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Research Article

Evaluation of Some Aspects of the Growth Parameters and Exploitation Rates of Deep-Water Rose Shrimp (*Parapenaeus longirostris*) from the Sea of Marmara

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ABSTRACT

The deep-water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846) (Decapoda, Penaeidae) is economically significant due to its distinctive long rostrum and attractive pink-red colouring, playing a crucial role in marine ecosystems. This study investigated the length frequency, growth pattern, sex ratio, condition factor, von Bertalanffy growth parameters ($L\infty$, k, t_0), growth performance index (φ), exploitation rate, and mortality rates of deep-water rose shrimp. Samples were collected from commercial fishermen using beam trawl nets at depths of 60–110 m around the Kapıdağ Peninsula in the Sea of Marmara from September 2021 to April 2022 (excluding January). The minimum total lengths recorded were 58 mm for females and 68 mm for males. The total length-weight relationship exhibited positive allometry, whereas the carapace length-weight relationship showed negative allometry. The sex ratio did not deviate significantly from 1:1. The condition factor of females was significantly higher than that of males. The overall growth parameters, based on total length, were $L\infty$ = 225.69 mm, k = 0.14 year^{-1}, t_0 = -0.17 year, and φ = 3.88. The estimated mortality rates were: total mortality = 0.83 year^{-1}, fishing mortality = 0.65 year^{-1}, natural mortality = 0.18 year^{-1}, and exploitation rate = 0.78. These findings provide valuable insights for the sustainable management of deep-water rose shrimp in the Sea of Marmara.

Keywords: Decapoda, Exploitation rate, Length-weight relationships, mortality rate, Türkiye

INTRODUCTION

The Sea of Marmara is a unique geographical feature, acting as a relatively shallow (average depth: 494 metres) semi-enclosed sea, with a maximum depth reaching 1350 m in some areas (Özsoy et al., 2016). It serves as a critical transitional zone between the saltier Mediterranean Sea, connected via the Çanakkale Strait, and the fresher Black Sea, linked by the Istanbul Bosphorus Strait (Öztürk, 2021). This strategic location designates the Sea of Marmara as a vital migration route for commercially valuable species of Atlantic-Mediterranean origin (Öztürk, 2021). These species, found in both the Aegean and Mediterranean Seas, utilise the Sea of Marmara as a corridor to reach the Black Sea (Kocataş et al., 1993).

The deep-water rose shrimp (Penaeidae: *Parapenaeus longirostris* Lucas, 1846) has a broad distribution in the Eastern Atlantic from Portugal to Angola and across the entire Mediterranean. It is also found in the Western Atlantic, ranging from Massachusetts, USA, to French Guiana (Ungaro & Gramolini, 2006). This species inhabits depths of 20 to 700 m, typically between 150 and 400 m, on muddy or muddy sand bottoms. They display sexual size dimorphism; typically, females grow larger than males, with females reaching up to 186 mm and males usually measuring between 140 and 160 mm (FAO, 1980). Although some variation exists, female deep-water rose shrimp across their range share a common reproductive pattern: extended spawning (1-3 peaks) in spring-summer and autumn-winter (location, temperature, and size dependent), with batch-produced eggs and a fecundity range of 20,000-400,000 (Bianchini et al., 2010).

The deep-water rose shrimp is a commercially valuable species, particularly prominent along the Mediterranean Sea coastline (FAO, 2008; Kocataş, 1981; Sbrana et al., 2006). Notably, the Kapıdağ Peninsula is recognised as the Sea of Marmara's most productive fishing ground for shrimp. Beam trawling, the primary method used to harvest crustaceans in the Sea of Marmara, is typically conducted with boats ranging from 7 to 13 m in length (Zengin et al., 2004). According to TÜİK data, 234 beam trawl and dredging vessels operating in the Sea of Marmara harvested 2,129 tonnes of shrimp in 2021 (TÜİK, 2021). The quantity of deep-water rose shrimp caught in the Sea of Marmara surpasses that of the Aegean and Mediterranean Seas, as illustrated in Figure 1, which depicts a 12-year (2011-2022) catch record of the species across these Turkish seas.

