Fisheries and Aquaculture Journal

Anderson and Simon, Fish Aquac J 2015, 6:3
DOI: 10.4172/2150-3508.1000129

Research Article | Open Access

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

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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_{wt}) 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 *Orconectes 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 [1,4], 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_{wt}) 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

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Received April 24, 2015; **Accepted** May 26, 2015; **Published** May 29, 2015

Citation: Anderson WE, Simon TP (2015) 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. Fish Aquac J 6: 129. doi:10.4172/2150-3508.1000129

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 grow 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 chelae 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, $\log(W_{wt})=b*\log(CL)+a$, where a=intercept, b=slope of regression line, W_{wt}=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 (R^2) 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 (W_{wt} ± SD). Mean carapace length (CL ± SD), mean wet weight (W_{wt} ± SD), and their respective ranges were calculated for male form I, male form II, female, and juvenile individuals as follows: CL_{MI}= 27.69 ± 7.85 mm (range=17.04-44.60 mm), CL_{MII}= 25.22 ± 7.54 mm (range=12.90-49.73 mm), CL_{Female}= 20.56 ± 7.13 mm (range=6.50-41.81 mm), and CL_{Juv}= 13.10± 1.91 mm (range= 8.28-15.94 mm), respectively (Table 1). Mean wet weight (W_{wt} ± SD), mean wet weight (W_{wt} ± SD), and their respective ranges were calculated for male form I, male form II, female, and juvenile individuals as follows: $W_{wt\ MI}$= 9.04 ± 7.09 g (range=1.53-27.44 g), $W_{wt\ MII}$= 5.43 ± 5.44 g (range=0.54-30.51 g), $W_{wt\ Female}$= 3.30 ± 3.39 g (range=0.08-17.19 g), and $W_{wt\ Juv}$= 0.63 ± 0.29 g (range= 0.14-1.31 g), respectively (Table 1). The normalized (Log_{10}) length-weight relationship for male form I was explained by the linear equation y= 3.2278x-3.8056, where R^2=0.9594 and F=662.27; male form II was explained by the linear equation y=3.0052x-3.5967, with R^2=0.9626 and F=2521.53; female length-weight was explained by the linear equation y= 3.1045x-3.7102, with R^2=0.9786 and F=6661.86; juveniles were explained by the equation y= 3.1024x-3.7007, with R^2=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): ChL_{MI}=26.80 ± 11.21 mm (range= 11.66-51.42 mm), ChL_{MII}=20.05 ± 8.97 mm (range=7.19-49.56 mm), ChL_{Female}=13.62

		Carapace length(mm)			Weight (g)			Parameters					
Sex and Sexual Form	**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	3.029-3.180	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=R^2 , A+ = positive allometric growth, a = slope, and b = intercept.

		Chelae Length (mm)			Chelae Width (mm)							
Sex and Sexual Form	**N**	**Mean (SD)**	**Min**	**Max**	**Mean (SD)**	**Min**	**Max**	**a**	**b**	**SE(b)**	**CL(b)**	**R^2**
M Form I	30	26.80 (11.21)	11.66	51.42	10.73 (3.92)	5.33	17.66	-0.212	0.873	0.035	0.803-0.943	0.959
M Form II	100	20.05 (8.97)	7.19	49.56	8.00 (3.34)	2.61	20.20	-0.289	0.917	0.037	0.874-0.960	0.954
Female	148	13.62 (5.69)	4.55	30.14	5.99 (2.61)	1.75	12.66	-0.412	1.047	0.049	1.002-1.092	0.941
Juvenile	64	8.48(1.53)	4.98	11.62	3.60(0.74)	1.79	5.62	-0.231	0.844	0.061	0.648-1.041	0.560

Table 2: Mean and standard deviations (SD) for chelae length (ChL) vs chelae width (ChW): 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=R^2.

Sex and Sexual Form	N	POCL Mean (SD)(mm)	Min	Max	POCL vs CL (a)	POCL vs CL (b)	SE(b)	CL (b)	R^2
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	0.0312	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)			**CW vs CL (a)**	**CW vs CL (b)**			
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
		Carapace Depth Mean (SD)(mm)			**CD vs CL (a)**	**CD vs CL (b)**			
M Form I	30	12.57(3.31)	8.08	19.02	0.415	1.069	0.019	0.871-0-0.992	0.972
M Form II	100	11.12(3.33)	5.14	19.60	0.430	0.175	0.030	0.934-1.031	0.942
Female	148	9.40(3.22)	3.53	18.65	0.431	0.443	0.029	0.930-0.989	0.965
Juvenile	64	5.99(0.89)	3.66	7.97	0.416	0.544	0.029	0.797-1.021	0.809
		Abdomen Width Mean (SD) (mm)			**ABW vs CL (a)**	**ABW vs CL (b)**			
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

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=R^2.

