

Some biological and morphological aspects of *Eriphia verrucosa* (Forskål, 1775) in the eastern Adriatic Sea

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Aim: To investigate and describe the length-weight relationship and sex ratio of the species *Eriphia verrucosa* in the eastern Adriatic and to determine whether there is external dimorphism by morphometric analysis of the body.

Methods: All samples were collected in the coastal area in the intertidal zone of Kaštela Bay (Split-Dalmatia County, Croatia). The sample catching was done at night after 10 p.m. with a hand net and an LED headlamp; afterwards, each specimen was weighed, prepared for further processing and frozen. The processing of each specimen included sex determination and detailed morphometric measurements. In females, a total of eight morphometric measures were measured and additionally the length of the gonopods in males. For each morphometric measure except gonopod length (GL), the average value and the corresponding 95% confidence interval were determined.

Results: A total of 73 individual specimens of *E. verrucosa* were sampled, of which 35 were males and 38 were females. The gender ratio was 0.92:1 in favor of females ($P=0.726$). The largest body weight measured during this research was a male with a mass of 263.6 g, and the smallest was also a male with a weight of 7.3 g. The largest number of individuals belonged to the length class of 45–50 mm. Sexual dimorphism between males and females was recorded for all morphometric measures. According to the b coefficient of length-weight yield, the growth of *E. verrucosa* can be characterized as negatively allometric.

Conclusions: In this research, the biological characteristics of the species *E. verrucosa* in the eastern Adriatic were analyzed. The length-weight ratio (CL-W) for the total sample was $W=0.0076 \times CL^{2.5086}$, for males $W=0.0078 \times CL^{2.5116}$ and for females $W=0.0169 \times CL^{2.2911}$. Based on the length-weight ratio, sex ratio and the morphometric analysis of the body, sexual dimorphism is documented, which was not previously found for the warty crab in that area.

Keywords: Crustacea; Decapoda; *Eriphia verrucosa*; morphometry; dimorphism; Adriatic Sea

Introduction

The species *Eriphia verrucosa* (*E. verrucosa*, also known as warty crabs) (Forskål, 1775) belongs to the genus *Eriphia* (Latreille, 1817) of the Eriphiidae family (MacLeay, 1838), which belongs to the Decapoda order (1) (Figure 1). It is often mentioned in the literature and recognized for its potential economic value (2-5). Previous research has relied mainly on descriptions as part of the list of the decapod species or the ecology of species within the genus or generally the entire family. For example, Crane (6) listed species of Brachyura crustaceans and described their habitat, while Holthuis (7) reported on a collection of decapod crustaceans and stomatopods from Turkey and the Balkans, describing the species collected on the expedition and their habitats. Recent research provides a more detailed description of the biology, ecology, and habitat of species of the genus *Eriphia*. Koh and Ng (8) provide a taxonomic overview of seven species of crabs from the genus *Eriphia* in most temperate and tropical seas and a key for identifying the species of all its members. In terms of reproductive biology, the seasonal variation of the ovaries and testes was described by Erkan and colleagues (9), along with the anatomy of the male reproductive organ, as well as the histology and histochemistry of the regional structure of the testes and *vas deferens* (10). The length-weight ratio of the *E. verrucosa* species has been determined for many geographic areas, such as the Aegean Sea (2), the Black Sea (3), and the Canakkale Strait (10). Meanwhile, Demirbaş et al. (11) determined its biochemical characteristics, while Karadurmuş (12), Karadurmuş and Aydın (4), and Jouili et al. (13) determined its biological and reproductive characteristics.

