Length-weight Relationship, Body Morphometrics, and Condition Based on Sexual Stage in the Rusty Crayfish, *Orconectes rusticus* Girard, 1852 (Decapoda, Cambaridae) with Emphasis on Management Implications

Wendy E Anderson and Thomas P Simon*

1 School of Public and Environmental Affairs, 1315 E. Tenth Street, Indiana University, Bloomington, IN 47405, USA

**Abstract**

The Rusty crayfish, *Orconectes rusticus* Girard, is an invasive crayfish species found in the Midwestern United States and Canada. *O. rusticus* has displaced native crayfish species throughout its range. Length-weight relationship, body morphometric relationship, and condition within the species native range in south-central Indiana were studied. Growth, size relationships based on gender, sexual phase for adults and juveniles and chelae-length, width relationships was used to interpret patterns in sexual dimorphism. Carapace length (CL)-wet weight (*W_w*) relationships for all genders (i.e., male, female, juvenile) and all male forms (form I and II) had positive allometric growth. Native *O. rusticus* were found to be larger in all measurements and heavier than the *O. rusticus* collected in the invasive range. *Orconectes rusticus* has a smaller mean carapace length and had a mean weight less than *O. limosus*, *Procambarus acutus*, *Procambarus fallax*, and *Procambarus clarkii*. *Orconectes rusticus* shows strong sexual dimorphism patterns, but compared to other freshwater crayfish it is generally smaller. To establish populations in occupied areas *O. rusticus* may use a combination of competitive and aggressive behaviors. *Orconectes rusticus* should be managed with depletion trapping and by restoring native predatory fish populations.

**Keywords:** Length-weight relationship; Morphometrics; Growth

**Introduction**

Invasive species can cause economic or environmental damage in that ecosystem [1]. The invasive nature of the rusty crayfish, *Orconectes rusticus* Girard can be understood by studying the relationship between length and weight [2]. Aggression is a key characteristic in competition to access to shelter, food, and mates [3]. *Orconectes rusticus* is known as an aggressive invader and displaces many native species of crayfish [4,4], destroys macrophyte beds [5], competes with fish for invertebrate prey, and decreases recruitment rates of sport fishes by eating eggs and removing macrophyte habitat [6-8].

The species was originally described from streams near Cincinnati in Hamilton County, Ohio, from the Ohio River basin, as well as the Whitewater and Maumee rivers in Indiana [2]. The range of *O. rusticus* include the Ohio River basin in Ohio, Kentucky, Indiana, West Virginia, and Tennessee, but it has extended its range to most of the Midwestern United States and Canada [9]. It was introduced widely by anglers through bait bucket release into lakes and streams where the species has outcompeted native crayfish species, especially in Wisconsin and Minnesota [7].

Sexual dimorphism within crayfish species can be determined by changes in specific characteristics between genders. Larger chelae cost more energy and are heavy; in many species chelae can be ornamental. Previous studies of *O. rusticus* morphometrics show that males had larger chelae and attained larger sizes than females, while female abdomen width was wider than males [10]. Length-weight relationships of crayfish enable understanding of each species growth and size at sexual maturity [11]. Growth of *O. rusticus* occurs during the spring molt. Males will molt from sexually inactive form II to sexually active form I with larger gonopods [12]. Male form I crayfish molt to form II by late summer and are sexually inactive until the following spring. Chelae typically grow in size during the spring since they are needed for copulation and amplexus. Relationships found for each sexual form can offer conclusions for sexual dimorphism between male form I, form II, and female.

The relationship of chelae length (ChL) to chelae width (ChW) is important for describing factors of aggressive behavior and competitive outcomes in rusty crayfish [10]. The chelae are used in antagonistic competition displays and in reproduction during amplexus [10,13-16].

The objectives for this study were to evaluate patterns in growth and condition between the carapace length (CL)- wet weight (*W_w*) relationship between male form I, male form II, female, and juvenile life stages. This study compared the carapace length (CL) to the post-orbital length (POCL), carapace width (CW), carapace depth (CD), and abdomen width (ABW) measurements taken from males form I, males form II, and females. This study also compares the CL, ChL, and ABW of rusty crayfish within the native and the invasive ranges. Comparison of growth data from other tertiary burrowing crayfish species was compiled to evaluate patterns in growth.