± 5.69 mm (range= 4.55-30.14 mm), and ChL_{Juv}=8.48 ± 1.53 mm (range=4.98-11.62 mm). The chelae-width (ChW ±SD) and range were also calculated for male form I, male form II, female and juveniles as follows, ChW_{MI}=10.73 ± 3.92 mm (range=5.33-17.66), ChW_{MII}=8.00 ± 3.34 mm (range=2.61-20.20 mm), ChW_{Female}=5.99 ± 2.61 mm (range=1.75-12.66), and ChW_{Juv}=3.60 ± 0.74 mm(range=1.79-5.62). The linear equations found for the relationship between ChL vs. ChW for each sexual form (form I, form II, female, juvenile) were as follows: y=0.8726x-0.2119, R^2=0.962, F=657.75; y=0.917x-0.2893, R^2=0.9537, F=1790.12; y=1.0471x-0.4123, R^2=0.9405, F=2103.01; y=0.8445x-0.2308, R^2=0.56, F=73.81. Chelae length was found to be larger in male form I when compared to the means of male form II and females. Likewise, in chelae-width male form I had wider chelae when comparing mean values. The male form II and female chelae did not differ in size based on a comparison of the means. No statistical difference was found when comparing the significant levels of all sexual stages for ChW (P<0.05).

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: $POCL_{MI}$=21.96 ± 6.06 mm (range=13.76-34.69), $POCL_{MII}$=20.27 ± 6.15 mm (range=8.62-38.88), $POCL_{Female}$=16.49 ± 5.92 mm (range=5.52-36.67), and $POCL_{Juv}$=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=0.9722x-0.0604, R^2=0.9821, F=1540.59; y=1.0158x-0.1178, R^2=0.9586, F=2271.14; y=1.0471x-0.4123, R^2=0.9405, F=2103.01; y=0.9905x-0.088, R^2=0.8962, F=535.02.

Male form I, form II, female, and juvenile measurements for CW (Mean±SD) and range are as follows: CW_{MI}= 15.05 ± 4.22 mm (range=8.96-22.93), CW_{MII}=13.03 ± 4.65 mm (range=5.99-25.88), CW_{Female}=10.98 ± 4.53 mm (range=3.61-25.56), and CW_{Juv}=6.33± 1.10 mm (range=4.01-8.91). The linear equations found for CL vs. CW in order of sexual forms are as follows (form I, form II, female, and juvenile): y=0.9574x-0.2051, R^2=0.8474, F=155.50; y=1.0747x-0.3884, R^2=0.8177, F=439.70; y=1.088x-0.3962, R^2=0.9028, F=1347.14; y=0.9643x-0.2784, R^2=0.6698, F=125.77.

Male form I, form II, female, and juvenile measurements for CD (Mean±SD) and range were as follows: CD_{MI}= 12.57 ± 3.31 mm (range=8.08-19.02), CD_{MII}=11.12 ± 3.33 mm (range=5.14-19.60), CD_{Female}=9.40 ± 3.22 mm (range=3.53-18.65), and CD_{Juv}=5.99 ± 0.89

mm (range=3.66-7.97). The linear equations found for CL vs. CD in order of sexual forms were as follows (form I, form II, female, juvenile): y=0.9312x-0.2428, R^2=0.9725, F=988.99; y=0.9824x-0.3317, R^2=0.9425, F=1605.66; y=0.9595x-0.2881, R^2=0.9653, F=4030.33; y=0.909x-0.2383, R^2=0.8091, F=262.76.