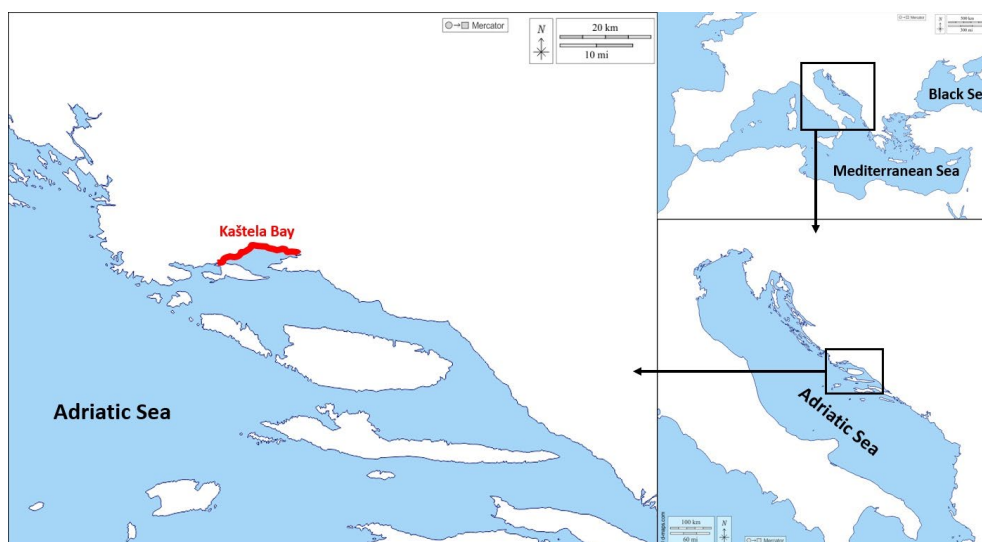


Figure 1. Red line – research area: Kaštela bay, the eastern Adriatic coast (source: <https://d-maps.com>).

The initial studies of Adriatic crustaceans can be found in the revision for the northern Adriatic by Štević (14), who later also published data on new and rare species (15). There are also detailed historical surveys of decapod crustaceans from the checklist of decapod fauna of all or some parts of the Adriatic (16-21). In all these studies, the warty crab is mentioned as an important part of the decapod fauna, but without information on its biological characteristics. Therefore, the purpose of this study was to provide the first ob-

servations and descriptions of certain biological characteristics of the species *E. verrucosa* in the eastern Adriatic by investigating and determining its morphometric measurements, the length-weight ratio, and the sex ratio.

Materials and methods

Research area

All samples were collected from the coastal area of Kaštela Bay (Split-Dalmatia County, Croatia) from depths of 0 to 3 meters deep in the upper infralittoral zone (Figure 1). The Kaštela Bay, which is the largest bay in central Dalmatia, is 14.8 km long, up to 6.6 km wide and up to 60 m deep. It stretches between the mainland, the island of Čiovo, and the Marjan peninsula, and is actually a sunken depression consisting of in flysch marl and sandstones (22). This area is known for its naturally formed rocky and rough beaches overgrown with various species of algae, but also for artificially created embankments. The intertidal zone is an extreme ecosystem as it is subject to constant changes, and the species represented in such a zone must be eurivalent, meaning that they must be tolerant of great oscillations in humidity, salinity and temperature. Moreover, this zone is a habitat for many types of organisms such as algae, bivalves, snails, urchins, crabs, and other marine organisms.

Sampling and processing of materials in the field and in the laboratory

A total of 73 individual specimens of *E. verrucosa* in the littoral zone from November 2020 to August 2021. Catches were made exclusively at night after, 10 p.m. during the colder season and after midnight during the warmer season. A scoop net (23) and a LED headlamp to collect the specimens. After the catch, each individual was weighed using a scale with a sensitivity of 0.01 grams. After weighing, individuals were placed in a separate bag and frozen at -23°C . After at least 8–12 hours in the freezer, individuals were kept at room temperature for several hours for further processing, which included gender determination and detailed morphometric measurements.

Morphometric measurement of the collected individuals

Morphometric processing of the specimens was performed using a digital clipper with an accuracy of 0.01 mm. The following morphometric measurements were performed:

- Carapace length (CL): The distance along the middle line from the anterior to the last posterior point of the carapace (Figure 2);
- Carapace width with spines (CW): The distance along the carapace between the two longest lateral spines (Figure 2);

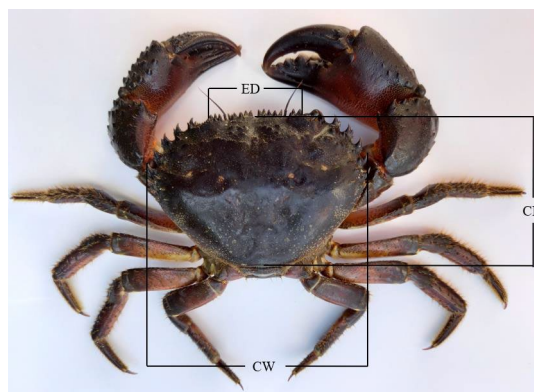


Figure 2. Dorsal side of *E. verrucosa*. Morphometric measurements: CW – carapace width, CL – carapace length and ED – interocular distance (source: P. Kuzmanić, personal collection).

- Interocular distance (ED): The distance between the bases of the eyeballs measured from the inside (**Figure 2**);
- Abdominal width (AW): The distance between the edges of the third abdominal segment, in males and females (**Figure 3**);



Figure 3. Ventral side of *E. verrucosa*. Morphometric measurements: AW – abdominal width and TW – thoracic width. **Panel A.** Male. **Panel B.** Female (source: P. Kuzmanić, personal collection).

