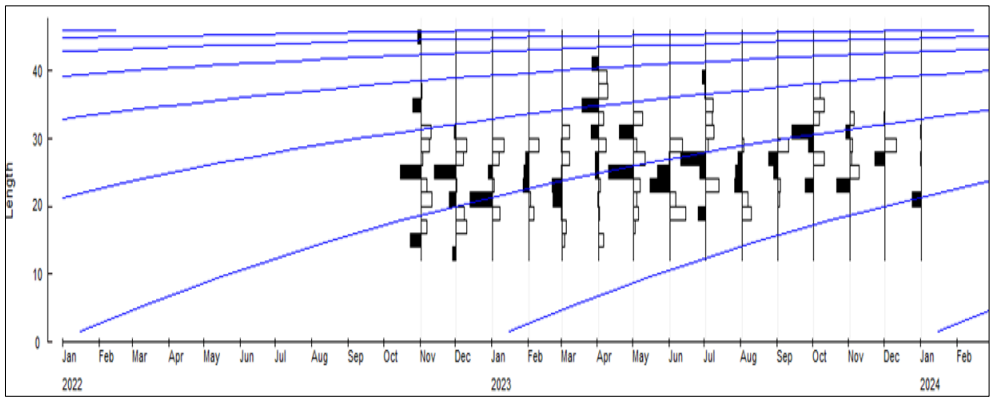

Figure 3. *Restructured length frequency distribution output from FiSAT II with superimposed growth curves. (Dark bars=actual frequency bars and white bars= reconstructed bars)*

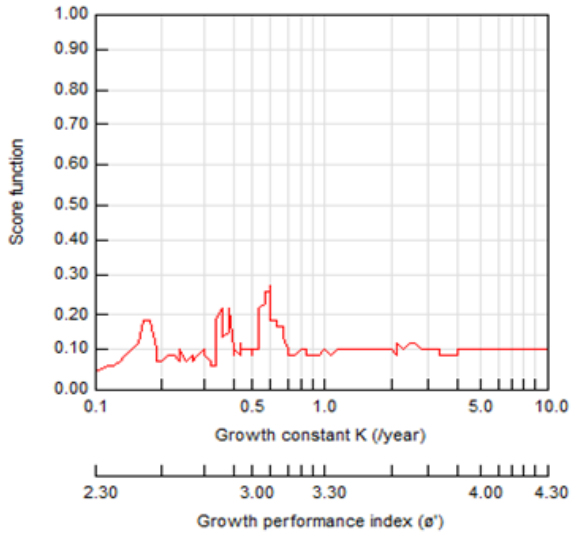

Figure 4. *Estimation of growth coefficient for P. longirostris by employing ELEFAN-I*

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The total mortality rate (Z) was estimated at 3.21 yr^{-1} and natural mortality (M) at 0.90 yr^{-1} according to Pauly's empirical model (1980). Fishing mortality (F) was estimated at 2.31 yr^{-1}, and the current exploitation rate (E) was estimated at 0.72 (*Fig. 5*).

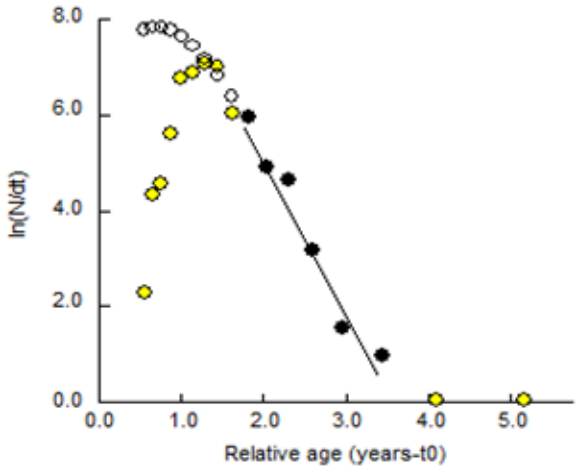

Figure 5. *Length-converted catch curve of P. longirostris from the Gulf of Annaba*

The length at the first capture (CLc_{50}) at which 50% of the *P. longirostris* population is vulnerable to fishing gear was estimated at 15. 30 mm. The lengths at which 25% and 75% of the shrimp caught by bottom trawl were CLc_{25} = 12.64 mm and CLc_{75} = 19.93 mm respectively (*Fig. 6*).

