Journal of Applied Ichthyology

J. Appl. Ichthyol. (2015), 1–7
© 2015 Blackwell Verlag GmbH
ISSN 0175–8659

Received: September 16, 2014
Accepted: February 28, 2015
doi: 10.1111/jai.12819

Technical contribution

Length–weight relationships of fish from Madeira River, Brazilian Amazon, before the construction of hydropower plants

By A. Cella-Ribeiro[1], M. Hauser[1], L. D. Nogueira[2], C. R. C. Doria[2] and G. Torrente-Vilara[3,4]

[1]*Programa de Pós-graduação da Rede de Biodiversidade e Biotecnologia da Amazônia Legal, Laboratório de Ictiologia e Pesca/Departamento de Biologia, Universidade Federal de Rondônia, Porto Velho, Rondônia,Brazil;* [2]*Programa de Pós-graduação em Desenvolvimento Regional e Meio Ambiente, Laboratório de Ictiologia e Pesca/Departamento de Biologia, Universidade Federal de Rondônia, Porto Velho, Rondônia, Brazil;* [3]*Departamento de Ciências do Mar da Universidade Federal de São Paulo, Campus Baixada Santista, Santos, São Paulo, Brazil;* [4]*Universidade Federal do Amazonas, Manaus, Amazonas, Brazil*

Summary

Length–weight relationships (LWRs) are presented for 112 freshwater fish species representing 23 families and five orders captured in the Madeira River, the largest white-water river tributary of the Amazon River. The allometry coefficient (b) of the LWR ($Wt = aSL^b$) ranged from 2.446 to 3.856 with a median value of 3.102. Eight new LWR records are presented for Amazonian species as information for FishBase. LWRs in the present study provide historical data on *a* and *b* coefficients prior to the damming of the Madeira River in November 2011, allowing comparison estimates of predicted future population parameters as influenced by human intervention.

Introduction

Length–weight relationships (LWRs) usually translate a common relationship between variables among fish populations as a useful tool to convert length to weight and vice versa (Merella et al., 1997). In fisheries biology, length–weight relationships are useful in determining weight and biomass when only length measurements are available, for indications of condition, and to allow comparisons of species growth between different regions (Koutrakis and Tsikliras, 2002). In some cases, it is easier to take measurements of weight rather than length; for example, in cephalopod species (Bello, 1991). However, in most fish and fisheries, weighing each organism individually under field conditions is very difficult; here, weight data can be converted to length by using the LWR (Dias et al., 2013).

The relationship between two variables, as observed in linear regressions, may be one of functional dependence of one on the other. That is, the magnitude of one of the variables (the dependent variable) is assumed to be determined by – i.e. is a function of – the magnitude of the second variable (the dependent variable), although the reverse situation is often not true. The slope of the regression line, the *b* value, expresses quantitatively the straight-line dependence of Y on X in the sample and the degree of dependence of Y on X (i.e.b#0) does not necessarily mean that there is dependence in the population (i.e.beta#0) (Zar, 1998).

An historical review shows that the intra-specific variance of the LWR may be quite large (from YOY to very senior specimens of a population) and that users should follow certain recommendations when using this relationship (Froese, 2006). Among the problems that may contribute to an increase in the LWR variability, Froese (2006) noted: a narrow range of body lengths in the sample; use of non-random samples; and use of one specific size gear for selection of specimens. Genera (sexes) are a category that can potentially result in LWR variability in the calculation: in commercial fisheries it is not possible in most species to distinguish females from males prior to their sale in the marketplace. Thus, despite these recommendations, an application of the LWR for adult fish populations (excluding YOY and immature specimens) should best fit the LWR to contribute to fisheries evaluation. Since LWRs may vary geographically (Sparre et al., 1989) it is often practical to make use of the local values and highly recommended to use the LWR relationships with data collected in the same area and close to the time of the study in order to minimize any bias in the weight estimation (Kimmerer et al., 2005).

This paper is a contribution that complements the current information on the biological parameters of commercial fish in the Madeira River Basin and represents a more complete list for this type of data on fish (commercial and non-commercial species), at least on the Brazilian side of the basin. Parameters of the length–weight relationships are reported for 112 freshwater fish species collected during four years of study and prior to the construction of two large power plants: Santo Antonio and Jirau.

Growth rates and length–weight relationships have been reported for six species in the Madeira River Basin on the Bolivian side: *Prochilodus nigricans* (Loubens and Panfili, 1995), *Colossoma macropomum* (Loubens and Panfili, 1997), *Pseudoplatystoma fasciatum* (*P. punctifer*, García-Dávila et al., 2013) and *P. tigrinum* (Loubens and Panfili, 2000), *Piaractus brachypomus* (Loubens and Panfili, 2001), *Plagioscion* *squamosissimus* (Loubens, 2003), *Pellona castelnaeana* (Le Guennec and Loubens, 2004); and on the Brazilian side: *Pellona castelnaeana* (Ikeziri et al., 2008), *Roestes molossus* (Torrente-Vilara et al., 2008), *Brachyplatystoma platynemum* and *Pinirampus pirinampu* (Sant'Anna et al., 2014), however a complete list of LWRs for most of the Madeira River freshwater fish has not been reported previously.

Material and methods

Study area

The Madeira River is a major waterway in South America (Albert et al., 2011) approximately 3250 km (2020 miles) in length. Environmental information from the Madeira River is available in Queiroz et al. (2013). Recently, the Santo Antônio and Caldeirão do Inferno Falls gave way to two large hydroelectric dams (Santo Antônio and Jirau power plants, respectively), and flooding permanently the Teotônio and Jirau waterfalls (Cella-Ribeiro et al., 2013).