- Thoracic width (TW): The distance across the thoracic sternum, between the notches at the bases of the secondary pereiopod (**Figure 3**);
- Propod length (PL): The maximum distance from the top of the propodus to the beginning of the joint with the carpus (**Figure 4**);
- Chela length (CD): The maximum distance between the dorsal and ventral sides of the propodus (**Figure 4**);
- Dactylus length (DL): The distance from the tip of the dactylus to the junction with the propodus (**Figure 4**), and;

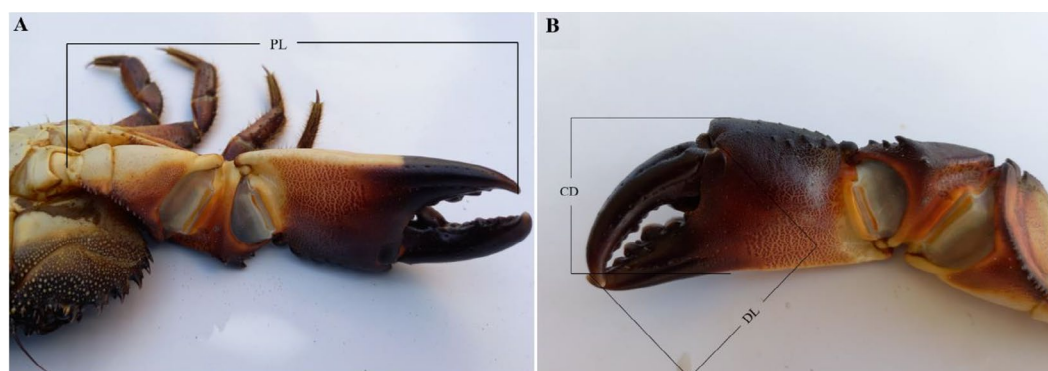


Figure 4. Details of the right pincer of the species *E. verrucosa*. Morphometric measurements: **Panel A.** PL – propod length. **Panel B.** CD – chela length and DL – dactylus length (source: P. Kuzmanić, personal collection).

- Gonopod length (GL): Measured only in males (Figure 5).

In females, the first eight morphometric measures were measured (Figure 2, Figure 3, Figure 4) and additionally, gonopod length was also measured in males (Figure 5).

For each morphometric measure (except gonopod length), we determined the average value and corresponding 95% confidence interval (CI). To determine differences in morphometric measures between males and females, each morphometric measure was standardized by carapace length, after which the average value of the difference in each measure between males and females and the corresponding 95% CI of the difference was calculated. For each mean value and for each mean value difference, a 95% CI was determined by the bootstrap method with 1000 iterations using the ‘infer’ package (24) in R, package version 1.0.0. (25).

Furthermore, the relationship between gonopod length and male carapace length was described by a linear model of the form $GL = a \times CL + b$. Coefficients a and b of the linear model were determined using the ‘lm()’ function and their 95% CIs through the ‘boot()’ function from the ‘boot’ package (26).

Length-weight ratio

Data on carapace length and weight of each specimen were used to determine the length-weight ratio, as per the following equation: $W = a \times CL^b$. The analysis was done separately for males, females, and for both sexes together.

The coefficients a and b were determined using the ‘nls()’ function and their 95% CIs using the ‘nlsBoot()’ function from the ‘nlstools’ package. The obtained values of the coefficient b can be used to determine whether the growth is isometric, positive, or negative allometric. If the 95% CI of the coefficient b contains the value 3, the growth can be characterized as isometric; if the average value of the coefficient b is greater than 3 and the 95% CI does not contain the value 3, the growth can be characterized as positive allometric; otherwise, it is negative allometric. Isometric growth of an individual specimen defines relatively uniform growth in length and mass while maintaining the usual shape. Positive allometry means faster growth in mass than length, while negative allometry means the opposite (27).

Results

Out of all sampled individual specimens of *E. verrucosa*, 35 were males (48%) and 38 females (52%). The gender ratio was 0.92:1 in favor of females, without a statistically significant difference ($\chi^2 = 0.12$; $P = 0.726$). Of the total 38 females collected, 9 carried eggs on

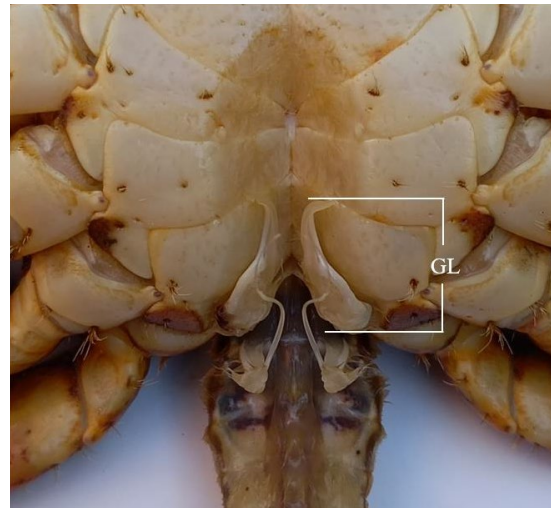


Figure 5. Ventral side of the male *E. verrucosa*. Morphometric measure: GL – gonopod length (source: P. Kuzmanić, personal collection).

pleiopods and were all captured in July or August. The mean body weight (W) of all grebes in the sample was 119.8 g (95% CI=104.4–134.8). The specimen with the largest body mass measured in this study was a male weighing 263.6 g, while the smallest body mass was also measured in a male at 7.3 g.

