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Length–weight relation for seven Neotropical freshwater fish species (Actinopterygii) endemic to Central America

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Abstract

In the presently reported study, we estimated length–weight relation (LWRs) for seven species of freshwater fishes from Central America. Samples were collected using seines from 60 sites across Nicaragua, Costa Rica, and Panama during field expeditions conducted between 1997 and 2012. The fishes were preserved and transported to the lab, where their total weight (W) was measured (to nearest 0.0001 g) and standard lengths were taken (to nearest 0.01 mm). Data were collected from four livebearers (Poeciliidae), *Alfaro cultratus* (Regan, 1908), *Phallichthys amates* (Miller, 1907), *Poecilia gillii* (Kner, 1863), and *Priapichthys annectens* (Regan, 1907); the cichlids (Cichlidae), *Parachromis dovii* (Günther, 1864) and *Parachromis managuensis* (Günther, 1867); and a silverside (Atherinopsidae), *Atherinella hubbsi* (Bussing, 1979). Estimates of parameter b ranged from 2.936 (*A. hubbsi*) to 3.696 (*P. gillii*), while estimates of parameter a ranged from 1.7×10^{-6} (*P. gillii*) to 1.9×10^{-5} (*P. managuensis*). Parameter b estimates were greater than three, consistent with allometric growth, with the exception of *P. annectens*, *P. managuensis*, and *A. hubbsi*, for which t-tests failed to reject the null hypothesis of isometric growth. Our results provide the first LWR information for five (71%) of these species and may prove useful for data imputation or estimating the biomass of poeciliid, cichlid, and atheriniform fishes in Central American rivers in the future.

Keywords

Costa Rica, ecology, freshwater fishes, LWRs, Nicaragua, Panama

Introduction

Characterizing length–weight relation (LWRs) is an essential and routine task in fisheries science (Froese 2006). The resulting data and parameters are useful for predicting weight (W) from the length (L) of individuals (Clark 1928), determining and comparing the 'condition' or 'robustness' of individuals and populations (Le Cren 1951), and comparing relative weights of populations, species, or treatment groups (Froese 2006). Moreover, LWRs aid in estimating ecosystem parameters, e.g., calculating species biomass from the length-frequency of a given sample. Recently, LWRs have also been applied for estimating fish length at first maturity (e.g., Hashiguti et al. 2019) and for building aquatic and marine ecosystem food-web models (e.g., Ecopath with Ecosim; Heymans et al. 2016). Once determined, LWRs also permit determining missing weight or length values from regression predictions (i.e., imputation); this is important, given that length can frequently be more readily and accurately measured than weight in field or laboratory studies of fishes.

With ~525 species, the freshwater fish assemblage of Central America (CA) is highly diverse relative to its drainage area and displays marked uniqueness, with 10 fish biogeographic provinces and up to 59.2% within-region endemicity (Albert et al. 2011; Matamoros et al. 2014). While the CA ichthyofauna has been increasingly well characterized over the past 60 years (e.g., Myers 1966; Bussing 1976, 1998; Bermingham and Martin 1998; Bagley and Johnson 2014a, 2014b; Matamoros et al. 2014), basic ecological data on the fauna remains broadly lacking, and LWRs provide an illuminating case in point. To date, of 353 CA freshwater fishes that are represented on FishBase (www.fishbase.org), only 76 (21.5%) are listed as containing LWR records (Froese and Pauly 2022).

In the presently reported study, we describe LWRs for seven Neotropical fish species that are endemic to freshwater rivers and streams of CA. The majority of our focal species are non-game, 'secondary' fishes from families identified as having the capacity to disperse through marine environments (Myers 1966); of these families—Poeciliidae, Cichlidae, and Atherinopsidae, the former two make up the majority of species in the region. Data were collected from four livebearers (Poeciliidae), *Alfaro cultratus* (Regan, 1908), *Phallichthys amates* (Miller, 1907), *Poecilia gillii* (Kner, 1863), and *Priapichthys annectens* (Regan, 1907); the cichlids (Cichlidae), *Parachromis dovii* (Günther, 1864) and *Parachromis managuensis* (Günther, 1867); and a silverside (Atherinopsidae), *Atherinella hubbsi* (Bussing, 1979). Despite being important constituents of local CA freshwater fish communities (e.g., Bussing 1976, 1998), material for these species is globally rare. Species were selected due to their overlapping geographical distributions, and based on the zero to limited reference LWRs available for them in FishBase. Our study provides the first LWR data and modeling results for 5/7 (71%) of the focal species.