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=0.9202x-0.2467, R^2=0.9278, F=1258.75; 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

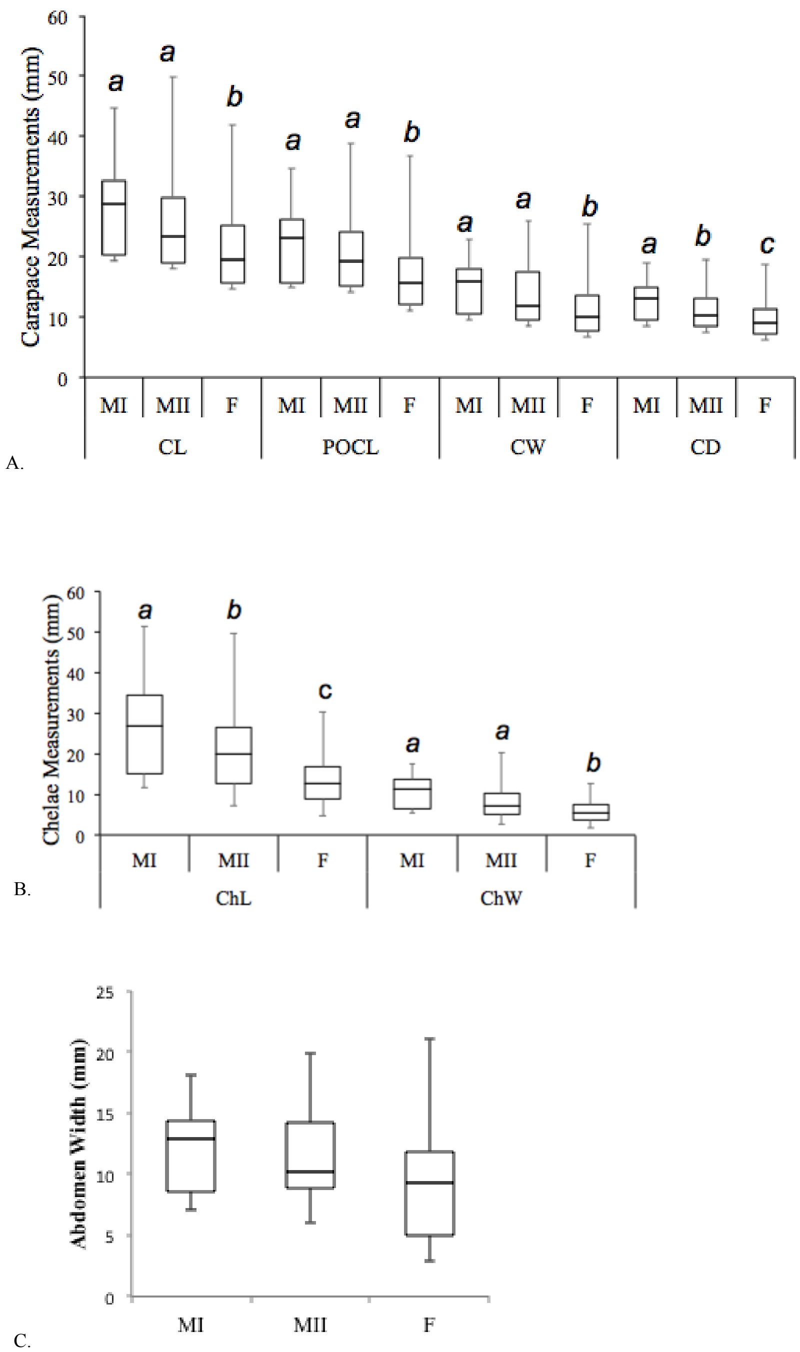

Figure 1: Box and whisker plots showing relationships among male form I, male form II, and female *Orconectes rusticus* based on, *A. carapace* measures, *B. chelae* measures, and C. abdomen width.

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 found for male form I, form II, female, and juvenile were 3.228, 3.005, 3.104 and 3.102 respectively. The slopes indicated positive allometric growth in each sexual form since each slope is greater than 3.0. In general, male crayfish from both forms were found to be larger compared to female crayfish. CL increased allometrically with weight for the entire population (Table 1). The Log_{10} transformed ANOVA test for CL vs. W_{wt} showed significance of the slopes and intercepts at the P<0.05 level. The study showed that mean values for male form I were larger than form II males overall, despite the largest crayfish measured being a form II male. The male form II and female individuals had more similar results than either of those groups compared to the male form I and juveniles, but length-weigh relationship generally decreased from male form I, male form II, female, and lastly juvenile. All carapace length-net weight regressions were significant at the P<0.0001 level.