Despite its commercial value, the deep-water rose shrimp faces exploitation pressure throughout its range from large fishing fleets in the Mediterranean and Eastern Atlantic, leading to declining stocks (Arculeo et al., 2014). This decline is further exacerbated by pollution and unsustainable fishing practises like beam trawling. The scarcity of recent data on the growth parameters and exploitation rates of deep-water rose shrimp collected from the Sea of Marmara necessitates further research. Consequently, this study, investigated: 1) length frequency, 2) growth pattern, 3) sex ratio, 4) condition factor, 5) von Bertalanffy growth equation parameters, 6) growth performance index (φ), 7) mortality and 8) exploitation rate of deep-water rose shrimp in the Sea of Marmara. The results of this study should contribute to the scientific literature on sustainable stock management for the region.

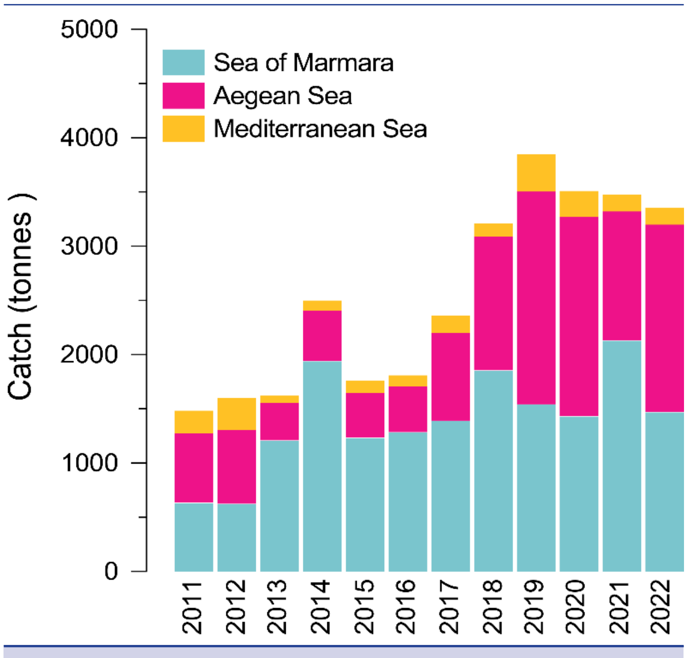

Figure 1. Catches (tonnes) of deep-water rose shrimp (*Parapenaeus longirostris*) in three Turkish seas over 12 years (2011-2022). Data source: TUIK, 2023.

MATERIALS AND METHODS

Sampling

The samples of deep-water rose shrimp were collected during the fishing season from September 2021 to April 2022 by commercial fishermen using beam trawl nets around the Kapıdağ peninsula in the Sea of Marmara at depths ranging from 60 to 110 m. Sampling was not conducted in January because of the closed fishing season. Samples were obtained from regions with high fishing intensity (Figure 2).

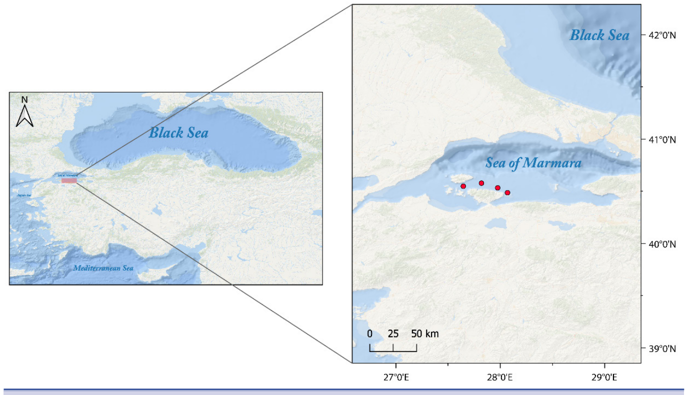

Figure 2. Sampling area in the Kapıdağ Peninsula, Sea of Marmara, for deep-water rose shrimp (*Parapenaeus longirostris*). Sources: QGIS 3.36.2, www.qgis.org

Laboratory work

In the laboratory, 932 deep-water rose shrimp individuals were examined. Each individual underwent the following measurements:

- **Weight (W):** Determined using a balance with a precision of 0.01 g.
- **Total Length (L_T):** Measured in millimetres (mm) from the tip of the rostrum (beak-like projection) to the end of the telson (tail fan) using a ruler with 1 mm precision.
- **Carapace Length (L_C):** Measured using callipers with an accuracy of 0.1 mm. The carapace refers to the hard upper shell covering the head and thorax of the shrimp.

In addition, the sex of each individual was determined through macroscopic observation. This involved examining the shrimp with the naked eye or a magnifying glass to identify any visual differences between males and females.

Statistical analysis of the data

Sex Ratio

The sex ratio of deep-water rose shrimp was investigated using the Chi-square (χ^2) test to determine whether it differed significantly from a 1:1 ratio.