Morphometry

The mean value of the carapace length (CL) in the studied sample was 45.6 mm (95% CI=43.2–47.9), with both the largest and smallest measurements taken in males at 62.6 mm and 19.5 mm, respectively. Most individuals in the sample were represented in the length class of 45–50 mm (Figure 6).

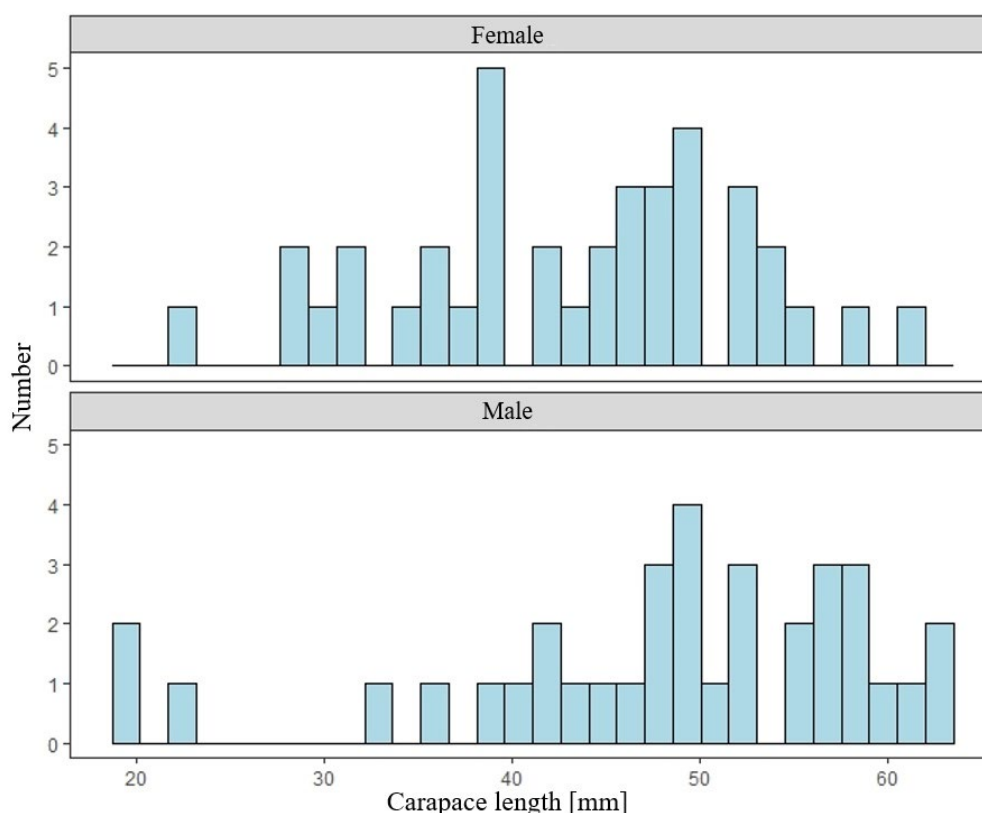


Figure 6. Length distribution of the carapace length (CL) of *E. verrucosa*.

The mean carapace width (CW) was 64.1 mm (95% CI=60.8–67.0), with both the largest (88.9mm) and smallest values (28.4 mm) recorded in males. The mean value of the width of the interocular distance was 27.6 mm (95% CI=26.3–28.8), where again the largest (7.8 mm) and smallest values (36.7 mm) were recorded in males. The mean value of abdominal width (AW) in the sample was 17.5 mm (95% CI=15.8–19.5). In short-tailed decapods, the width of the abdomen is generally greater in females, which also applies to the studied species. The greatest width of the abdomen was measured in females (31.9 mm), while the smallest was measured in males (3.5 mm). The mean value of thoracic width (TW) in total was 30.7 mm (95% CI=29.1–32.0), with both the largest (40.4 mm) and smallest values (12.2 mm) measured in males.

In the entire sample, the mean length of the right pincer propod (PL) was 76.3 mm (95% CI=72.1–80.9), with a range of 27.2 to 115.8 mm. The mean value of the length of the right chela in the entire sample was 25.2 mm (95% CI=23.7–26.7), with a range of 8.5 to 39.6 mm. Finally, the mean value of the length of the right dactylus (DL) was 27.1 mm (95% CI=25.5–28.8), with a range of 10.3 to 43.8 mm. Average lengths of all measurements separately by gender are shown in **Table 1**.

