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Technical contribution

Length–weight and length–length relationships for common fish and crayfish species in the Everglades, Florida, USA

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Summary

Length–weight and length–length relationships are reported for 18 species of fish and two species of crayfish within the Everglades, FL, USA. This study provides updated relationships for native species, as well as initial relationships for established exotic species in this region. Additionally, 14 length–weight and two length–length relationships are presented to FishBase for the first time.

Introduction

The Everglades is a vast wetland system of natural marshes and deep water canals covering approximately 7,000 km^2 in south Florida, USA (25°14′–26°22′N; 80°27′–81°15′W). This ecosystem is the focus of a large restoration effort that will alter hydrologic patterns and reduce nutrient pollution. Characteristics of aquatic fauna are indicators for this restoration effort (Trexler and Goss, 2009) and they are the foodbase for predatory wading birds, another prominent group of indicator species (Frederick et al., 2009). Thus, detailed information on characteristics of fish and crayfish (*Procambarus* spp.), such as size, density, and biomass are central to the restoration and management of the Everglades, as they are to other wetland ecosystems (Cvetkovic and Chow-Fraser, 2011; Horváth et al., 2012).

Length–weight relationships (LWR) are useful for determining biomass when only length is known (Froese, 2006). Length–length relationships (LLR) are useful for converting between several measures of body length, such as standard length (SL) to total length (TL). This study provides updated length–weight and length–length relationships for 18 fish and two crayfish species common within the Everglades system. Additionally, weight–length relationships for 14 species and length–length relationships for two species are presented to FishBase (Froese and Pauly, 2012) for the first time.

Materials and methods

Fish and crayfish were sampled with 1-m x 1-m throw-traps (Kushlan, 1981) during the dry season (approximately January – May) from 2005-2012. Sampling sites were arranged across the Everglades landscape. Fish and crayfish samples were taken to the laboratory for processing. SL, TL, and wet weight were measured to the nearest millimeter and 0.01 gram, respectively. Sex and age class were noted when possible for certain species, but this only applied to 35% of the specimens. For crayfish species, carapace length was used as a substitute for standard length. TL and SL relationships were delineated for the equation TL = a + b*SL. For LWR delineation, we used the log-transformed equation: $\log_{10}(W) = \log_{10}(a) + b*\log_{10}(L)$ where W is wet body weight (g), L is standard length (cm), a the intercept, and b the allometric coefficient. The PROC REG procedure in SAS 9.3 (SAS Institute, 2012) was used to estimate parameters a and b, 95% confidence limits (CL) for each parameter, and the coefficient of determination, r^2. SAS (PROC REG) was also used to identify outliers via standardized residuals. To improve r^2 values and eliminate the influence of outliers, we removed standardized residuals <–2 or >2. However, this method only statistically changed the parameter estimates for crayfish species. Therefore, we report crayfish LWR and LLR with standardized residuals removed, but only removed points for fish LWR and LLR in four cases where we suspected a measurement or recording error.

Results and discussion

Length–weight relationships applied to 46 506 fish specimens belonging to seven families and 2293 crayfish specimens are reported in Table 1. Length–length relationships applied to 33 542 fish specimens and 1467 crayfish specimens are reported in Table 2. All LWRs were statistically significant ($P < 0.001$), and most with r^2 values >0.90. Exceptions include all sex classes in *Heterandria formosa* and *Gambusia holbrooki*, female and male sex classes in *Jordanella floridae* and *Lucania goodei*, and male sex class in *Procambarus alleni* and *Poecilia latipinna*. The LLRs were also statistically significant ($P < 0.001$) with r^2 values >0.954.

Species with lower r^2 values had large variation in weight for similar standard lengths. This variation could be attributed to smaller sample sizes or measurement error within narrower length ranges for a specific species or sex class, particularly male *H. formosa* (r^2 = 0.376). *H. formosa* are naturally smaller sized fishes (average SL = 1.3 cm) with a SL range of only 2.2 cm within our dataset. We explored the

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Table 1
Descriptive statistics and parameter estimates of length-weight relationships ($W = aL^b$) for crayfish and fish species in the Everglades, Florida, USA, 2005-2012