Length-weight relationships

The relationships between the body weight of deep-water rose shrimp and their lengths (either L_T or L_C) were determined using a simple power function (Dürrani, 2023):

$$W = a \times L_{\mathrm{T}}^{b} \quad (1a)$$

$$W = a \times L_{\mathrm{c}}^{b} \quad (1b)$$

The estimated value of *b* indicates the growth pattern of deep-water rose shrimp: isometric growth (b ≈ 3), positive allometric growth (b > 3), or negative allometric growth (b < 3)

Condition factor

The condition factor (C_F) was computed using the following function (Htun-Han, 1978).

$$C_{\mathrm{F}} = \frac{W \cdot 100}{{L_{\mathrm{T}}}^{3}} \quad (2)$$

von Bertalanffy Growth Function

Age classes were determined using the Bhattacharya method in the FISAT (FAO-ICLARM Stock Assessment Tools) programme. The von Bertalanffy growth function was used to determine the size-at-age relationship for deep-water rose shrimp (Bal et al., 2018):

$$L_{\mathrm{T}} = L_{\mathrm{T}\infty}(1 - e^{-k(t-t_o)}) \quad (2a)$$

$$L_{\mathrm{c}} = L_{\mathrm{c}\infty}(1 - e^{-k(t-t_o)}) \quad (2b)$$

where L_T and L_c are the total length and carapace length at age t, $L_{T\infty}$ and $L_{c\infty}$ are the asymptotic total length and carapace length, k is the growth coefficient, t_0 is the hypothetical age at which the length (total length or carapace length) is zero.

Growth performance index

The growth performance index (φ) was estimated using the Munro and Pauly (1983) equation:

$$\varphi = 2 \times \log_{10}(L_\infty) + \log_{10}(k) \quad (3)$$

Mortality rates

- **Total mortality (Z):** It was calculated using Pauly's method (1984):

$$\log_{10}(Z) = \log_{10}(M) + \log_{10}(F) \quad (4a)$$

- **Natural mortality (M):** It was estimated using Pauly's empirical relationship (1980):

$$\log_{10}(M) = -0.0066 - 0.279 \times \log_{10}(L_\infty) + 0.6543 \times \log_{10}(k) + 0.4634 \times \log_{10}(T) \quad 4b$$

where *T* is the annual average water temperature in degrees Celsius (℃). The average temperature values measured during the fishing period were obtained from the official website of the General Directorate of Meteorology of the Republic of Türkiye. Between September 2021 and April 2022, the annual average water temperature was 14.98℃.

- **Fishing Mortality (F):** It was determined by the difference between total mortality (Z) and natural mortality (M) Gulland (1971):

$$F = Z - M \quad (4c)$$

- **Exploitation rate:** The exploitation rate (E) of the stock was calculated as follows Gulland (1971):

$$E = \frac{F}{Z} \quad (4d)$$

All statistical analyses, including data processing, visualisation, and hypothesis testing, were performed using R software.

RESULTS

Sex ratio

The examination of 932 deep-water rose shrimp specimens revealed a near parity in sex ratio with 49% (n = 458) males and 51% (n = 474) females, translating to a ratio of approximately 1 male:1.03 females. The Chi-Square test also confirmed the absence of a statistically significant difference between male and female counts ($\chi^2 = 0.137$, $P = 0.711$).

Size and Growth

Length frequency distribution

The deep-water rose shrimp exhibited variation in both L_T and L_C, with L_T ranging from 58 to 155 mm for females and 68 to 156 mm for males; and L_C varying from 13.0 to 38.0 mm for females and 12.0 to 38.0 mm for males. The average L_T was 105.9 mm for females and 98.6 mm for males, with average L_C of 21.5 mm and 23.4 mm, respectively. The length frequency distribution based on L_T is provided in Figure 3.

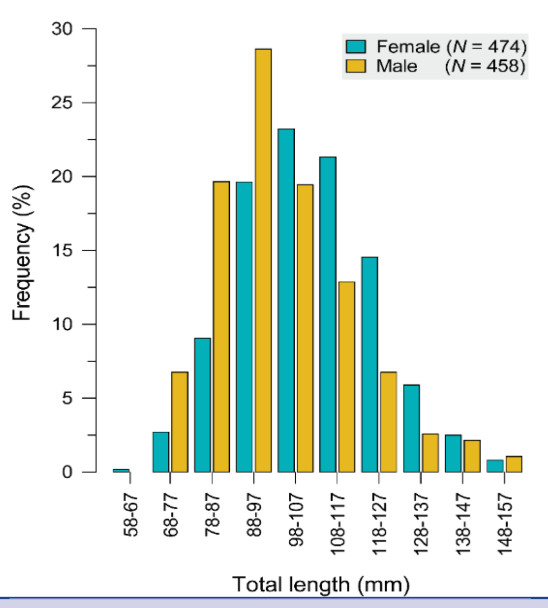

Figure 3. Length frequency distribution of female and male deep-water rose shrimp (*Parapenaeus longirostris*) collected from the Kapıdağ Peninsula, Sea of Marmara