**Methods**

**Study area**

The study area included portions of the native and introduced range of the rusty crayfish in the Midwestern United States. Portions of...
northern, central, and southeastern Indiana and the state of Wisconsin were sampled. Individuals of rusty crayfish were collected from sites throughout the native and introduced range in the state following standard methods [17]. Individuals were sampled from a range of counties (See supplemental materials) including introduced areas such as Hendricks, Shelby, Lake, LaGrange, Jay, Delaware, Franklin, Carroll, Grant, and Decatur, while native counties included Ripley and Madison.

Sample collection and analysis

Specimens (n=343) were measured for carapace length and weight based on gender. Individuals were identified as male Form I (n=32), male Form II (n=151), female (n=152), and juveniles (n=105). Males were classified as either reproductively active (form I) or inactive (form II) [18]. Form I males are sexually mature adults, and contribute to growing at a decreasing rate. Form I males are identified by an ischial hook on one pair of their periopods and a hardened, elongate and well-defined gonapod [18]. Form II males are not reproductively active. Form II males have less defined, blunt, and club-like gonopods. The annulus ventralis of females is an opening between the last pair of walking legs, located adjacent to a pair of seminal receptacles. Juveniles were identified based on size threshold of 15 mm. Specimens with a carapace length (CL) of fewer than 15 mm were classified as juveniles.

Each individual crayfish was measured for eight morphological characteristics including carapace length (CL), postorbital carapace length (POCL), carapace depth (CD), carapace width (CW), chelae length (ChL), chelae width (ChW), abdomen width (ABW), and wet weight [18]. A Neiko stainless steel 200 mm digital caliper was used to take the measurements to the nearest 0.01 mm. The CL was measured from the tip of the rostrum to the end of the carapace; POCL was measured from the spine adjacent to the orbit to the posterior terminus of the carapace; CW was measured laterally at the widest part of the carapace; CD was measured from the dorsum of the carapace to the ventrum along the sternum; ChL was measured from the posterior attachment of the chela to the tip of the dactyl; ChW was measured at the widest point laterally along the palm; ChD was measured from the dorum of the palm to the greatest thickness ventrally. The ABW was measured laterally at the widest posterior point.

The individual net weight was taken using a Mettler Toledo PR503 balance and recorded to the nearest 0.001 g. A residual weight was recorded after the crayfish was removed from the balance. The wet weight was the adjustment from the net weight and the residual weight to account for the wet weight. Specimens with damaged or regrown chelae were not used for any chelae measurements.

Relationships between length-weight was determined using a linear regression analysis based on the equation y = mx + b. We used the log-transformed Fulton-Condition Index equation, log(Wwt)=b*log(CL)+a, where a=intercept, b=slope of regression line, Wwt=wet weight of samples (g), and CL=carapace length (mm). Sexual stages and species with slope greater than 3 have positive allometry, less than 3 have negative allometry, while a b value of exactly 3 is isometric. Positive allometry means that weight is gaining faster than length. Gender and trend lines determined best-fit regression models and residuals (R2) graphed for carapace length (mm) and wet weight (g) [19]. Relationships between chelae (mm), abdomen, and carapace length were regressed with a best-fit regression model trend line. Significant differences in gender relationships were analyzed with Kruskal-Wallis with α= 0.05. Regression statistics were reported by sexual stage and the independent measure.

Morphometric relationships were found in other published papers and compared to this original O. rusticus data. No statistical analysis was done comparing O. rusticus to other species.

