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RESEARCH ARTICLE

Morphometric characteristics of crayfish, *Cherax gherardiae*, from Maybrat, West Papua, Indonesia

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Abstract. The objectives of this study were to determine the length-weight relationships (LWRs), chelae length (ChL)-width (ChW) relationships, carapace length (CL)-width (CW) relationships, sexual dimorphism, and condition factor (K) of *Cherax gherardiae* from Maybrat, West Papua Indonesia. The sex ratio of *C. gherardiae* was found to be 1.04:1. The LWRs for males, females, and all individuals were $W = 0.225L^{1.96}$, $W = 0.181L^{2.02}$, and $W = 0.187L^{2.03}$, respectively. Males and females exhibited negative allometric growth (b<3). There was no significant difference in lengths between males and females; however, the weight of males was greater than that of females. The K values for males, females, and all individuals were 3.17, 3.09, and 3.13, respectively. The ChL of the crayfish ranged from 1.0 to 7.5 cm, and the ChW ranged from 0.4 to 2.5 cm. The CL of crayfish ranged from 1.6 to 6.0 cm, and the CW ranged from 0.6 to 4.1 cm. Males had longer chelae and carapaces than did females. There was no significant difference in chelae width or carapace width between males and females. The ChL-ChW relationships for males, females, and all individuals were ChW = 0.312ChL + 0.260, ChW = 0.397ChL - 0.050, and ChW = 0.345ChL + 0.119, respectively. The CL-CW relationships for males, females, and all individuals were CW = 0.750CL-0.955, CW = 0.526CL - 0.178, and CW = 0.635CL-0.543, respectively.

Keywords: *Cherax*, crayfish, morphometry, Papua

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Introduction

Freshwater crayfishes of the family Parastacidae are typical fauna representatives of Papua, Indonesia. Holthuis (1982) reported that all crayfish in Papua, Indonesia and New Guinea belong to this family and the genus *Cherax*. Although the crayfish of Papua, Indonesia and New Guinea have been studied extensively (Holthuis 1949, 1956, 1958, 1982, 1986, 1996, Lukhaup and Pekny 2006, 2008, Lukhaup and Herbert 2008, Lukhaup 2015, Lukhaup et al. 2015, 2017, Patoka et al. 2015a, 2015b), previous research focused on the taxonomy and morphological description of the new species of *Cherax*. Very few studies have been conducted on the basic morphometric characters of these crayfish including *Cherax gherardiae*. To our knowledge, only Weya et al. (2017) have studied the length-weight relationship and condition factor of crayfish in Papua Indonesia, but they excluded *C. gherardiae*.

C. gherardiae is endemic to the Ayamaro Lakes and the Ayamaro River and its surrounding area in Maybrat Regency, West Papua, Indonesia (Lukhaup and Pekny 2008). *C. gherardiae* from West Papua are captured in the field and exported by Indonesian wholesalers to the European, North American, and Japanese pet markets (Lukhaup and Herbert 2008, Patoka et al. 2015a). To date, the *Cherax* from West Papua that are traded have yet to be described scientifically, and their quantities in which they are captured are not registered by any relevant authorities (Patoka et al. 2015a); therefore, the possible decline of the abundance of these species remains unknown.

Measuring individual body length and weight is a basic morphometric procedure in the scientific study of the species. The length-weight relationship (LWR) is a very important parameter for the characteristics of crayfish populations, and it is used to estimate growth rates, to evaluate size at sexual maturity, to calculate weights at certain lengths (and vice versa), and to calculate condition factor to permit comparisons among populations from different regions (Lindqvist and Lahti 1986, Milosevic and Talevski 2016). The condition factor can be used to assess the degree of well-being of organisms in their habitats (Mac Gregoer 1959). When the condition factor value is higher than one, this means that the animal has attained a better condition. The condition factors of aquatic organisms can be affected by a number of elements such as stress, food availability, season, and habitat water quality (Lindqvist and Lahti 1986, Milosevic and Talevski 2016). Furthermore, relations among body parts are used to segregate males from females and to compare crayfish populations from different regions (Deniz et al. 2010). An LWR study of a species can provide important insights into its ecology (Froese 2006). Pauly (1993) states that LWR provides valuable information on the habitat where a species lives. Therefore, understanding the relationship between length and weight might have important implications for the management of crayfish in their natural habitats.