Length-weight relationships

The relationships between the total length–weight and carapace length–weight are illustrated in Figure 4. The results of Student's *t*-test revealed significant deviation from isometric growth for the total length-weight relationship. This indicates positive allometry: deep-water rose shrimp exhibit a trend of becoming relatively heavier than its total length increases. Conversely, for carapace length, weight increases more slowly than increases in carapace length (Figure 4).

Condition factor

It was determined that the difference between men and women in terms of condition factors was significant, and the female condition factor was significantly higher than the male ($t_{(930)}$= 2.67, P < 0.001). The monthly variation graph of the condition factor is provided in Figure 5.

von Bertalanffy growth parameters

For the total samples in the study area, asymptotic total lengths, growth coefficients, age at which the size is 0, and growth performance index were calculated as $L_{T\infty}$ = 225.69, k = 0.140, t_0 = −0.170 and φ =3.884, respectively. The maximum age was deter-

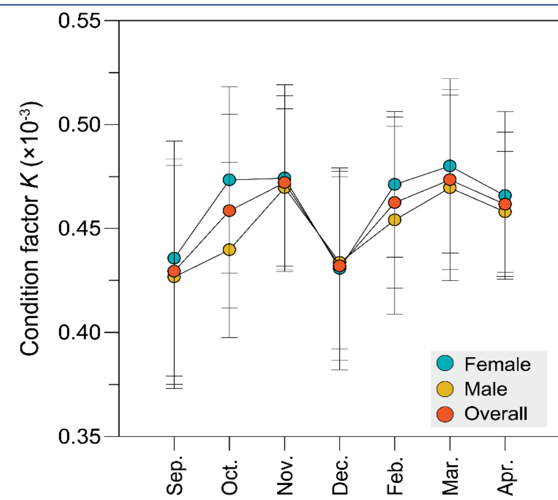

Figure 5. Monthly variation in the condition factor (mean ± s. d.) of deep-water rose shrimp (*Parapenaeus longirostris*) collected from the Kapıdağ Peninsula, Sea of Marmara