Results

Length-weight relationship

A simple linear regression model was used to analyze length-weight variables. Table 1 shows the descriptive statistics for mean total carapace length (CL ± SD) and mean wet weight (Wwt ± SD). Mean carapace length (CL ± SD), mean wet weight (Wwt ± SD), and their respective ranges were calculated for male form I, male form II, female, and juvenile individuals as follows: CLmale I= 27.69 ± 7.85 mm (range=17.04-44.60 mm), CLmale II= 25.22 ± 7.54 mm (range=12.90-49.73 mm), CLfemale= 20.56 ± 7.13 mm (range=6.50-41.81 mm), and CLjuv= 13.10± 1.91 mm (range= 8.28-15.94 mm), respectively (Table 1). Mean wet weight (WwtI ± SD), mean wet weight (WwtII ± SD), and their respective ranges were calculated for male form I, male form II, female, and juvenile individuals as follows: WwtI= 9.04 ± 7.09 g (range=1.53-27.44 g), WwtII= 5.43 ± 5.44 g (range=0.54-30.51 g), Wwtfemale= 3.30 ± 0.33 g (range=0.08-17.19 g), and Wjwt= 0.63 ± 0.29 g (range= 0.14-1.31 g), respectively (Table 1). The normalized (Log10) length-weight relationship for male form I was explained by the linear equation y= 3.2278x-3.8056, where R2=0.9594 and F=662.27; male form II was explained by the linear equation y=3.0052x-3.5967, with R2=0.9626 and F=2521.53; female length-weight was explained by the linear equation y= 3.1045x-3.7102, with R2=0.9786 and F=6661.86; juveniles were explained by the equation y= 3.1024x-3.7007, with R2=0.867 and F=404.14.

Morphometric relationship

The correlation between Chl and ChW showed that male form I have larger ChW and ChL (Table 2). Chelae width and length decreased as sexual form changes. Form II males had the second largest chelae, followed by females, then juveniles. Mean chelae length (ChL ± SD) and range were found for male form I, male form II, female, and juveniles as follows (Table 2): Chlmale I=26.80 ± 11.21 mm (range= 11.66-51.42 mm), ChlI=148.25 ± 20.56 (range=148.25-20.56 mm), ChlII=148.25 ± 20.56 (range=148.25-20.56 mm), ChlFemale= 20.56 ± 7.13 mm (range= 6.50-41.81 mm), and ChlJuveniles= 13.10± 1.91 mm (range= 8.28-15.94 mm).

| Sex and Sexual Form | Carapace length(mm) | Weight (g) | Parameters |
|---------------------|---------------------|------------|------------|
|                     | N                   | Mean (SD)  | Min        | Max        | Mean (SD)  | Min        | Max        | a         | b         | SE        | CL        | R²        | Type of Growth |
| Male Form I         | 30                  | 27.69 (7.85)| 17.04      | 44.60      | 9.04 (7.09)| 1.530      | 27.44      | -3.806    | 3.228     | 0.084     | 2.971     | 3.485     | 0.959     | A+         |
| Male Form II        | 100                 | 25.22 (7.54)| 12.90      | 49.73      | 5.43 (5.44)| 0.540      | 30.51      | -3.597    | 3.005     | 0.074     | 2.886     | 3.124     | 0.963     | A+         |
| Female              | 148                 | 20.56 (7.13)| 6.50       | 41.81      | 3.30 (3.39)| 0.080      | 17.19      | -3.710    | 3.104     | 0.074     | 3.028     | 3.180     | 0.979     | A+         |
| Juvenile            | 64                  | 13.10 (1.91)| 8.28       | 15.94      | 0.63 (0.29)| 0.135      | 1.307      | -3.701    | 3.102     | 0.081     | 2.794     | 3.411     | 0.865     | A+         |

Table 1: Carapace Length –Net Weight Measurements and descriptive statistics for sex and sexual forms. Standard of Error of b= SE, Confidence limits of b= CL, The number of crayfish=N, Coefficient of determination=R², A+ = positive allometric growth, a = slope, and b = intercept.
forms. Standard of Error of b= SE, Confidence limits of b= CL, The number of crayfish=N, Coefficient of determination=R²

Table 2: as follows: y=0.8726x-0.2119, R²=0.962, F=657.75; y=0.917x-0.2893, R²=0.994, F=700.75; y=0.9905x-0.088, R²=0.992, F=125.77.