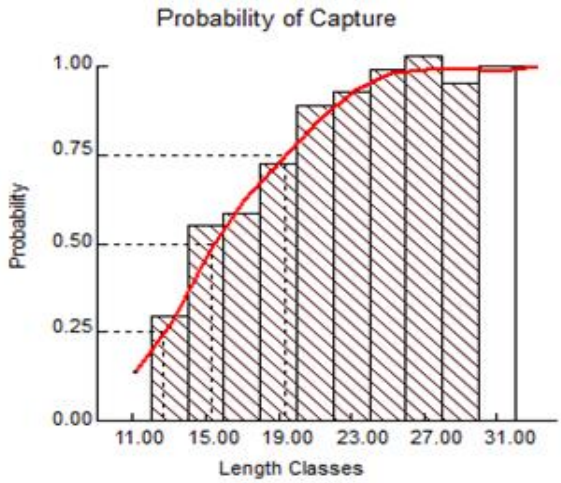

Figure 6. *Length at first capture(CLc_{50}) of P. longirostris from the Gulf of Annaba*

The estimates of the relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) using the Knife-edge option (*Fig. 7*) were $E_{0.1}$ = 0.45, $E_{0.5}$ = 0.31 and E_{max} = 0.53. It is clear that, the current level of exploitation (0.72) is higher than both E_{max} and $E_{0.5}$. Concerning the yield isopleths, they place the *P. longirostris* fishery in quadrant D (Pauly and Soriano, 1986), based on the interception of CrL (CLc_{50} / $CL\infty$) = 0.323 mm and E (0.72) (*Fig. 8*).

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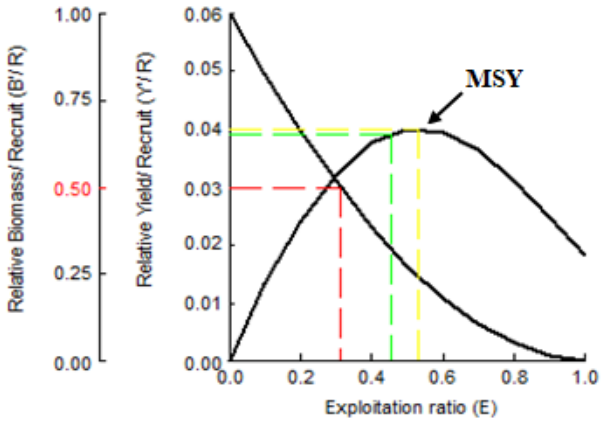

Figure 7. *Relative yield per recruit and biomass per recruit of P. longirostris from the Gulf of Annaba ($E_{0.5}$: red; $E_{0.1}$: green and E_{max}: yellow)*