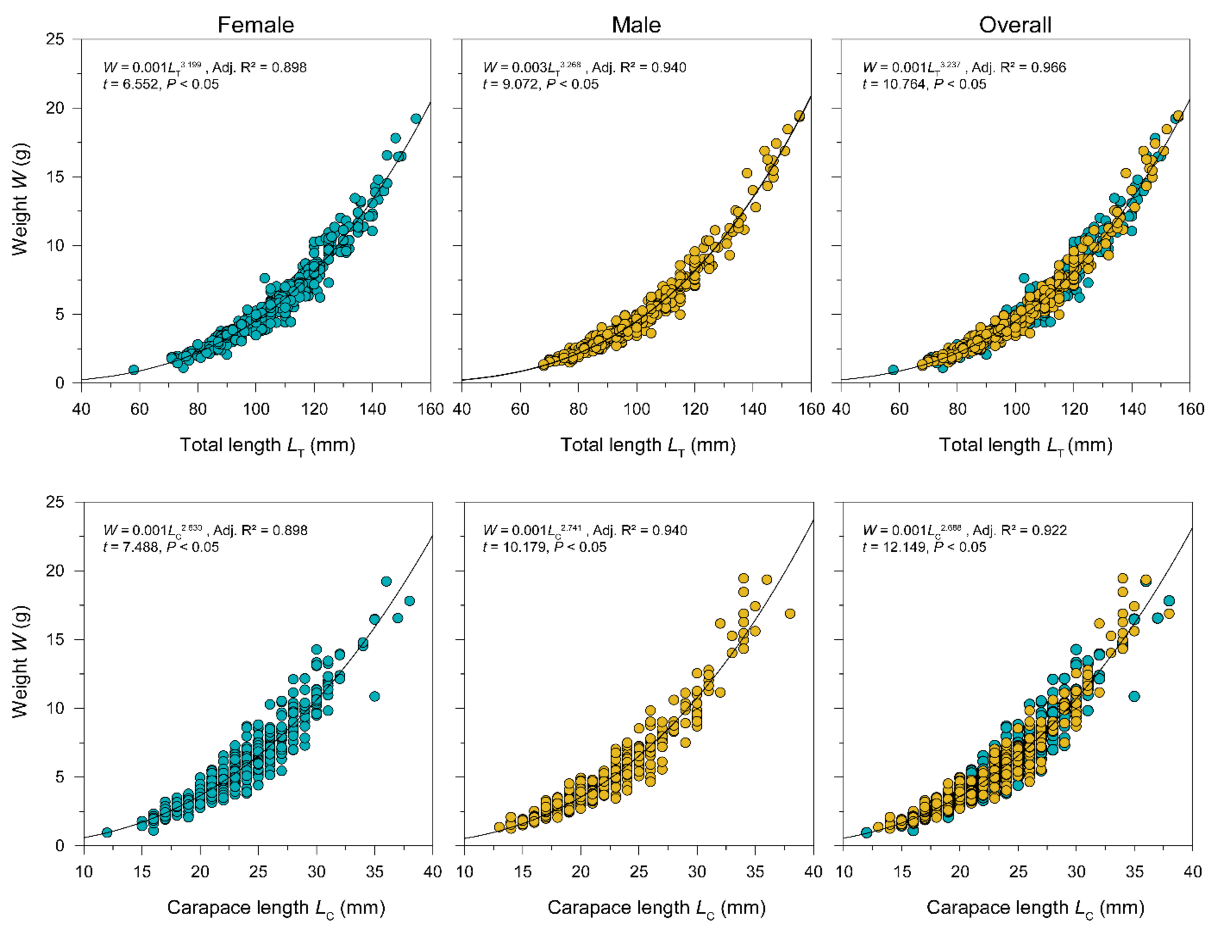

Figure 4. Length-weight relationships of deep-water rose shrimp (*Parapenaeus longirostris*) collected from the Kapıdağ Peninsula, Sea of Marmara. The solid line represents the fitted power regression function. The results of Student's t-test are provided as t-value and P-value, indicating whether the estimated slope b of the power regression function deviates significantly from the isometric growth value.

mined as 5 years for females and 4 years for males. When applying carapace length in the von Bertalanffy growth function, for males, the parameters were determined as $L_{c\infty}$ = 66.08 mm, k = 0.11 year^{-1}, and t_0 = −1.66 years. Meanwhile, for combined male and female data, the parameters were $L_{c\infty}$ = 110.09 mm, k = 0.05 year^{-1}, and t_0 = −2.07 years. However, the von Bertalanffy growth function parameters obtained for the female samples using carapace length fell outside an acceptable range and are therefore not included in the analysis. The growth curve drawn according to the von Bertalanffy growth function parameters is provided in Figure 6.

Mortality and Exploitation Rate

Mortality rate parameters were estimated separately for males, females, and all samples combined. For males, the natural mortality rate was estimated to be 0.23, the fishing mortality rate was 0.56, and the total mortality rate was 0.79. This resulted in an exploitation rate of 0.70. Similarly, for females, the estimated values were as follows: natural mortality rate = 0.11, fishing mortality rate = 0.49, total mortality rate = 0.60, and exploitation rate = 0.81. When considering the overall population, the estimated rates were as follows: natural mortality rate = 0.18, fishing mortality rate = 0.65, total mortality rate = 0.83, and exploitation rate = 0.78. These rates indicate different dynamics between male and female deep-water rose shrimp. Males exhibited a higher natural mortality rate than females (0.23 vs. 0.11), but a slightly lower exploitation rate (0.70 vs. 0.81). The overall exploitation rate of 0.78 suggests that a substantial portion of the population is being harvested.

DISCUSSION

This study explored the length-weight relationship of deep-water rose shrimp using both total length and carapace length. While carapace length indicated negative allometry (b<3), consistent with previous research (e.g., Tosunoğlu et al., 2009), total length revealed positive allometry (b>3) for both sexes. This finding emphasises the importance of considering both metrics for accurate growth assessments. The sex ratio in this study was 1:1.03, consistent with some previous studies (Demirci & Hoşsucu, 2007; İhsanoğlu & İşmen, 2020; García-Rodríguez et al., 2009), but differing from others (Dereli, 2010; Çiloğlu & Ateş, 2022; Kapiris et al., 2013), suggesting variations due to factors like mortality differences and behavioural traits such as migration (Amin et al., 2009).