Table 3: Preorbital Carapace Length (POCL), Carapace Width (CW), Carapace Depth (CD), and Abdomen Width (ABW) with descriptive statistics and parameter relationships. Carapace Length: measurements, parameters, and descriptive statistics for sex and sexual forms. Standard of Error of b= SE, Confidence limits of b= CL, The number of crayfish=N, Coefficient of determination=R²

| Sex and Sexual Form | N  | POCL Mean (SD)(mm) | Min | Max | POCL vs CL (a) | POCL vs CL (b) | SE(b) | CL(b) | R² |
|---------------------|----|-------------------|-----|-----|----------------|----------------|-------|-------|----|
| M Form I            | 30 | 21.96(6.06)       | 13.76| 34.69| 0.767          | 0.715          | 0.017 | 0.921| 1.023 | 0.982 |
| M Form II           | 100| 20.27(6.15)      | 8.62 | 38.88| 0.806          | -0.058         | 0.027 | 0.974| 1.058 | 0.959 |
| Female              | 148| 16.49(5.92)      | 5.52 | 36.67| 0.476          | 6.727          | 0.031 | 0.970| 1.033 | 0.964 |
| Juvenile            | 64 | 10.45(1.62)      | 6.31 | 14.03| 0.806          | -0.109         | 0.022 | 0.905| 1.076 | 0.896 |
|                    |    | Carapace Width Mean (SD)(mm) |     |      |                |                |       |       |      |
| M Form I            | 30 | 15.05(4.22)      | 8.96 | 22.93| 0.495          | 1.332          | 0.051 | 0.800| 1.115 | 0.847 |
| M Form II           | 100| 13.30(4.65)      | 5.99 | 25.88| 0.521          | 0.673          | 0.063 | 0.973| 1.176 | 0.818 |
| Female              | 148| 10.98(4.53)      | 3.61 | 25.56| 0.573          | -0.116         | 0.057 | 1.030| 1.147 | 0.903 |
| Juvenile            | 64 | 6.33(1.10)       | 4.01 | 8.91 | 0.473          | 0.125          | 0.045 | 0.792| 1.136 | 0.670 |
|                    |    | Abdomen Width Mean (SD) (mm) |     |      |                |                |       |       |      |
| M Form I            | 30 | 12.14(3.36)      | 7.10 | 18.08| 0.412          | 0.724          | 0.030 | 0.889| 1.076 | 0.943 |
| M Form II           | 100| 11.03(3.08)      | 5.98 | 19.99| 0.414          | 0.581          | 0.032 | 0.869| 0.972 | 0.928 |
| Female              | 148| 9.53(3.65)       | 2.85 | 21.08| 0.483          | -0.545         | 0.044 | 1.029| 1.119 | 0.949 |
| Juvenile            | 64 | 5.75(1.04)       | 3.16 | 7.69 | 0.481          | -0.553         | 0.041 | 0.968| 1.279 | 0.771 |

All other measurements were regressed against CL (Table 3). Carapace length was the independent variable for all comparisons, when POCL, CW, CD, and ABW were all tested. POCL (Mean±SD) and range measurements for male form I, male form II, female, and juvenile were as follows: POCL =21.96 ± 6.06 mm (range=13.76-34.69), POCL =20.27 ± 6.15 mm (range=8.62-38.88), POCL =16.49 ± 5.92 mm (range=5.52-36.67), and POCL =10.45 ± 1.62 mm (range=6.31-14.03). The linear equations found for POCL vs. CL in order of sexual forms are as follows (form I, form II, female, juvenile): y=0.972x+0.0604, R²=0.9821, F=1540.59; y=1.0185x-0.1178, R²=0.9586, F=2271.14; y=1.0471x-0.4123, R²=0.9405, F=2103.01; y=0.9905x-0.0888, R²=0.9862, F=535.02.