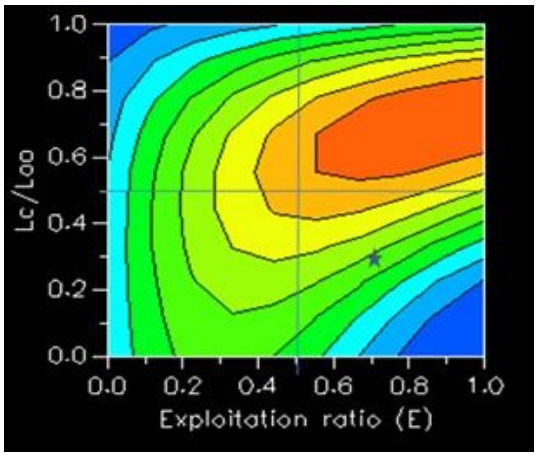

Figure 8. *Isopleth diagram of P. longirostris from the Gulf of Annaba*

Discussion

Cephalothoracic length or carapace length (CL) has been established as a standard and reference measure by several authors across different countries, including Farmer (1986), Dall et al. (1990), Ben Mariem (1995), Ragonese et al. (1997), Rodriguez et al. (2009), Kapiris et al. (2013), Chatzispyrou (2018), Awadh and Aksissou (2020), İhsanoğlu et al. (2020), Ciloglu and Ates (2022). Consequently, our study adopted this measurement as well. Our data indicated that the maximum total lengths (TL) of *P. longirostris* ranged from 64 to 153 mm, while their cephalothoracic sizes (CL) ranged from 12 to 45 mm. The majority of sampled individuals had carapace lengths (CL) falling between 20 and 32 mm. *Table 1* highlights the findings obtained across various regions.

Pink shrimp *P. longirostris* carapace lengths (CL) from the Gulf of Annaba were close to those reported by Fellah et al. (2021) from the central Algerian coast and Bekadja et al. (2009) from the west of the country (Oran) (*Table 1*). This consistency can be attributed to the shared characteristics of their search areas. Although our results closely align with those observed in the Mediterranean, slight variations in size may be influenced by differences in fishing techniques, population densities, and specific environmental conditions of the study cites.

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Table 1. *The growth parameters of P. longirostris in different geographical areas*

Locality	Sex	N	CL (mm)	CL_∞ (mm)	K (yr^{-1})	t_0 (y)	ϕ'	a	b	Authors
Alicante Gulf (Spain)	♀ ♂ ♀♂	6665 4948 11613	7 - 42 12 - 34 7 - 42	36.0 47.0 45.0	0.49 0.43 0.39	0.0754 0.1335 0.1019	-	0.0028 0.0023 0.0019	2.495 2.677 2.611	Rodriguez et al. (2009)
South Adriatic Sea (Greece)	♀ ♂ ♀♂	1593 628 2221	14 - 37 14 - 32 14 - 37	-	-	-	-	0.0047 0.0096 -	2.309 2.032 -	Kapiris et al. (2013)
South Ionian Sea (Greece)	♀ ♂ ♀♂	1282 866 2148	7 - 38 8 - 29 7 - 38	-	-	-	-	0.0010 0.0030 -	2.620 2.389 -	
Aegean Sea (Greece)	♀ ♂ ♀♂	246 208 804	10 - 35 10 - 27 10 - 35	-	-	-	-	-	-	Chatzispyrou et al. (2018)
Ionian Sea. (Greece)	♀ ♂ ♀♂	435 369 454	10 - 32 10 - 29 10 - 32	-	-	-	-	-	-	
Tuzla (Turkey)	♀ ♂ ♀♂	2410 1416 3826	8 - 31 11 - 28 8 - 31	32.55 28.67 -	0.76 0.95 -	-	2.91 2.89 -	0.0105 0.0126 -	2.686 2.610 -	Ciloglu and Ates (2022)
M'diq zone (Moroccan Mediterranean coast)	♀♂	1510	15-62	52.87	0.39	-0.35	-	0.0034	2.312	Awadh and Aksissou (2020)
Oran (Western Algeria)	♀ ♂	1021 646	11 - 38 -	44.48 34.03	0.54 0.68	-0.41 -0.31	3.02 2.89	0.0020 0.0050	2.606 2.307	Bekadja et al. (2009)
Bou Ismail Bay (Algerian Center)	♀ ♂ ♀♂	651 348 799	15 - 43 14 - 38 14 - 43	48.80 41.40 -	0.60 0.62 -	-0.53 -0.54 -	-	0.4490 0.5620 -	2.603 2.367 -	Fellah et al. (2021)
Annaba Gulf (Eastern Algeria)	♀♂	**899**	**12-45**	**47.25**	**0.59**	**-0.24**	**3.12**	**0.0010**	**2.477**	**Present study**