Family/Species	Sex	n	SL Range (cm) Min	Max	Parameter estimates a	b	r^2	a $CL_{95\%}$	b $CL_{95\%}$
Crayfish Species									
Cambaridae									
Procambarus alleni[a]	Females	446	0.5	3.5	0.209	2.84	0.929	0.199–0.220	2.77–2.92
	Males	458	0.6	4.0	0.229	2.82	0.873	0.215–0.244	2.72–2.92
	All individuals	1496	0.5	4.0	0.217	2.85	0.919	0.211–0.223	2.80–2.89
Procambarus fallax[a]	Females	241	0.8	3.2	0.193	3.07	0.971	0.184–0.202	3.00–3.14
	Males	262	0.9	3.3	0.188	3.06	0.924	0.177–0.201	2.95–3.16
	All individuals	797	0.5	3.3	0.192	3.03	0.945	0.187–0.198	2.98–3.08
Fish Species									
Centrachidae									
Enneacanthus gloriosus[b,c]	All individuals	64	1.2	5.8	0.0299	2.99	0.975	0.0266–0.0336	2.87–3.12
Lepomis macrochirus[c]	All individuals	26	1.6	4.4	0.0300	2.94	0.943	0.0229–0.0393	2.63–3.24
Lepomis marginatus[b,c]	All individuals	93	1.0	5.7	0.0250	3.12	0.976	0.0223–0.0279	3.02–3.22
Lepomis microlophus[c]	All individuals	69	1.1	6.0	0.0301	3.03	0.981	0.0268–0.0337	2.93–3.13
Lepomis punctatus[b,c]	All individuals	205	1.1	9.0	0.0252	3.13	0.976	0.0235–0.0270	3.07–3.20
Chichlidea									
Hemichromis letourneuxi[b,d]	All individuals	54	1.2	5.8	0.0371	2.91	0.986	0.0330–0.0418	2.82–3.01
Cyprinodontidae									
Cyprinodon variegatus[b]	All individuals	346	0.9	3.5	0.0233	3.35	0.946	0.0223–0.0243	3.26–3.43
Jordanella floridae[b]	Females	297	1.6	3.4	0.0340	3.06	0.838	0.0299–0.0386	2.90–3.21
	Males	104	1.7	4.5	0.0345	3.01	0.861	0.0276–0.0433	2.77–3.25
	All individuals	5068	0.7	4.5	0.0330	2.98	0.912	0.0324–0.0336	2.96–3.01
Elassomatidae									
Elassoma evergladei[b]	All individuals	1402	0.7	3.1	0.0253	3.15	0.911	0.0247–0.0259	3.10–3.20
Fundulidae									
Fundulus chrysotus[b]	All individuals	1536	0.7	6.5	0.0207	2.94	0.963	0.0202–0.0213	2.91–2.97
Fundulus confluentus[b]	All individuals	1421	0.8	6.8	0.0190	3.02	0.975	0.0185–0.0195	2.99–3.04
Lucania goodei[b]	Females	546	1.0	3.3	0.0196	2.85	0.878	0.0183–0.0211	2.76–2.94
	Males	265	1.1	3.0	0.0237	2.64	0.837	0.0210–0.0267	2.50–2.79
	All individuals	5775	0.4	4.2	0.0183	2.86	0.911	0.0181–0.0186	2.84–2.89
Ictaluridae									
Ameiurus natalis[c]	All individuals	32	3.5	8.7	0.0207	3.00	0.936	0.0126–0.0340	2.70–3.29
Noturus gyrinus[b]	All individuals	63	1.8	6.2	0.0240	2.87	0.910	0.0180–0.0320	2.64–3.10
Poeciliidae									
Belonesox belizanus[b,d,c]	All individuals	17	1.9	6.8	0.00718	3.20	0.985	0.00513–0.0100	2.98–3.42
Gambusia holbrooki	Females	6799	0.7	3.9	0.0195	3.02	0.806	0.0192–0.0198	2.97–3.07
	Males	1181	0.9	3.1	0.0145	3.22	0.809	0.0136–0.0154	3.13–3.31
	All individuals	18951	0.7	4.7	0.0172	3.02	0.894	0.0170–0.0173	3.01–3.03
Heterandria formosa[b]	Females	3705	0.6	2.6	0.0195	3.02	0.806	0.0192–0.0198	2.97–3.07
	Males	1041	0.8	2.7	0.0210	2.18	0.376	0.0202–0.0218	2.00–2.35
	All individuals	9713	0.5	2.7	0.0195	2.80	0.770	0.0193–0.0197	2.77–2.83
Poecilia latipinna[b]	Females	605	1.1	4.3	0.0260	2.88	0.900	0.0245–0.0277	2.81–2.96
	Males	193	1.6	4.5	0.0256	2.83	0.897	0.0227–0.0286	2.70–2.97
	All individuals	1671	0.6	5.4	0.0267	2.88	0.930	0.0259–0.0275	2.86–2.92

n, sample size; SL, standard length; a, intercept; b, slope; r^2, coefficient of determination; CL, 95% confidence limits.
[a]Carapace length given in place of standard length.
[b]No LWR reference in FishBase.
[d]Non-native species.
[c]Mostly early juveniles.