Male form I, form II, female, and juvenile measurements for CW (Mean±SD) and range are as follows: CW =15.05 ± 4.22 mm (range=8.96-22.93), CW =13.03 ± 4.65 mm (range=5.99-25.88), CW =10.98 ± 4.53 mm (range=3.61-25.56), and CW =6.33 ± 1.10 mm (range=4.01-8.91). The linear equations found for POCL vs. CW in order of sexual forms are as follows (form I, form II, female, juvenile): y=0.9574x-0.2051, R²=0.8474, F=155.50; y=1.0747x-0.3884, R²=0.8177, F=439.70; y=1.088x-0.3962, R²=0.9028, F=1347.14; y=0.9643x-0.2784, R²=0.6698, F=125.77.

Male form I, form II, female, and juvenile measurements for CD (Mean±SD) and range were as follows: CD =12.57 ± 3.31 mm (range=8.08-19.02), CD =11.12 ± 3.33 mm (range=5.14-19.60), CD =9.40 ± 3.22 mm (range=3.53-18.65), and CD =5.99 ± 0.89 mm (range=4.01-5.62).

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Abdomen Width (ABW) (Mean±SD) and range measurements for males form I, males form II, females, and juveniles were as follows: ABW_{MI}= 12.14 ± 3.36 mm (range=7.10-18.08), ABW_{MII}=11.03 ± 3.08 mm (range=5.98-19.99), ABW_{female}=9.53 ± 3.65 mm (range=2.85-21.08), and ABW_{juv}=5.75 ± 1.04 mm (range=3.16-7.69). The linear equations found for CL vs. ABW in order of sexual forms were as follows (form I, form II, female, juvenile): y=0.9822x-0.333, R^2=0.9432, F=464.84; y=1.0741x-0.4353, R^2=0.939, F=4030.33; y=1.1233x-0.4977, R^2=0.7709, F=208.59.

Male form I was significantly larger than Male form II for CD and ChL (P<0.05) (Figure 1). Male form I was significantly larger than

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**Figure 1:** Box and whisker plots showing relationships among male form I, male form II, and female *Orconectes rusticus* based on, A. carapace measures, B. chelae measures, and C. abdomen width.
female for CL, POCL, CW, CD, ABW, ChL, and ChW (P<0.05) (Figure 1). Male form II was significantly larger than female for CL, POCL, CW, CD, ABW, ChL, and ChW (P<0.05) (Figure 1).

Range relationships

The crayfish collected from the Rusty Crayfish native range in Indiana (n=51; Ripley and Madison Counties) had significant larger CL, CW, CD, ChW, ChL, and ABW (P<0.05), and was also significantly heavier (P<0.05) compared to the Rusty Crayfish collected from their invasive range (n=291).

Condition factor

The condition factor for adult male and female were above 3.0 as shown in Table 1. This shows that the individual genders are in very good condition. The highest value (3.228) was observed for form I male, while the lowest value (3.005) was observed for form II male individuals. The slopes indicated positive allometric growth in each sexual form since each slope is greater than 3.228, 3.005, 3.104 and 3.102 respectively. The slopes found for male form I, form II, female, and juvenile were 3.228, 3.005, 3.104 and 3.102 respectively. The lowest value (3.005) was observed for form II male individuals. Additionally, O. rusticus, A. pallipes, P. clarkii, P. acutus, and P. fallax were found to have positive allometric growth, while Procambarus alleni and O. limosus had negative allometric growth.

Discussion

Length-weight relationship

Variation in intraspecific growth and length-weight relationship compared to other tertiary burrowers is an important management need for restricting further invasive species spread. Orconectes rusticus