This study found the condition factor C_F to be highest in March (spring) and lowest in September (autumn), which is in line with observations by Arslan İhsanoğlu and İşmen (2020) in the Sea of

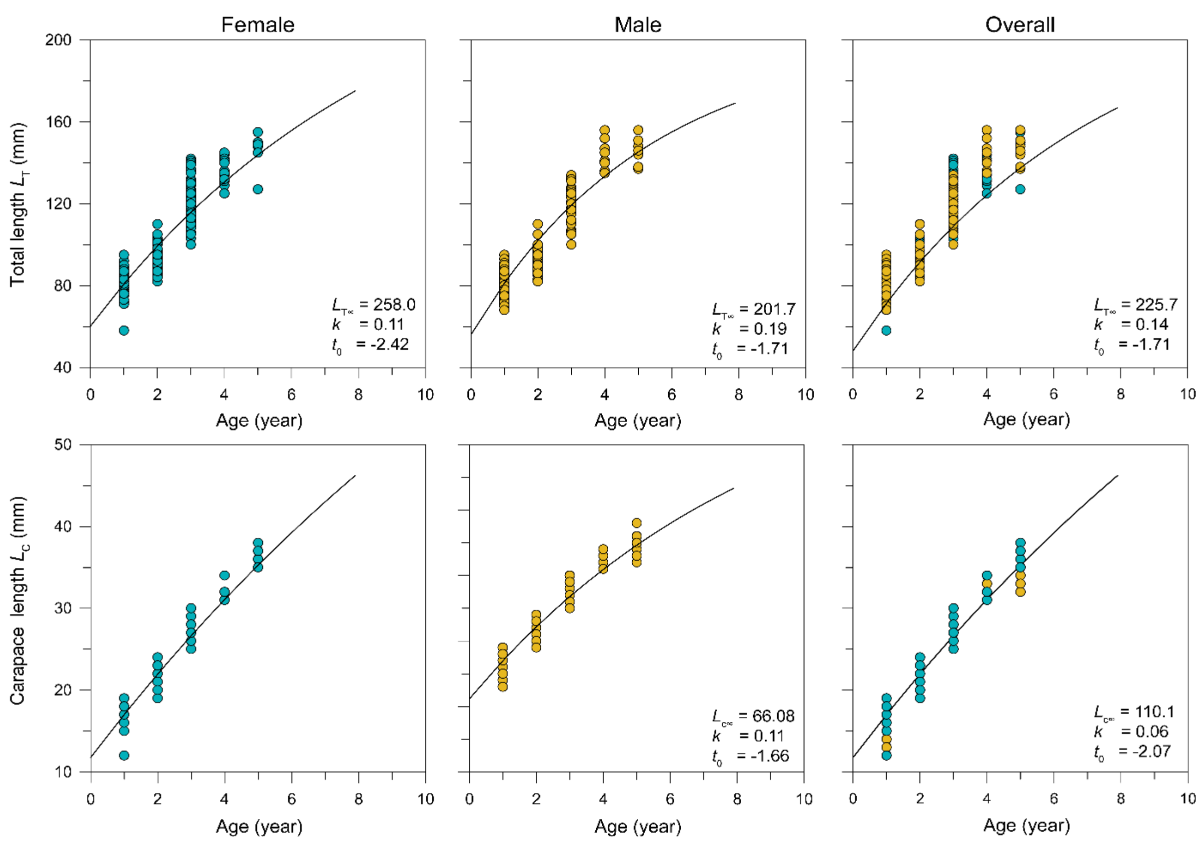

Figure 6. The von Bertalanffy growth function fitted to the size-at-age relationship for deep-water rose shrimp (*Parapenaeus longirostris*) collected from the Kapıdağ Peninsula, Sea of Marmara. The curve illustrates the predicted growth trajectory derived from the estimated parameters of the function for male and combined samples. The curve for females was provided using the estimated parameters of the overall samples.

Marmara (2011-2014). Piper (1972) found C_F to be stable with consistent water temperature and feeding rates, further supported by Ahmad & Ahmed (2019), who observed that seasonal changes in feeding intensity and reproduction likely drive the observed C_F variations.