Materials and methods

The study area spans the CA Isthmus, from the Motagua Fault Zone in Guatemala, southeast to the Darién Isthmus, Panama (~523 000 km^2; Fig. 1). We surveyed the CA ichthyofauna at 60 sites in Nicaragua, Costa Rica, and Panama during field expeditions conducted between 1997 and 2012. Fish specimens were sampled using 2 m × 1.7 m and 3.3 m × 1.7 m seines with 0.48–1.27 cm mesh size netting. Following field identification, specimens were preserved in 95% ethanol and then transported to the laboratory. Specimens were measured to the nearest 0.01 mm standard length (SL) using digital calipers

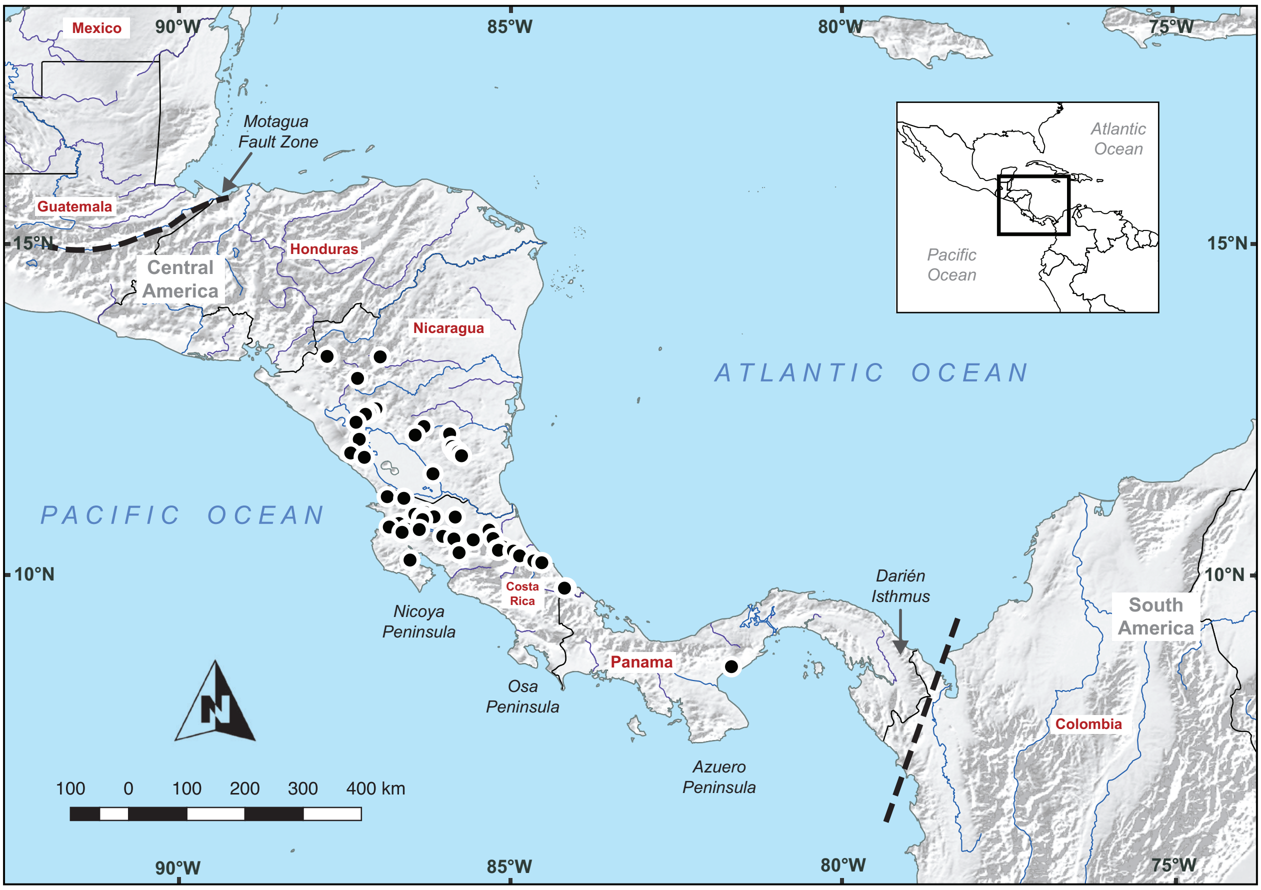

Figure 1. Map of the study area. The boundaries of Central America (Motagua Fault Zone to the north, Darién Isthmus at Panama's connection with South America) and some major physiographic elements are shown. Geographical sampling localities (n = 60) for this study are shown (black circles with white outlines; see accompanying Mendeley Data accession for additional details).

and weighed to the nearest 0.0001 g on a Mettler-Toledo ME104TE/00 analytical balance. Data were collected from seven species listed in Table 1, including four livebearing fishes (Poeciliidae), two cichlid fishes (Cichlidae) that typically are predators of the poeciliids, and one silverside (Atherinopsidae) species (Bussing 1998). Taxonomy, common names, geographical distributions, and prior LWR data for these species are summarized in Table 1.