| Species                  | N  | Mean(SD) | Min | Max | Parameter | Condition Factor | Equation              | R²     | Citation                  |
|--------------------------|----|----------|-----|-----|-----------|------------------|-----------------------|--------|--------------------------|
| Astroptomatobius pallipes| 276|          |     |     |           |                  |                       |        | Rhodes and Holdich, [24] |
| Total Male               | 60 | 29       | 58.68| -5.1006| 3.324     | Y=3.3247x+5.1006   | 0.9935                |        | Rhodes and Holdich, [24] |
| Total Female             | 30.7|        | -4.8231| 3.1390| 0.238     | Y=0.238x-3.1390    | 0.9882                |        | Rhodes and Holdich, [24] |
| Male form I              | <29.0|      | -5.783 | 3.6858 | 0.0358    | Y=0.0358x-5.783    | 0.929                |        | Rhodes and Holdich, [24] |
| Male form II             | >30.7|       | -4.8238 | 3.1411 | 0.0352    | Y=0.0352x-4.8283   | 0.994                |        | Rhodes and Holdich, [24] |
| Female (immature)        | 35 |         | -4.8762| 3.1759| 0.0352    | Y=0.0352x-4.8762   | 0.933                |        | Rhodes and Holdich, [24] |
| Male (Form I and II)     | 569|         | 60   | 29  | 46        | 0.031            | Y=0.031x+60         | 0.980  | Duris et al. [22]        |
| Female                   | 678|         | 116.5| 49.2| 49.2      | 0.0358           | Y=0.0358x+116.5     | 0.981  | Duris et al. [22]        |
| Orconectes limosus       | 1,247|     | 21.15| 6.50| 45.93     | 3.93(4.80)       | 0.080                | 0.501  | Original Data             |
| Total                   | 342|          | 30.7| 27.69| 17.04     | 4.09(7.09)       | 1.530                | 0.789  | Original Data             |
| Male form I             | 30 |          | 27.69| 17.04| 14.46     | 4.09(7.09)       | 1.530                | 0.789  | Original Data             |
| Male form II            | 100|         | 25.22| 12.90| 49.73     | 5.43(5.44)       | 0.540                | 0.789  | Original Data             |
| Female                  | 148|         | 20.56| 6.50| 41.81     | 3.30(3.39)       | 0.080                | 0.789  | Original Data             |
| Procambarus acutus Total| 722|          | 71.55| 17    | 130       | 8x10^-4           | 3.3                 | 0.99   | Mazlum et al. [13]        |
| Male form I             | 147|          | 97.33| 72    | 130       | 16.40(16.54)     | 0.07                 | 0.97   | Mazlum et al. [13]        |
| Male form II            | 114|          | 78.55| 60    | 92        | 22.03(16.63)     | 2.91                 | 0.95   | Mazlum et al. [13]        |
| Female                  | 249|          | 88.48| 51    | 125       | 17.80(16.54)     | 30                   | 0.95   | Mazlum et al. [13]        |
| Procambarus alleni Total| 1496|         | 5    | 40   | 0.217     | 2.85              | Y=2.85x+0.217        | 0.919  | Klassen et al. [21]      |
| Males (Form I and II)   | 458|          | 6    | 40   | 0.229     | 2.82              | Y=2.82x+0.229        | 0.873  | Klassen et al. [21]      |
| Female                  | 446|          | 5    | 35   | 0.209     | 2.84              | Y=2.84x+0.209        | 0.929  | Klassen et al. [21]      |
| Procambarus fallax Total| 1,059|        | 97.33| 49    | 72        | 3.06              | Y=3.06x+0.188        | 0.924  | Klassen et al. [21]      |
| Male (Form I and II)    | 337|          | 68.51| 18    | 106       | 18.85(15.75)     | 0.18                 | 0.83   | Wang et al. [25]         |
| Female                  | 341|          | 69.91| 24    | 111       | 17.50(13.48)     | 0.47                 | 0.67   | Wang et al. [25]         |

Table 4: Carapace Length- Weight descriptive statistics of tertiary burrower crayfish species.
is a competitively dominant invasive species that has expanded over much of the Midwestern United States [20,21] and Great Lakes region, expanding into parts of Wisconsin, Michigan, and other northern states [22]. Length-weight and morphometric relationships are important to understand species growth. Invasive crayfish species have been found to be generally larger, while within species females are typically smaller than the males [10]. In northern Wisconsin lakes, two invasive species (O. rusticus and O. propinquus) had larger chelae than the native O. virilis [10]. The box and whisker plots (Figure 1) provide an analysis of sexual forms and differences in growth.