Table 1. Average value of morphometric sizes for males and females of *E. verrucosa*, presented as median mms (95% CI)

Parameter	Females	Males
Carapace length	43.3 (40.4–46.1)	48.0 (44.0–51.6)
Carapace width	61.5 (57.4–65.0)	66.9 (62.1–71.3)
Interocular distance	26.7 (25.2–28.2)	28.6 (26.3–30.7)
Abdominal width	23.8 (21.9–25.6)	10.8 (9.9–11.5)
Thoracic width	30.0 (28.2–31.8)	31.4 (29.1–33.5)
Chela length	22.6 (21.3–24.3)	27.8 (25.2–30.1)
Dactylus length	24.3 (22.6–26.0)	30.2 (27.8–32.7)
Propod length	68.6 (64.3–73.1)	84.7 (78.0–91.5)

Sexual dimorphism between males and females was recorded for all measures (**Figure 7**). The differences between the mean values of 95% CIs of males and females do not contain 0, with the values of abdomen width, thoracic width, and interocular distance being statistically significantly higher in females compared to males (**Figure 7**). This is best seen in the abdominal width measure, which is also used as the basic difference when determining gender (**Figure 3**).

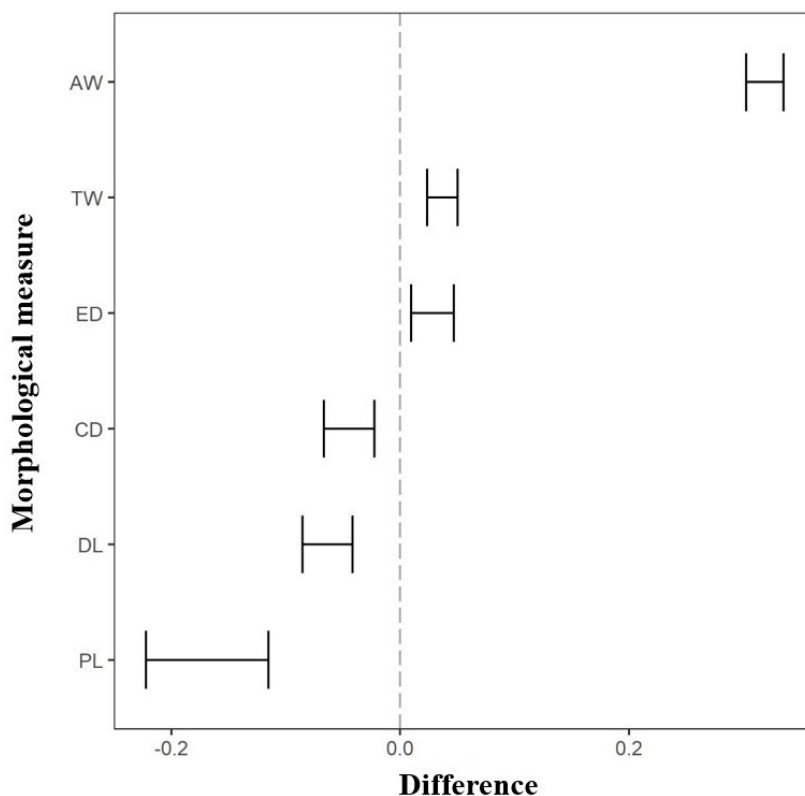


Figure 7. Morphological measures between females and males of *E. verrucosa*: the difference between the mean values of 95% confidence intervals for males and females.

The mean value of the gonopod length (GL) of the males was 15.2 mm (95% CI=14.1–16.2), and ranged from 7.3 mm to 21.2 mm. As the length of the carapace (CL) increased, the length of the gonopods also increased (Figure 8), with the coefficients of the linear model describing this relationship being $a = 0.216$ (95% CI=0.146–0.273) and $b = 4.786$ (95% CI=2.189–8.319).