In crustaceans, chelae length and width are important factors in aggressive behavior, and they play a significant role in determining competitive outcomes. Crayfish species compete for limited resources such as food, shelter, and space (Nakata and Goshima 2003, Mazlum and Eversole 2005); thus, morphometric relationships between chelae length and width are very important subjects to study. The objective of this study was to determine the L-W relationships, ChL-ChW relationships, CL-CW relationships, sexual dimorphism, and condition factors of *C. gherardiae* from Maybrat, West Papua, Indonesia.

Materials and methods

Male and female *C. gherardiae* were caught in creeks located to the northeast of Ayamaro Lake, Maybrat Regency West Papua (lat. 1°6'6.06" - 1°7'22.62"S; 132°29'30.48" – 132°29'32.94"E) Indonesia (Fig. 1). Specimens were collected between November 2016 and January 2017 in creeks measuring 4-8 m in width and 0.3-0.7 m in depth. The beds of the creeks consisted of stones, rocks, and pebbles and offered plenty of shelter for crayfish. The river banks were overgrown with dense vegetation.

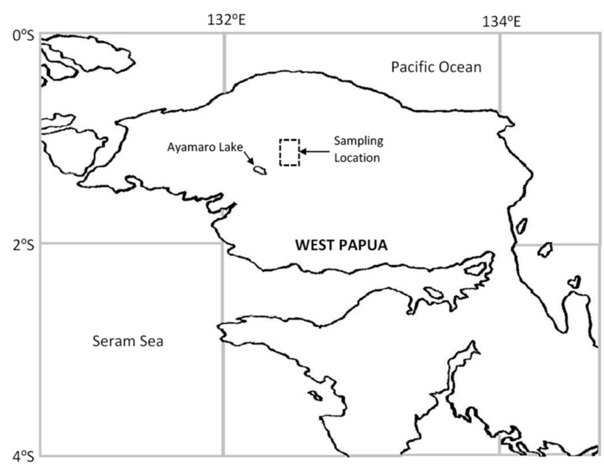

Figure 1. Sampling location of *Cherax gherardiae* in Maybrat, West Papua, Indonesia.

The crayfish were collected with the assistance of the local people using cast nets, noken (a knotted net or woven bag handmade from wood fiber or leaves by communities in Papua Indonesia), and by hand to pick and dislodge them from their burrows. The

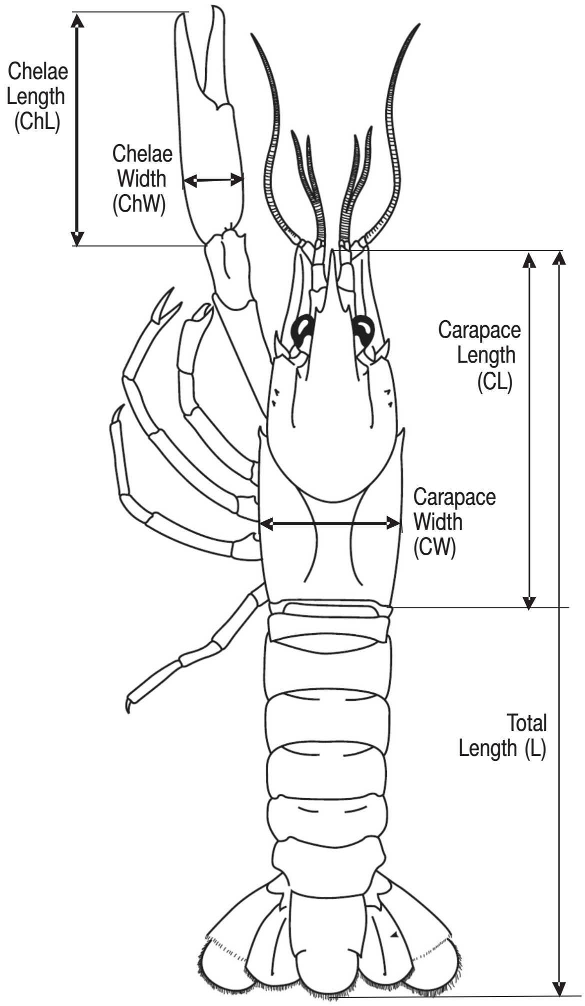

Figure 2. Morphometric measurements taken for *Cherax gherardiae* individuals. L = total length, CL = carapace length, CW = carapace width, ChL = chelae length, ChW = chelae width. Line art modified from Loughman and Simon (2011).

animals were placed in clean plastic buckets and transported to the laboratory for analysis. The morphological identification followed Patoka et al. (2015a, 2015b). The crayfish were placed on filter paper for several minutes to remove excess water, then weighed to the nearest 0.01 g. Total length (L), carapace length (CL), carapace width (CW), chelae length (ChL), and chelae width (ChW) were measured to the nearest 0.01 cm (Fig. 2). Only individuals with complete chelipeds, a full complement of walking legs, and no visible body deformations were used to determine the length-weight relationships. Individuals were segregated by sex, and ovigerous females were noted, but they were not included in the morphometric analysis.