Carapace length (CL)–wet weight (Ww) relationships for all genders (i.e., male, female, juvenile) and all male forms (form I and II) had positive allometric growth. As carapace length increased the net weight increased as well. For the chelae length (Chl)–carapace length (CL) growth relationships, all sexes and sexual forms grew positive allometrically. Based on the data collected, when comparing mean of ChW and CL. Male form I have larger chela length than male form II and females. Chelae width (CW)–carapace length (CL) relationships show the same comparison as Chl when comparing gender and sexual forms. The increased growth and larger length of O. rusticus impacts sexual forms and is a factor in the reproductive dominance of the species. The positive allometric growth in male form I compared to male form II is essential in successful reproduction. Female length, weight, and growth rate (G) is not significantly different from male form II.

Morphological differences can contribute to the displacement of native species [10]. Larger body size and larger chelae allow for better opportunities for predation, competition, and reproduction [10]. The current study shows that O. rusticus male form I are larger than male form II and females, which tend to be more similar in size. Garvey and Stein [10] reported that O. rusticus grew allometrically and this study validates their findings. Other native crayfish populations generally are at a competitive disadvantage, which was a finding emphasized by Garvey and Stein [10] compared to invasive crayfish. Typically, if an invasive species is larger than the native species it will most likely out-compete the native species and displace it [10]. Evaluating sexual dimorphism in crayfish is important because male and female interactions enable species to be influential in establishing populations within stable communities [23,24]. Predator pressure, sexual aggression, and habitat utilization are all size dependent attributes that selection for larger body and chelae size. O. rusticus growth patterns are consistent with the various sexual stages. Figure 1 shows a comparison of all measurements taken in the study for male form I, male form II, and female. The box and whisker chart shows the comparison of measurements within sex and between different sexes and sexual forms. Sexually active male form I will be larger and possess larger chelae than male form II. Male form I will be heavier than male form II because of the larger chelae growth rate.

Male form II and female are similar in size within their native distribution, but have a number of factors that can determine differences. Differences in length–weight may vary between populations and can be influenced by population density, food abundance, water level, temperature, or habitat quality, making it important to consider length–weight relationships within invaded habitats compared to native habitats for a species [25].

Sexual dimorphism is common in freshwater crayfish [26]. Orconectes rusticus shows strong sexual dimorphism patterns compared to other freshwater crayfish and have been seen using their generally larger size to establish populations in occupied invaded areas.

Range relationships

Orconectes rusticus collected in the native range had significantly larger CL, CD, CW, ChL, ABW, and weighed more than the O. rusticus collected from the invaded range in Indiana. Individuals collected in the invaded range may invest fewer resources into CL, Chl, and ABW than the populations in the native range, and instead use those resources on aggression, mobility, and competition.

Condition factor

Orconectes rusticus had positive size and growth rate in both genders. If the slope was greater than 3 than the growth as positive allometric, meaning that weight is gaining faster than length. If the slope is equal to 3 there is isometric growth, where length and weight are growing at the same rate. When the slope is less than 3, there is negative allometric growth and length is gaining faster than weight. O. rusticus, A. pallipes, P. clarkii, P. acutus, and P. fallax have positive allometric growth, while Procambarus alieni and O. limosus had negative allometric growth. Since O. rusticus is smaller and lighter than other tertiary burrowing crayfish (Table 4), the length of neither the carapace nor the weight give it an advantage over the other species. O. rusticus may utilize a combination of behavioral traits to gain a competitive advantage over these other tertiary burrowing crayfish.

Interspecifics rates of growth, length, and weight comparisons among tertiary burrowing crayfish are shown in Table 4. Overall, O. rusticus shows similar growth as other tertiary crayfish. Males are larger than females and form I male is the largest overall. Compared to other crayfish species, O. rusticus as an invader is often successful due to larger size and aggression from possessing larger chelae [10]. The condition was also determined based on the slope value of the crayfish. Overall, O. rusticus had smaller mean CL and had a mean weight less than Orconectes limosus, Procambarus acutus, Procambarus fallax, and Procambarus clarkii.

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