effect of measurement error within narrow length ranges on the coefficient of determination by generating LWR equations for similar fish species (*G. holbrooki, L. goodei, Fundulus confluentus*, and *Fundulus chrysotus*) restricted to the same standard length size and range as *H. formosa*. In all cases the coefficient of determination decreased by 15–20%, suggesting that narrow length ranges account for 15–20% of the variability in r^2 values. Further reductions in the coefficient of determination, or increased weight variability across similar length ranges, could be due to variation in resource availability across our sampling landscape or to a differential ability of a sex class or species to compete for resources. Slightly lower r^2 values for crayfish species could be due to the stepwise growth pattern between molts.

Most LWR equations in this study were similar to those in Kushlan et al. (1986). Predicted weight of an average length of fish differed between studies by <0.05 g (<10% body weight) for each species. However, the predicted weight for an average

Table 2
Parameter estimates of length-length relationships (TL = a + b × SL) for crayfish and fish species in the Everglades, Florida, USA, 2005–2012

Family/Species	n	Parameter estimates a	b	r^2	b $CL_{95\%}$
Crayfish Species					
Cambaridae					
Procambarus alleni[a]	765	0.175	2.04	0.973	2.01–2.06
Procambarus fallax[a]	702	0.0660	2.08	0.977	2.06–2.10
Fish Species					
Centrachidae					
Enneacanthus gloriosus[b]	60	−0.0498	1.26	0.987	1.22–1.29
Lepomis macrochirus[b]	24	−0.0132	1.20	0.983	1.14–1.27
Lepomis marginatus[b]	93	0.154	1.19	0.987	1.16–1.21
Lepomis microlophus[b]	67	0.0289	1.22	0.994	1.19–1.24
Lepomis punctatus[b]	203	0.0457	1.21	0.984	1.19–1.23
Chichlidea					
Hemichromis letourneuxi[c,d]	52	0.111	1.20	0.994	1.17–1.22
Cyprinodontidae					
Cyprinodon variegatus	341	−0.0341	1.20	0.984	1.19–1.22
Jordanella floridae	3876	0.146	1.14	0.958	1.13–1.15
Elassomatidae					
Elassoma evergladei	852	0.0606	1.19	0.974	1.17–1.20
Fundulidae					
Fundulus chrysotus	928	0.101	1.16	0.988	1.15–1.17
Fundulus confluentus[c]	979	0.153	1.13	0.989	1.12–1.14
Lucania goodei	3600	0.0986	1.13	0.980	1.13–1.14
Ictaluridae					
Ameiurus natalis[b]	32	−0.156	1.23	0.988	1.18–1.28
Noturus gyrinus	62	0.219	1.14	0.975	1.10–1.19
Poeciliidae					
Belonesox belizanus[d,a]	17	0.0573	1.15	0.995	1.10–1.20
Gambusia holbrooki	14434	0.0599	1.19	0.968	1.19–1.19
Heterandria formosa	6674	0.0234	1.19	0.954	1.18–1.20
Poecilia latipinna	1248	0.0636	1.17	0.981	1.16–1.18

n, sample size; a, intercept; b, slope; r^2, coefficient of determination; CL, 95% confidence limits.
[a]Carapace length given in place of standard length.
[b]Mostly early juveniles.
[c]No LLR reference in FishBase.
[d]Non-native species.

length *P. alleni* was statistically larger (2.42 ± 1.01 g) in Kushlan et al. (1986) than in our study (0.98 ± 0.03 g). This is surprising given that the carapace length mean and range was similar in both studies. This difference could be attributed to the small sample sizes, in that Kushlan et al. (1986) had only 107 *P. alleni* specimens, whereas our study used 1496 specimens to develop the equation. It is also possible that the large changes in hydrologic patterns and nutrient inputs to the Everglades ecosystem since the 1970s have made the ecosystem less suitable for the growth of *P. alleni*.

Our results provide the initial LLRs and LWRs for two established exotic fish species, as well as initial LLRs and updated LWRs based on larger samples for common Everglades species. Differences between previously published LWRs support the use of large sample sizes to delineate relationships. Additionally, we present two LLRs and 14 LWRs to FishBase (Froese and Pauly, 2012) for the first time.

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