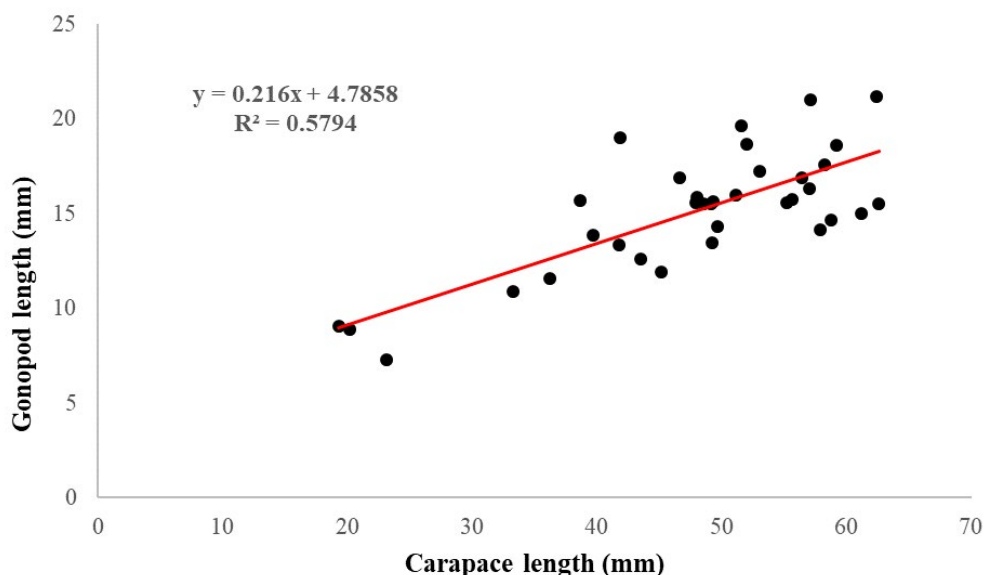


Figure 8. Graphic representation of the dependence of the length between the gonopod length and the length of the male carapace.

Length-weight ratio

The length-weight ratio of females, males, and females and males together are shown in Figure 9, Figure 10, and Figure 11, while the average values of the coefficients a and b of the length-weight ratio are given in Table 2.

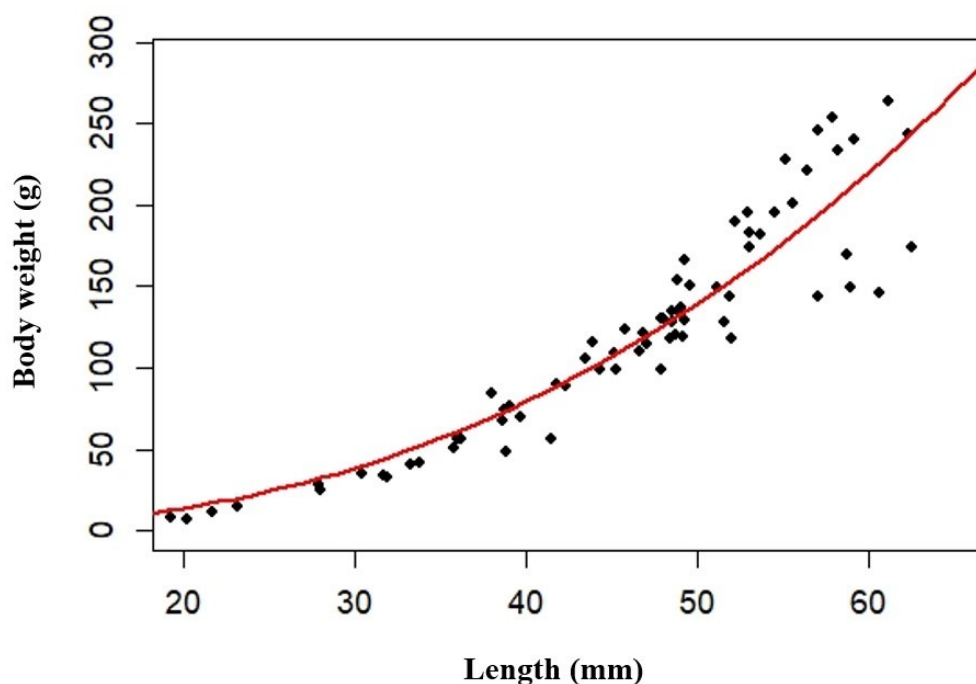


Figure 9. Length-weight ratio of the species *E. verrucosa* in the eastern Adriatic.