Orconectes rusticus had smaller CL and weighed less than other, published information for tertiary burrowers (Table 4), including *Austropotamobius pallipes, Orconectes limosus, Procambarus acutus, Procambarus alleni, Procambarus fallax,* and *Procambarus clarkii.* 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*

		Carapace Length (mm)			Weight (g)			Parameter	Condition Factor	Equation		
Species	**N**	**Mean(SD)**	**Min**	**Max**	**Mean (SD)**	**Min**	**Max**	***a***	**b**		**R^2**	**Citation**
Austropotamobius pallipes	276											Rhodes and Holdich, [24]
Total Male		60	29				58.68	-5.1006	3.324	Y=3.3247x-5.1066	0.9935	Rhodes and Holdich, [24]
Total Female			30.7					-4.8231	3.1390	Y=3.1390x-4.8231	0.998	Rhodes and Holdich, [24]
Male form I			<29.0					-5.783	3.6858	Y=3.6858x -5.7834	0.929	Rhodes and Holdich, [24]
Male form II			>30.7					-4.8283	3.141	Y=3.1411x-4.8283	0.994	Rhodes and Holdich, [24]
Female (immature)					35			-4.8762	3.1759	Y=3.1759x-4.8762	0.933	Rhodes and Holdich, [24]
Orconectes limosus	1,247											Duris et al. [22]
Male (Form I and II)	569			107			46	0.031	0.0913	Y=0.0913x-0.031	0.980	Duris et al. [22]
Female	678			116.5			49.2	0.0358	0.0898	Y=0.0898x-0.0358	0.981	Duris et al. [22]
Orconectes rusticus Total	342	21.15(8.078)	6.50	49.73	3.93(4.80)	0.080	30.51	-3.6979	3.0961	Y=3.0961x - 3.6979	0.976	Original Data
Male form I	30	27.69 (7.85)	17.04	44.60	9.04 (7.09)	1.530	27.44	-3.806	3.228	Y=3.2278x -3.8055	0.959	Original Data
Male form II	100	25.22 (7.54)	12.90	49.73	5.43 (5.44)	0.540	30.51	-3.597	3.005	Y=3.0052x-3.5967	0.962	Original Data
Female	148	20.56 (7.13)	6.50	41.81	3.30 (3.39)	0.080	17.19	-3.710	3.104	Y= 3.1044x-3.7102	0.963	Original Data
Procambarus acutus Total	722	71.55(29.50)	17	130				$6x10^{-8}$	3.3	$Y=3.3x+6x10^{-8}$	0.99	Mazlum et al. [13]
Male form I	147	97.33(13.94)	72	130	16.40(16.54)	0.07	76.82	$6x10^{-3}$	3.61	$Y=3.61x+6x10^{-3}$	0.97	Mazlum et al. [13]
Male form II	114	78.55 (7.26)	60	92	22.03(16.63)	2.91	76.82	$6x10^{-9}$	3.26	$Y=3.26x+6x10^{-9}$	0.95	Mazlum et al. [13]
Female	249	88.48(22.70)	51	125	17.80(16.54)	30	61.17	$6x10^{-4}$	3.5	$Y=3.5x+6x10^{-4}$	0.98	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								0.192	3.03	Y=3.03x+0.192	0.945	Klassen et al. [21]
Male (Form I and II)		97.33(13.95)	49	72				0.188	3.06	Y=3.06x+0.188	0.924	Klassen et al. [21]
Female								0.193	3.07	Y=3.07x+0.193	0.971	Klassen et al. [21]
Procambarus clarkii Total	678		18	111		0.18	83.43	-1.7695	3.467	Y=3.467x-1.7695		Wang et al. [25]
Male (Form I and II)	337	68.5(1.70)	18	106	18.85(15.75)	0.18	83.43	-1.853	3.63	Y=3.63x-1.853		Wang et al. [25]
Female	341	69.9(1.84)	24	111	17.50(13.48)	0.42	67.38	-1.699	3.350	Y=3.35x-1.699		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 (W_{wt}) 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 ChL Male form I have larger chelae 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 (CL) 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 f**orm** 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, ChW, 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 alleni* 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.

Interspecific 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*.

Acknowledgments

Special thanks to professional staff associated with the Indiana Biological Survey, Aquatic Research Center, Bloomington, for field collection assistance and for professional training and other courtesies. Sarah Strobl edited a previous draft of this manuscript. Funding for this study was provided through a donation from Charles R. Sporleder through Indiana University in support of the Simon Laboratory.

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Citation: Anderson WE, Simon TP (2015) 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. Fish Aquac J 6: 129. doi:10.4172/2150-3508.1000129