The standard modern equation of weight (W; body mass) in relation to length (L) takes the form

$$W = aL^b$$

where the scalar a and exponent b are constants. Beginning with Clark (1928), it was recognized that natural log-transformation of both sides resulted in a linearized form of the LWR model as

$$\log(W) = \log(a) + b \log(L)$$

(reviewed by Le Cren 1951; Froese 2006). We determined LWRs for each species (while pooling data across sexes and years) using the linearized equation above and custom scripts run in R v3.6.3 (R Core Team 2020), which drew partly on functions in the *FSA* and *FSAmisc* R packages (Ogle 2022; Ogle et al. 2022). Outliers were determined by visual inspection of graphical plots in R and excluded prior to final analyses (cf. Froese 2006). We tested the null hypothesis (H_0) that $b = 3$, indicating 'isometric' growth, against the alternative hypothesis (H_A) of allometric growth ($b \neq 3$), using t-tests implemented in the 'hoCoef' function of *FSAmisc* (Ogle 2022). We also calculated 95% confidence intervals for the slope (b) and intercept [log(a)] of linear models using the 'confint' function available in the *FSAmisc* package (Ogle 2022).

Raw length–weight data and collections data are archived in a Mendeley Data accession (archived version: https://doi.org/10.17632/kphrvvgwwz.1).

Results

The inferred length–weight relation are presented in Table 2, which lists family names, species names, sample sizes (n), size ranges (SL measurements in mm), length–weight parameter a and b estimates and their 95% confidence intervals (CIs), and the adjusted-R^2 values for each species LWR linear model. All LWR regressions were significant ($P < 0.001$), with R^2 values greater than or equal to 0.93. Estimates of parameter b ranged from 2.936 in *Atherinella hubbsi* to 3.696 in *Poecilia gillii*, while estimates of parameter a ranged from 1.7×10^{-6} in *P. gillii* to 1.9

Table 1. List of focal species examined in the presently reported study, with summaries of their taxonomic information, geographical distributions (Bussing 1976, 1998; Matamoros et al. 2014), and current state of knowledge of their length–weight relation (LWRs).

Family	Species name	Common name(s)	Geographical distribution	Current LWR *n*
Poeciliidae	*Alfaro cultratus* (Regan, 1908)	Knife-edged livebearer	N, CR, P	0
Poeciliidae	*Phallichthys amates* (Miller, 1907)	Merry widow livebearer	G, H, N, CR, P	0
Poeciliidae	*Poecilia gillii* (Kner, 1863)	Molly	G, H, N, CR, P	0
Poeciliidae	*Priapichthys annectens* (Regan, 1907)	Olomina	CR	0
Cichlidae	*Parachromis dovii* (Günther, 1864)	Guapote, wolf cichlid	H, N, CR	1
Cichlidae	*Parachromis managuensis* (Günther, 1867)	Jaguar cichlid	H, N, CR	2
Atherinopsidae	*Atherinella hubbsi* (Bussing, 1979)	Silverside	N, CR	0

CR = Costa Rica, G = Guatemala, H = Honduras, N = Nicaragua, P = Panama; n = sample size; Current LWR n indicates the number of LWR records available for the species on FishBase (Froese and Pauly 2022) before this study.

Table 2. Summary of length–weight relation for seven freshwater stream fishes from Central America.