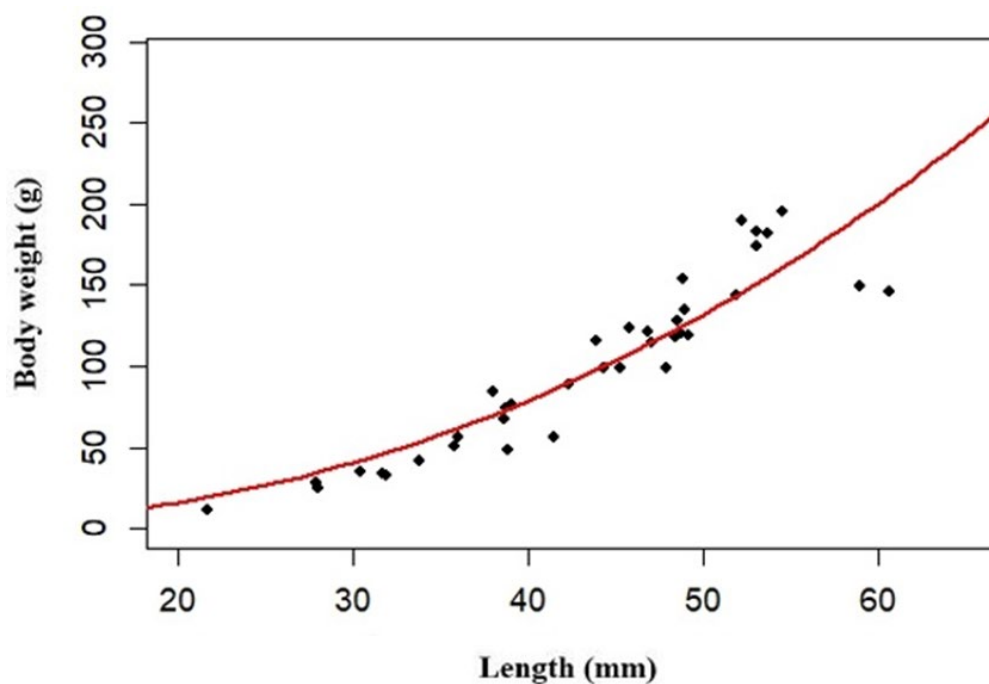


Figure 10. Length-weight ratio of females of the species *E. verrucosa* in the eastern Adriatic.

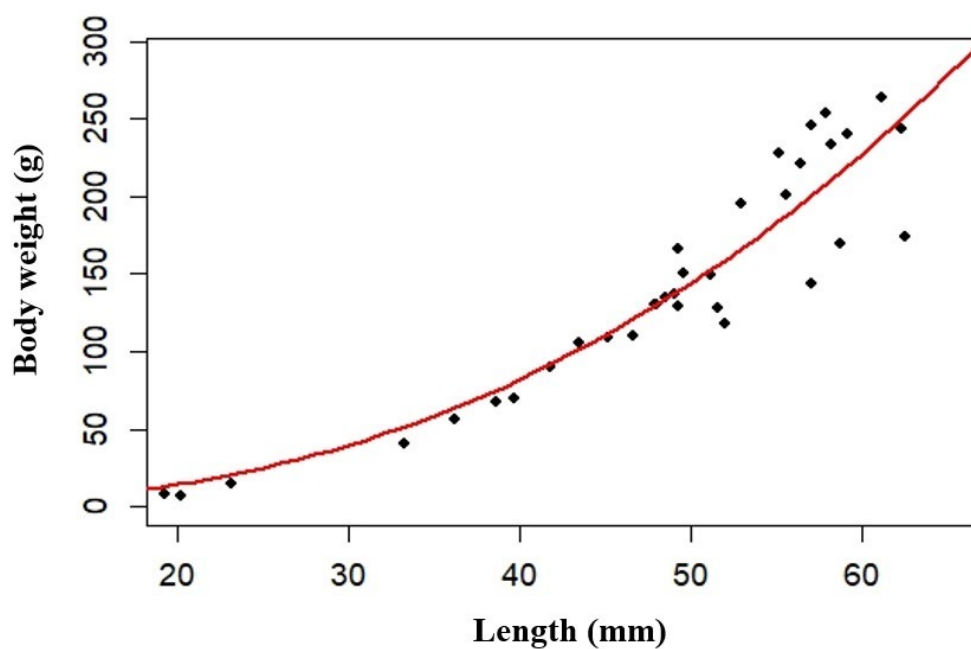


Figure 11. Length-weight ratio of males of the species *E. verrucosa* in the eastern Adriatic.

Table 2. The coefficients a and b in a common length-weight relationship along with their 95% confidence intervals for both sexes.

Parameter	a (95% CI)	b (95% CI)
Total	0.0076 (0.0036–0.0816)	2.5086 (1.8883–2.6828)
Males	0.0078 (0.0034–0.07835)	2.5116 (1.9091–2.6974)
Females	0.0169 (0.0033–0.0811)	2.2911 (1.8941–2.7137)

Discussion

The body mass of the warty crab in this sample ranged from 7.3 to 263.9 g, with a mean value of 119.8 g. This is in line with the data reported by Ulaş and Aydin (2) in the sample of 129 individuals (range = 74.6–391 g, mean = 221.4 g). Aydin (3) processed a much larger sample of 1863 individual specimens (compared to 73 in this study) and obtained a wider range of body mass than in present study (range = 4.1–312 g), but the mean value remained similar to the present results (mean = 111.2 g, standard deviation = 52.7).