♀: female; ♂: male; ♀♂: both sexes; N: number; CL: carapace length; $CL\infty$: asymptotic carapace length; K: growth coefficient; t_0: theoretical age at length zero; ϕ': growth performance; a: regression constant; b: allometry coefficient

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The growth parameters estimated for *P. longirostris* using ELEFAN I were CL_∞= 47.25 mm and K = 0.59 yr^{-1} with t_0 = -0.24 yr (*Table 1*). These values for asymptotic length (CL∞), indicating linear growth, and the growth rate coefficient (K) in Annaba Gulf, were close to those reported by Fellah et al. (2021) for the central Algerian coastline (CL_∞ = 48.80 mm, K = 0.60 yr^{-1} in females) and by Rodríguez et al. (2009) for the Alicante Gulf, Spain (CL_∞ = 45 mm, K = 0.39 yr^{-1} in the total population). However, they differed from findings by Awadh and Aksissou (2020) on the Moroccan Mediterranean coasts (CL_∞ = 52.87 mm, K = 0.39 yr^{-1}) and Ciloglu and Ates (2022) in the eastern part of the Sea of Marmara (CL_∞ = 32.55 mm, K = 0.76 yr^{-1} in females and CL_∞ = 28.67 mm, K = 0.95 yr^{-1} in males) (*Table 1*). This variation in growth may be attributed to environmental differences such as trophic conditions and productivity (Arculeo et al., 2014). *P. longirostris* is known to prefer warm waters and is more abundant in the southeastern Mediterranean than in the northwest basin (Abello et al., 2002). Nevertheless, our results align with the general concept proposed by Pauly and Munro (1984) that penaeid shrimp typically exhibit K values between 0.25 and 2.5 per year.

According to Baijot et al. (1994), population study results are considered reliable if the growth performance index (ϕ') falls between 2.65 and 3.32, which is the case in this study (ϕ' = 3.12). However, our result showed slight differences compared to other studies in the Mediterranean (*Table 1*). Rahman et al. (2016) suggest that species' growth performance tends to vary with environmental conditions, as well as with the number of species sampled and the size of the largest individual.

The length-weight relationship (n = 899) for *P. longirostris* in this study was described by the equation TW = 0.0010 $CL^{2.477}$, resulting in a b-value less than 3, indicating that weight grows proportionally slower than the cube of carapace length (*Table 1*). This negative allometry confirms findings from other studies across the Mediterranean (Rodriguez et al., 2009; Kapiris et al., 2013; Awadh and Aksissou, 2020; Ciloglu and Ates, 2022) and Algeria (Bekadja et al., 2009; Fellah et al., 2021) (*Table 1*). Therefore, it can be concluded that the pink shrimp *P. longirostris* of Annaba Gulf exhibits a demographic structure and relative growth type comparable to that described in the literature for the species within its range.

The total mortality (Z) estimated by the length-converted catch curve for *P. longirostris* (3.21 yr^{-1}) in the waters of the Gulf of Annaba was close to the value (3.49 yr^{-1}) reported by Awadh and Aksissou (2020) on the Moroccan Mediterranean coasts, but exceeded the values (2.66 yr^{-1} for females and 2.03 yr^{-1} for males) estimated by Fellah et al. (2021) in the center of the Algerian coastline, while Ciloglu and Ates (2022) estimated values of 2.29 yr^{-1} for females and 2.04 yr^{-1} for males in the eastern part of the Sea of Marmara (*Table 2*). The higher fishing mortality rate (2.31 yr^{-1}) compared to the natural mortality rate (1.81 yr^{-1}) observed for *P. longirostris* in this study (*Table 2*) indicates an unbalanced state of the stock. The exploitation rate (E) calculated at 0.72 suggests that the *P. longirostris* fishery in the Gulf of Annaba is overexploited. This conclusion aligns with the criterion that a stock is considered overexploited when the exploitation rate exceeds 0.5 (Gulland, 1971). This finding is consistent with previous studies by Awadh and Aksissou (2020), Fellah et al. (2021), and Ciloglu and Ates (2022). Thus, the deep-water pink shrimp *P. longirostris* appears to be more susceptible to fishing pressure than to natural mortality in its habitat.