The chi-squared (χ^2) test was used to evaluate differences in the sex ratio for the entire sample. The length-weight relationships (LWRs) were calculated using the equation $W=aL^b$, where W is the total weight of the crayfish (g), L is the total length (cm), a is the intercept, and b is the slope (Ricker 1975). The parameters a and b were estimated by the linear regression of the transformed equation: $\log W = \log a + b \log L$. The determination coefficient (r^2) was used as an indicator of the quality of the linear regression. Slope (b) is used to describe the growth type of the crayfish: for $b = 3$ growth is isometric, for $b < 3$ is negatively allometric, and for $b > 3$ is positively allometric (Zar 1999). The relationships between ChL-ChW and CL-CW for each sex were also determined using regression analysis. Differences in L, W, ChL, ChW, CL, and CW values between males and females were tested using Student's t-test (Zar 1999). Analysis of covariance (ANCOVA) was used to compare the L-W, ChL-ChW, and CL-CW regressions between males and females for significant differences. Before being subjected to a parametric statistical test, the normality of the measurement variables was verified with the Kolmogorov-Smirnoff normality test. If the data did not fit a normal distribution, we applied log transformations to make the data normally distributed.

Fulton's condition factor (K) was calculated using the equation $K = 100 \times (W \times L^{-3})$ (Ricker 1975), where W is the total weight of the crayfish (g) and L is the total length (cm). K values of crayfish were determined separately according to the total length of female and male individuals. Differences between the K values of females and males was tested using Student's t-test (Zar 1999).

During crayfish collection, the water quality parameters of the habitat were measured, as follows: temperature with glass mercury thermometers (°C); pH with a pH meter (Lutron PH 207 HA); dissolved oxygen (DO) with DO meter (Hach Sension 6); turbidity with portable turbidity meter (Hanna HI 98703). The values of temperature, pH, dissolved oxygen, and turbidity were 26.0-26.5°C, 7.40-7.62, 7.7-8.2 mg L^{-1}, and 1.77-2.64 NTU, respectively.

Results

Sex ratio, length-weight relationship, and condition factor

The characteristics of the crayfish samples are presented in Table 1. The sex ratio was found to be 1.04:1 (53 females/51 males). This value was not significantly different from the theoretical 1:1 values (χ^2 = 0.2, P > 0.05). In total, 75 specimens (male = 38, female = 37) were examined for LWRs (Table 2).

Table 1
Crayfish sample characteristics

Category	N	Number of crayfish with incomplete chelipeds	Ovigerous female
Male	51	13	-
Female	53	11	5
Total	104	24	5

Note: N = number of crayfish

The LWRs for males, females, and all individuals were described as follows: W = $0.224L^{1.96}$, W = $0.181L^{2.02}$, and W = $0.187L^{2.03}$, respectively. The males, females, and all individuals exhibited negative allometric growth (b<3). The length-weight regression differed significantly between males and females (ANCOVA; length P = 0.000; sex P = 0.011; corrected model P = 0.000; r^2 = 0.893). The condition factor (K) of males, females, and all individuals ranged from 1.62 to 6.30, 1.52 to 6.60, and 1.52 to 6.60, respectively (Table 2). There were no significant differences in K between males and females (P > 0.05).

ChL-ChW and CL-CW relationships

The regressions for the ChL-ChW relationship for males, females, and all individuals were ChW = 0.312ChL + 0.260, ChW = 0.397ChL - 0.050, and ChW = 0.345ChL + 0.119, respectively (Table 3). The ChL-ChW regressions did not differ significantly between males and females (ANCOVA; chelae length P = 0.000; sex P = 0.346; corrected model P = 0.000; r^2 = 0.749).