Family	Species	n	n_R	Standard length [mm]	Weight [g]	a [95% CIs]	b [95% CIs]	R^2
Poeciliidae	*Alfaro cultratus*	102	92	22.24–66.33	0.1005–4.3930	2.3×10^{-6} [1.5×10^{-6}, 3.7×10^{-6}]	3.446 [3.321, 3.570]	0.971
Poeciliidae	*Phallichthys amates*	44	42	15.96–42.27	0.0604–2.3576	5.3×10^{-6} [2.4×10^{-6}, 1.2×10^{-5}]	3.439 [3.199, 3.680]	0.953
Poeciliidae	*Poecilia gillii*	49	48	19.33–53.91	0.0829–3.510	1.7×10^{-6} [8.5×10^{-7}, 3.6×10^{-6}]	3.696 [3.490, 3.902]	0.965
Poeciliidae	*Priapichthys annectens*	69	63	17.09–51.94	0.0780–2.5573	1.5×10^{-5} [8.9×10^{-6}, 2.6×10^{-5}]	*3.0901* [*2.926*, *3.254*]	0.958
Cichlidae	***Parachromis dovii***	**22**	—	**12.87–96.80**	**0.0390–23.691**	**1.4×10^{-5} [9.9×10^{-6}, 2.1×10^{-5}]**	**3.1588 [3.057, 3.260]**	**0.995**
Cichlidae	***Parachromis managuensis***	**7**	—	**32.37–55.51**	**0.9260–4.8221**	**1.9×10^{-5} [6.1×10^{-6}, 5.7×10^{-5}]**	***3.1051* [*2.811*, *3.399*]**	**0.992**
Atherinopsidae	*Atherinella hubbsi*	14	—	32.82–57.43	0.2509–1.3047	9.7×10^{-6} [1.5×10^{-6}, 6.2×10^{-5}]	*2.9359* [*2.458*, *3.414*]	0.932

CIs = confidence intervals; n = sample size; n_R = size of reduced dataset after outlier removal, if deemed necessary, R^2, adjusted-R^2 from linear regression. Species in **boldface** font are also represented in FishBase (Froese and Pauly 2022). Estimated values of $b < 3$, or whose 95% CIs overlapped $b = 3$, are set in *italic* font.

× 10^{-5} in *Parachromis managuensis*. Parameter *b* estimates were generally greater than three, consistent with allometric growth, and *t*-tests were statistically significant for the majority of species ($P < 0.05$). However, for *P. annectens*, *P. managuensis*, and *A. hubbsi*, *t*-tests failed to reject the null hypothesis of isometric growth ($P > 0.05$).

Discussion

The LWRs presented herein had exponent values within the expected range of $b = 2.5–3.5$ for fishes (Froese 2006). The majority of species had *b* estimates slightly greater than three indicating positive allometric growth, with fish growing plumper with increasing size (Blackwell et al. 2000). By contrast, three species had $b < 3$ or with 95% CIs overlapping $b = 3$, indicative of possible isometric growth, which is rare in fishes. However, two of those species had small sample sizes, thus we cannot rule out a possible sample-size effect. We consider LWRs for these species, *Parachromis managuensis* and *Atherinella hubbsi*, to be provisional, and we recommend limiting missing data imputation to the observed length classes. By contrast, the inference of isometry in *Priapichthys annectens* ($b = 3.0901$) based on robust sampling seems a rare exception but should be tested further to account for the full range of geographic, seasonal, and inter-annual variation in the species.

Our study provides the first LWR data and modeling results for 5 out of 7 (71%) of our species. For the two species with previously recorded LWRs on FishBase, our results improve the estimates greatly. The *Parachromis dovii* LWR record on FishBase was estimated by R. Froese in (1999) from a single maximum total length (TL) record and arbitrarily assigned $b = 3$. We more confidently estimate $b = 3.1588$ for this species based on 22 specimens (Table 2), although all size classes were not covered. By contrast, the two existing *P. managuensis* LWR records on FishBase included one *b* estimate based on angling records of much larger specimens (26.7–54.6 cm TL), with no 95% CIs, and another much-improved estimate from Velázquez-Velázquez et al. (2015) with $b = 3.161$ based on 83 specimens. Our *P. managuensis* estimate of $b = 3.1051$ is within 2% of their estimate, with overlapping 95% CIs. All of our other LWRs and parameter estimates are new to science.

It is widely recognized that a number of different factors influence the growth and LWRs of fishes. Such factors include sex, health, the effect of gonad maturity on somatic growth, seasonality of resources, stomach fullness, sample size, and preservation techniques (e.g., Le Cren 1951; Wootton 1998), and these were not accounted for in our study. For example, samples were pooled across sexes and years, and thus LWR parameter estimates represent species mean values. Nevertheless, we followed Froese's (2006) guidelines for LWRs, which are recommended for standardizing LWR results across studies. Moreover, our results provide baseline information useful for calculating CA fish biomass or imputing missing data in future studies of this speciose and endemic fauna.

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