It has been recorded that the warty crab can reach a carapace length of 70 mm (12). In the studied sample, the mean value of carapace length (CL) was 45.6 mm with a range from 19.3 to 62.6 mm, which is consistent with other studies (2–4). The slight differences between studies could be due to the variations of sampling regions and sampling methods. Specimens used in this study were only collected at night with a scoop net, while the specimens in the abovementioned studies were collected over a longer period of time by snorkeling, SCUBA diving, trawls, trammel nets, and dredges.

The width of the carapace (CW) of the warty crab reaches up to 9 cm (28). In this study, the mean value of carapace width was 64.1 mm (95% CI = 60.8–67.0). The range of carapace width recorded in this work was between 28.41 and 88.93 mm and agrees with the values obtained by other authors (3, 4, 13), although it was determined on a much smaller sample.

Sex dimorphism in warty crabs, as in most brachyurans, is usually observed by interpreting typical characteristic forms of their abdomen (triangular in males and circular in females) and the appearance of the first two pairs of pleopods (modified to gonopods in males) (4). The abdominal width (AW) in short-tailed decapods is generally larger in females and is also the most important morphological difference between the sexes (Figure 3), which was also shown in this study. The greater pincer width of the males could possibly be related to their increased aggressiveness in fighting for territory and holding the female during mating (29, 30). In general, the right or dominant pincers are usually larger in both sexes and used to crush hard prey. In this study, all these sizes were larger in males and differed statistically significantly between the sexes.

The length-weight ratio showed a negative allometry in the warty crab, which corresponds with results reported by Karadurmuş and Aydin (4) ($W = 1.1556 \times CL^{2.919}$) and Aydin (3) ($W = 1.205 \times CL^{2.893}$). In general, the differences in length-weight ratio between this study ($W = 0.0076 \times CL^{2.5086}$) and others may have resulted from differences in study location, water temperature, salinity, food availability, and many other factors.

In this study, the sex ratio was in favor of females (0.92:1), without a statistically significant difference compared to the theoretical ratio of 1:1. Karadurmuş (12) observed a sex ratio of 1:0.41 in favor of males in a sample of 1350 of individuals. Karadurmuş and Aydin (4) found a similar male-to-female ratio of 1:0.42 in a sample of 1360 individuals, while Erkan colleagues (9) found a sex ratio of 1:0.43 in a sample of 203 individuals. A similar male-to-female ratio (1:0.44) was also reported for a sample of 1863 individuals (3), while Jouili and colleagues (13) reported a ratio of 1:0.47 for a sample of 315 individuals and Özekinci and Acarli (10) found a ratio of 1:0.66 for a sample of 598 individuals. In contrast to the ratio found in this study (0.92:1), where females had a slight advantage, the other authors

showed a significant difference from the expected ratio of 1:1, consistently in favor of males. The reason for the differences mentioned could be that the samples were taken in different time periods or at different salinities and temperatures in the different habitats. Likewise, the dynamics of specimen collection during the research were not uniform. Additionally, we carried out our study on a smaller sample than other authors (3, 4, 10, 12), some of whom claimed that the number of males increases with increasing carapace width (4).

Of the total of 38 females collected, 9 of them carried eggs on pleiopods and were all caught in July or August, which agrees with the statements that the species reproduces from late spring to late summer and females, as eggs were observed in the mentioned months in previous studies (4, 9, 31).

The importance of studying warty crab lies in its potential economic importance in the future, in the eastern Adriatic. Although the species is still economically neglected, it is very likely that its exploitation will increase in the future. A major advantage for humans in the exploitation of *E. verrucosa* is the accessibility of this species whose habitat is in the upper infralittoral area, which greatly eases its capture. Moreover, hand tools are used for fishing, which is mostly done from land, further facilitating human access. So far, the exploitation of *E. verrucosa* in Croatia is rather localized (32). In some countries – for example, in Italy and Turkey – *E. verrucosa* is commercially exploited (33-35). Additionally, it also might serve as food in aquaculture for farmed species such as octopus, due to its short breeding cycle and good placement in the market. Based on this, we can assume that *E. verrucosa* has great economic potential for the future, and one of the prerequisites for long-term sustainable use is a good knowledge of its bio-ecological characteristics.

In this study, certain biological characteristics of the species *Eriphia verrucosa* in the eastern Adriatic Sea, such as morphometric measurements, length-weight ratio and sex ratio, were observed and described for the first time. Using the length-weight ratio presented, we determined the length-weight estimates for the warty crab based on a single measurement. Current indications suggest that this species is likely to be the subject of many studies in the future. Thus, the results of this research are a contribution to a better understanding of the biological characteristics of *E. verrucosa* and could serve in future biological research on this species.

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Authorship declaration: The first author (PK) collected and processed the sample; conducted the analysis; and wrote the manuscript. The senior author (VN) provided guidance in conducting the research and writing/revising the manuscript.

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