Table 2
Length-weight relationship analysis and condition factor (K) of crayfish from Maybrat West Papua Indonesia

		Total length (cm)			Weight (g)			Parameter of L-W relationship			Growth	K	
Category	N	Mean ± SD	Min	Max	Mean ± SD	Min	Max	a	b	r^2	type	Range	Mean ± SD
Male	38	7.07 ± 1.85[a]	4.2	12.5	11.21 ± 7.06[b]	4.11	39.84	0.225	1.96	0.874	-A	1.62 - 6.30	3.17 ± 1.04[a]
Female	37	6.44 ± 1.57[a]	3.6	11.1	8.33 ± 4.95[a]	3.08	20.74	0.181	2.02	0.897	-A	1.52 - 6.60	3.09 ± 0.91[a]
Total	75	6.76 ± 1.73	3.6	12.5	9.79 ± 6.24	3.08	39.84	0.187	2.03	0.883	-A	1.52 - 6.60	3.13 ± 0.97

Note: N = number of crayfish, SD = standard of deviation, K = condition factor, a = intercept, b = slope, r^2 = determination coefficient, -A= negative allometric growth, different letters indicate significant differences (P < 0.05, a<b)

Table 3
Chelae length, chelae width, and chelae length-width regression of crayfish from Maybrat West Papua Indonesia

		Chelae length (cm)			Chelae width (cm)			Parameter of ChL-ChW regression		
Category	N	Mean ± SD	Min	Max	Mean ± SD	Min	Max	a	b	r^2
Male	51	3.53 ± 1.40[b]	1.4	7.5	1.36 ± 0.47[a]	0.6	2.5	0.260	0.312	0.853
Female	48	2.72 ± 0.92[a]	1.0	4.6	1.03 ± 0.47[a]	0.4	2.3	-0.050	0.397	0.597
Total	99	3.13 ± 1.25	1.0	7.5	1.20 ± 0.50	0.4	2.5	0.119	0.345	0.746

Note: N = number of crayfish, SD = standard of deviation, a = intercept, b = slope, r^2 = determination coefficient, different letters indicate significant differences (P < 0.05, a<b)

The regressions for the CL-CW relationship for males, females, and all individuals were CW = 0.750CL - 0.955, CW = 0.526CL - 0.178, and CW = 0.635CL - 0.543, respectively (Table 4). There were no significant differences in the CL-CW regressions between males and females (ANCOVA; carapace length P = 0.000; sex P = 0.878; corrected model P = 0.000; r^2 = 0.864).

Sexual dimorphism

The L of the 75 crayfish ranged from 3.6 to 12.5 cm, and the W ranged from 3.08 to 39.84 g (Table 1). There was no significant difference in L between males and females (P > 0.05); however, the W of males was greater than that of females (P < 0.05). The ChL of the 99 crayfish ranged from 1.0 to 7.5 cm, and the ChW ranged from 0.4 to 2.5 cm (Table 3). The CL of crayfish ranged from 1.6 to 6.0 cm, and the CW ranged from 0.6 to 4.1 cm (Table 4). Males had longer chelae and carapaces that did females (P < 0.05). There were no significant differences in either chelae and carapace widths between the males and females (P > 0.05).

Table 4

Carapace length, carapace width, and carapace length-width regression of crayfish from Maybrat West Papua Indonesia

		Carapace length (cm)			Carapace width (cm)			Parameter of CL-CW regression		
Category	N	Mean ± SD	Min	Max	Mean ± SD	Min	Max	a	b	r^2
Male	51	3.54 ± 0.86[b]	1.6	6.0	1.70 ± 0.69[a]	0.6	4.1	-0.995	0.750	0.894
Female	48	3.30 ± 0.89[a]	2.0	5.2	1.56 ± 0.50[a]	0.6	2.6	-0.178	0.526	0.880
Total	99	3.42 ± 0.88	1.6	6.0	1.63 ± 0.60	0.6	4.1	-0.543	0.635	0.864

Note: N = number of crayfish, SD = standard of deviation, a = intercept, b = slope, r^2 = determination coefficient, different letters indicate significant differences (P < 0.05, a<b)

Discussion

The sex ratios in most natural crayfish populations are close to 1:1 (Abrahamsson 1971, Kirjavainen and Westman 1999). Our study found that the sex ration of the crayfish *C. gherardiae* form Maybrat West Papua was: 1.04:1 (females/males), which was not significantly different from the expected value of 1:1. Our results differ from the findings of other research conducted on crayfish species such as *Orconectes limosus* (Alekhnovich et al. 1999), *Austropotamobius pallipes* (Fenouil and Chaix 1985, Gherardi et al. 1997, Grandjean et al. 2000), *Astacus leptodactylus* (Deniz et al. 2010), and *Pacifastacus leniusculus* (Kirjavainen and Westman 1999, Capurro et al. 2007). Most authors found higher catches of males than females, and they suggest that this could result from the crayfish males being more active than females, and also because females are inactive during and after the breeding season; therefore, collection tends to be biased toward males (Gherardi et al. 1997, Kirjavainen and Westman 1999, Grandjean et al. 2000, Capurro et al. 2007).