In this study, the maximum age observed was 5 years, consistent with a study conducted in Sığacık Bay, documenting a maximum age of 6 years (Tosunoğlu et al., 2009). However, previous studies in the Mediterranean region reported lower maximum ages of 4 and 3 years (Demirci & Hoşsucu, 2007; Manaşırlı et al., 2008), and another study in the Sea of Marmara reported a maximum age of 3 years (Zengin et al., 2004). The estimated von Bertalanffy growth function parameters using total length differed from those reported by Zengin et al. (2004). Their study found female and male $L_{T\infty}$ values of 170.2 mm and 157.9 mm, respectively, with corresponding *k* values of 0.58 and 0.38 (Table 1). In contrast, this study estimated a larger $L_{T\infty}$ for both females (258.0 mm) and males (201.7 mm), suggesting a greater potential size for this shrimp in the studied area. Additionally, the *k* values obtained in this study were considerably lower (females: 0.11, males: 0.19) than those obtained by Zengin et al. (2004), indicating a slower growth rate in the studied population. Notably, both studies estimated negative t_0 values (females: −2.42 years, males: −1.71 years; overall: −1.71 years), which is typical for the von Bertalanffy growth function. Compared to using total length, carapace length L_c has been applied by several studies to fit the carapace length-at-age relationship (Table 1). The lowest calculated $L_{c\infty}$ for individuals caught in the Sea of Marmara was 16.28 mm (Deval et al., 2006), whereas the highest $L_{c\infty}$ was recorded on the Mediterranean coast of Morocco at 52.87 mm (Awadh & Aksissou, 2020). In this study, $L_{c\infty}$ was determined to be 66.1 mm for males, while no estimation was performed for the female samples. Furthermore, the estimated $L_{c\infty}$ from combined data was 110.1 mm, which could be the highest estimation recorded to date. Consequently, the estimation of the carapace length-at-age relationship with von Bertalanffy growth function in this study might need further confirmation.

The growth performance index in this study was generally similar to the results of previous study for both gender groups. However, in a study conducted on the Balearic Islands, the growth index was calculated as 6.88 for males, 7.40 for females, and 7.20 for all samples (Guijarro et al., 2009). The exploitation rate was determined to be much higher than that in previous studies conducted in the Sea of Marmara and the Aegean Sea, indicating significant catch pressure on the species (Demirci & Hoşsucu, 2007; Tosunoğlu et al., 2009; Dereli, 2010; Çiloğlu & Ateş, 2022; İhsanoğlu & İşmen, 2020). In contrast, the exploitation rate found in this study was higher than that found in other previous studies, indicating high fishing pressure on the species.

CONCLUSIONS

This study elucidates the growth and population dynamics of the deep-water rose shrimp in the Sea of Marmara. By analysing both the total length and carapace length, this study revealed a

Table 1. Length-weight parameters, growth types, sex ratios, and growth parameters of deep-water rose shrimp (*Parapenaeus longirostris*) from this study and existing literature.

Sex	n	Sex ratio	Length-weight relationship			GT	von Bertalanffy growth parameters				Mortality rates				φ	Location	References
			a	*b*	r^2		$L_{T\infty}$	$L_{c\infty}$	*k*	t_0	F	NM	Z	E			
M	923		0.002	2.625	0.91			31.2	0.76	−0.39	3.86	1.31	5.17	0.74	2.87	Babadillimanı	Manaşırlı et al. (2008)
F	2859		0.001	2.819	0.95			32.3	0.77	−0.39	2.12	1.29	3.41	0.62	2.90		
O	3886		0.001	2.795	0.95			32.1	0.76	−0.39	2.71	1.29	4.00	0.67	2.89		
M	1313		0.001	2.690	0.94			35.0	0.41		0.54	0.67	1.21	0.45		Aegean Sea	Dereli (2010)
F	2456		0.001	2.700	0.95			41.3	0.31		1.71	0.77	2.48	0.69			
O	3768	1:09	0.001	2.700	0.95												
O	2238	1:1.2	1.871	1.843				34.6	0.48	−1.01	0.34	1.29	1.63	0.21	2.76	Northeastern Mediterranean	Demirci & Hoşsucu (2007)
M	1073		0.011	2.590	0.93												
F	869		0.006	2.950	0.95											Sea of Marmara	Yazıcı (2004)
M	1076		0.006	2.862	0.96											Sea of Marmara	
F	2679		0.003	3.130	0.98												Bayhan et al. (2005)
O	3755		0.003	3.160	0.97												
O	12932							16.3	0.49		1.86	0.97	2.83			Sea of Marmara	Deval et al. (2006)

Table 1. Continue.