The estimated length at first capture (CLc_{50} = 15.30 mm) was found to be lower than the minimum market size set at 20 mm by the Algerian Ministry of Fisheries and Fishery

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Products in accordance with Executive Decree Nº. 04-188 of July 7, 2004. Our findings indicate a smaller size at capture compared to other studies. In the center of the Algerian coast, Fellah et al. (2021) reported CLc_{50} values of 17.14 mm for females and 16.30 mm for males, while Awadh and Aksissou (2020) on the Moroccan Mediterranean coasts observed a first capture size of 27.25 mm. Similarly, Ciloglu and Ates (2022) reported female sizes of 18.78 mm and 18.07 mm for males in the eastern part of the Marmara Sea. These results suggest that commercial captures in the Gulf of Annaba consist predominantly of immature individuals, which could be attributed to the mesh size of the fishing gear used to capture *P. longirostris*. Increasing the mesh size could improve resource exploitation and enhance spawning stock biomass (Rinelli et al., 2005).

Table 2. *Various mortality and Exploitation rates estimated for deep-water pink shrimp P. longirostris from different locations*

Locality	Sex	Z (y^{-1})	M (y^{-1})	F (y^{-1})	E	Authors
Tuzla (Turkey)	♀ ♂	2.29 2.04	1.09 1.33	1.20 0.71	0.52 0.35	Ciloglu and Ates (2022)
M'diq zone (Moroccan Mediterranean Coast)	♀♂	3.49	1.98	1.51	0.68	Awadh and Aksissou (2020)
Bou Ismail Bay (Algerian Center)	♀ ♂	2.66 2.03	0.89 1.04	1.77 0.99	0.66 0.49	Fellah et al. (2021)
Annaba Gulf (Eastern Algeria)	♀♂	**3.21**	**0.90**	**2.31**	**0.72**	**Present study**

♀: female; ♂: male; ♀♂: both sexes; Z: total mortality; M: natural mortality; F: fishing mortality; E: exploitation rate

Based on the analysis of relative performance per recruit (Y'/R) and relative biomass per recruit (B'/R) of *P. longirostris* in the Gulf of Annaba, determined by CLc_{50}/CL_{∞} (0.32) and M/K (1.52), the current exploitation rate (E = 0.72) significantly exceeds E_{max} and $E_{0.5}$ (0.53 and 0.31, respectively). This confirms our earlier assessment that the *P. longirostris* stock is overexploited. To sustainably manage the stock, the exploitation rate should be reduced from 0.72 to 0.31 (57%) to maintain adequate spawning stock biomass. Yield contours predict the response of relative yield per recruit to changes in CrL (CLc_{50}/CL_{∞}) (critical length) and E (exploitation rate). Comparing the yield isopleth diagram from our study with that of Pauly and Soriano (1986), the placement of CLc_{50}/CL_{∞} and exploitation rate falls within quadrant D, indicating that fishing in the Gulf of Annaba predominantly affects small individuals at a high level of fishing effort. Therefore, implementing effective management measures are crucial to prevent potential stock collapse. Increasing mesh size and reducing fishing effort are recommended strategies for the fishery's regulation and sustainability.

Conclusion

This study represents the initial comprehensive assessment of *P. longirostris* fisheries on the Algerian east coast, providing foundational insights crucial for sustainable management approaches. Our findings underscore significant challenges for the species, such as exploitation rates that exceed critical thresholds (E > 0.5) and E_{max} and $E_{0.5}$ values.

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These results emphasize the urgent need for stringent management measures to mitigate potential future collapse. Implementing effective biological reference points, alongside strategies to reduce fishing effort and regulate mesh size, is imperative for safeguarding the long-term sustainability of *P. longirostris* fisheries in the region.

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