In our studies, the length-weight relationships of *C. gherardiae* males, females, and all individuals showed negative allometric growth (b<3.0). Similar results were reported for *Procambarus alleni* (Hobbs et al. 1989) and *C. snowden* (Weya et al. 2017). Other results showed positive allometric growth (b>3.0) for *P. zonangulus* (Romaire et al. 1977), *C. quadricarinatus*, *C. destructor* (Austin 1995), *P. alleni* (Acosta and Perry 2000), *P. acutus acutus* (Mazlum et al. 2007), and *A. leptodactylus* (Deniz et al. 2010), and isometric growth (b=3.0) for *A. leptodactylus* (Aydin et al. 2015) and *P. fallax* (Hobbs et al. 1989). These differences could be the reflection of a number of factors, including population density, food abundance, water level fluctuations, water temperature, water quality, and photoperiod (Huner and Romaire 1979, Chien and Avault 1983, Acosta and Perry 2000). Lindqvist and Lahti (1983) suggest that the variation of length-weight relationships among crayfish species is also affected by sex, sexual stage, and ecological conditions.

Sexual dimorphism is common in freshwater crayfish species (Lindqvist and Lahti 1983, Holdich 2001, Mazlum et al. 2007, Wang et al. 2011). Our study determined that the mean carapace length of the males was longer than that of the females. Since there was no difference in body lengths between male and female *C. gherardiae*, at equal-size the females of this species had longer abdomens than males. A longer abdomen in females could be because they carry eggs under the abdomen (Wang et al. 2011). Variation in abdomen length is commonly found in freshwater crayfish and is always related to sex, sexual maturity, and size (Wetzel 2002, Simon and Stewart 2014).

The most obvious sexual dimorphism in crayfish is seen in the disproportionately rapid growth of chelae in males compared to that of females. Differences between male and female chelae lengths are well documented in crayfish (Deniz et al. 2010, Wang et al. 2011, Simon and Stewart 2014). In the present study, the chelae of male *C. gherardiae* were longer than those of females. With longer chelae, male crayfish have a distinct advantage in activities related to sexual reproduction (Stein 1976) and to competition for food, shelter, and space (Nakata and Goshima 2003, Mazlum and Eversole 2005). Chybowski (2007), in a study of the morphometric characters of the spiny-cheek crayfish (*Orconectes limosus*), reports that at the same body length the females had shorter cheliped lengths and narrower widths than those of the males. These same characters were also observed in signal crayfish, *Pacifastacus leniusculus* (Chybowski 2014).

The condition factors (K) of male and female *C. gherardiae* were not significantly different. Their average values were 3.17 for males and 3.09 for females. To the best of our knowledge, no data exists on the condition factor of this species from other locations. Therefore, we cannot compare our data with other findings on the same species. According to Lindqvist and Lahti (1986) and Milosevic and Talevski (2016), *C. gherardiae* attained a better condition (K > 1) in this habitat. Other researchers also reported that most crayfish species demonstrated higher K values including *A. torrentium* (3.3) (Streissl and Hodl 2002), *P. acutus* (1.6) (Mazlum et al. 2007), *P. clarkii* (2.3) (Wang et al. 2011), *O. rustucus* (1.5) (Anderson and Simon 2015*), O. virilis* (5.8) (Simon and Stewart 2014), and *A. leptodactylus* (2.6) (Aydin et al. 2015). The difference of condition factors of crayfish among species and locations could be a reflection of a number of factors, including population density, sex, sexual stage, food abundance, photoperiod, water level fluctuations, and water quality (Lindqvist and Lahti 1983, Acosta and Perry 2000). Crayfish inhabiting habitats that are under no anthropogenic pressure and with a variety of suitable shelters have higher K values (Vorburger and Ribi 1999, Streissl and Hodl 2002, Maguire and Klobucar 2011). Similarly Weya et al. (2017) report that crayfish living in a habitat that provides a more suitable environment and a higher supply of food have higher K values.

Conclusions

The present study is the first report on the growth and morphometry of *C. gherardiae* from West Papua, Indonesia, especially from Maybrat Regency. This study provides baseline information on length-weight relationships, chelae length-width relationships, carapace length-width relationships, sexual dimorphism, and condition factors of crayfish that will be beneficial for further reference.

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