Sex	n	Sex ratio	Length-weight relationship				von Bertalanffy growth parameters				Mortality rates				φ	Location	References
			a	*b*	r^2	GT	$L_{T\infty}$	$L_{c\infty}$	*k*	t_0	F	NM	Z	E			
M	1416		0.012	2.610		A–		28.6	0.95	−0.76	0.71	1.33	2.04	0.35	2.89	Sea of Marmara	
F	2410		0.010	2.687		A–		32.5	0.76	−0.23	1.20	1.09	2.29	0.52	2.91		Çiloğlu & Ateş (2022)
O	3826	1:1.7															
F	20384		0.002	2.500	0.94	A–		41.0	0.27	−0.78	0.57	0.52	1.09	0.52	2.66	Sea of Marmara	İhsanoğlu & İşmen (2020)
M	15904		0.003	2.430	0.89	A–		36.8	0.37	−0.69	1.56	0.66	2.22	0.70	2.70		
O	36288	1:1.3	0.002	2.520	0.94	A–		42.0	0.35	−0.69	0.99	0.61	1.60	0.62	2.79		
F	2456		0.0001	2.840	0.95	A–		41.3	0.31	1.039	1.71	0.77	2.48	0.69	2.73	Aegean Sea	Tosunoğlu et al. (2009)
M	1313		0.0001	2.760	0.94	A–		35.0	0.41	1.016	0.54	0.67	1.21	0.45	2.70	(Sığacık Bay)	
O	3768		0.0001	2.830	0.95	A–		42.0	0.5		1.18	0.77	1.95	0.60	2.95		
F								34.7	1.05	−0.95			1.19		3.14	Aegean Sea	Bilgin et al. (2009)
M								27.0	1.49	−0.88			0.88		3.00	(Saros Bay)	
O																	
F	2483		0.005	2.930	0.95		170.2		0.581	0.96					4.23	Sea of Marmara	Zengin et al. (2004)
M	1964		0.009	2.700	0.91		157.9		0.380	1.42					3.98		
O	4447		0.005	2.970	0.95												
M	214		0.002	2.530	0.97			31.3	1.00	0.49					6.88	Balearic Island	Guijarro et al. (2009)
F	593		0.002	2.560	0.98			44.0	0.67	0.21					7.16		
O	807		0.002	2.560	0.98			40.0	0.84	0.49					7.20		
M								33.1	0.93	0.05					3.01	Tiran Sea	Ardizzone et al. (1990)
F								44.4	0.74	0.13					3.16		
O			0.006	2.270				30.5	0.63	0.190			1.23		2.77	Sicilian Channel	Levi et al. (1995)
O	1510		0.003	2.312	0.97	A–		52.8	0.39	−0.35			3.49	0.68		Morocco	Awadh & Aksissou (2020)
M	866		0.003	2.380	0.94										2.87	Ionian Sea	Kapiris e al. (2013)
F	1282		0.001	2.620	0.91			37.2							2.87		
O	2148	1:0.6													3.02		
M	4948		0.003	2.490	0.91	A–		36.0	0.49	0.07						Gulf of Alicante	García-Rodríguez et al. (2009)
F	6665		0.002	2.560	0.96	A–		47.0	0.43	0.13							
O	11613	1:1.3	0.002	2.610	0.96	A–		45.0	0.39	0.10							
M	458		0.003	3.260	0.93	A+	201.7		0.19	−1.71	0.56	0.23	0.79	0.80	3.89	Sea of Marmara	Present study
F	474		0.001	3.190	0.89	A+	258.0		0.11	−2.42	0.49	0.11	0.60	0.81	3.87		
O	932	1:1.03	0.001	3.230	0.96	A+	225.6		0.14	−1.71	0.65	0.18	0.83	0.78	3.85		
M	458							66.1	0.11	−1.66							
F	474																
O	932							110.1	0.06	−2.07							

M = male, F = female, O = overall (F+M); n = size; a = regression constant, b = coefficient of allometry; GT = growth type: A- = negative allometry, A+ = positive allometry; $L_{c\infty}$ = maximum theoretical size of carapace length (mm); $L_{T\infty}$ = maximum theoretical size of total length (mm); NM: natural mortality; φ = growth performance index larger potential size, but slower growth rate compared with prior studies. The observed differences in growth patterns between length measures emphasise the importance of using appropriate metrics. Additionally, the estimated maximum age, exploitation rate, and sex ratio provide valuable insights for stock assessment and management. However, some extreme values, particularly in carapace length, necessitate further investigation. In sum, this study demonstrates the complex interplay of biology and environment on deep-water rose shrimp, emphasizing the imperative for ongoing research and implementation of sustainable management practises.

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