Fish sampling

Fish fauna was sampled on 23 occasions, including the flood and dry seasons from 2008 to 2011 before the closing of the Santo Antônio and Jirau dams. Sampling sites were established at the mouth of the eight main tributaries and two varzea lakes of Madeira River in the Brazilian territory. A set of 13 gill nets (mesh sizes from 30 to 200 mm between opposite knots; total catch area = 480 m^2) was exposed over a 24-h period, with a specimen collection every 4 h. Fish specimens were maintained in insulated iceboxes and transported to the laboratory at the Universidade Federal de Rondônia in Porto Velho, Rondônia state, Brazil for measuring (SL, nearest 0.1 cm standard length and Wt, 0.01 gram precision). The fish specimens were later identified to species level, and an in-depth taxonomic revision of each species by family was performed by specialists (Queiroz et al., 2013). As gillnets are not efficient in catching some species of the genus *Brachyplatystoma* and *Pseudoplatystoma*, data from fisheries were used for those species obtained at the fish market and artisanal fisheries in the cities of Humaitá, Porto Velho, Nova Mamoré, Guajará-Mirim, Jaci-Paraná and Abunã, and the villages of Calama, São Carlos, Nazaré, São Sebastião and Cachoeira do Teotônio. In the specific case of *Brachyplatystoma rousseauxii*, specimens collected with gill nets between 2012 and 2013 were added in order to find a better coefficient of determination r^2 for these species. All data were collected under the Santo Antonio Energia Fish Conservation Program.

Data analysis

All species analyzed in this work were collected by gillnets in the Madeira River (Queiroz et al., 2013). From 112 species, SL and Wt pairs were plotted to identify and exclude possible outliers, represented by minor errors during laboratorial proceedings. The LWR was calculated using the power regression $W = aL^b$ (Haimovici and Velasco, 2000a,b), where a is the intercept and b the slope, W the weight and L the length. The degree of association between W and L was measured through the coefficient of determination (r^2). The regression coefficients '*a*' and '*b*' obtained for each species were compared to those published in FishBase that were obtained by Bayesian Hierarchical Approach (BHA) for LWRs estimated for practically all known 32000 species of fish (Froese et al., 2014). We tested for differences between our estimates for Madeira River fish and the values available in FishBase using a paired *t*-test. Our hypothesis is that if the differences are random we would find estimates of '*a*' and '*b*' above or below those in FishBase and the *t*-test would be not significant. If the differences were systematic, the paired *t*-test would otherwise give significant p values. Thus, consistent differences between the expected (in FishBase) and observed values would suggest important differences for the Madeira river fish.

To evaluate the species with new records of maximum lengths the references used were: Loubens and Panfili (1995, 2000, 2001, 2000), Loubens and Panfili (2001), Le Guennec and Loubens (2004), Ikeziri et al. (2008), Torrente-Vilara et al. (2008), García Vásquez et al. (2009), Giarrizzo et al. (2011, 2015), Silva et al. (2011), Vegh et al. (2014), FishBase database (Froese and Pauly, 2015).

Results

Overall, 28 559 specimens were analyzed, and the length–weight relationship of 112 fish species representing 23 families and five orders are presented in Table 1. The most diverse families were Serrasalminae (16 species), Pimelodidae (11 species) and Curimatidae (10 species), followed by Auchenipteridae (nine species), Characidae and Cichlidae (eight species each), Anostomidae (seven species), Doradidae, Hemiodontidae and Loricariidae (six species each), Cynodontidae (five species), Acestrorhynchidae (four species), Pristigasteridae and Prochilodontidae (three species each), Alestidae, Ctenoluciidae and Engraulidae (two species each). The families Achiridae, Cetopsidae, Erythrinidae and Sciaenidae were represented by only one species. All regressions were significant for all species ($P < 0.001$), with the coefficient of determination r^2 ranging from 0.95 to 0.99.

The allometry coefficient (b) of the LWR ($Wt = aSL^b$) ranged from 2.446 for *Squaliforma* cf. *emarginata* to 3.856 for *Anodus orinocensis*, with a mean value of 3.103. From the 112 species evaluated, eight are new to FishBase (unpublished LWR), and presented here: *Acestrorhynchus falcirostris* (Cuvier, 1819), *Brycon melanopterus* (Cope, 1872), *Boulengerella cuvieri* (Agassiz, 1829), *Hydrolycus scomberoides* (Cuvier, 1816), H. sp. 'rabo de fogo' (undescribed species; Queiroz et al., 2013), *Oxydoras niger* (Valenciennes, 1821), *Brachyplatystoma filamentosum* (Lichtenstein, 1819) and *Pseudoplatystoma punctifer* (Castelnau, 1855). These values are within the expected range of 2.0–4.0, as suggested by Le Cren (1951). However, of the 104 species remaining, some 41 revealed '*a*' and/or '*b*' values beyond the FishBase range prediction (Froese et al., 2014): 28 species for the linear coefficient (a) and 24 for the angular (b) coefficient, respectively (Table 1). The paired *t*-test confirmed linear coefficient '*a*' for Madeira River species smaller than BHA means from FishBase for

Table 1
Descriptive statistics and length–weight relationship parameters for 112 fish species, Madeira River, Amazon

Order	Family	Species	N	SL (cm)		Wt (g)		*a*	*b*	r^2
				Min	Max	Min	Max			
Characiformes	Acestrorhynchidae	*Acestrorhynchus* cf. *pantaneiro* Menezes, 1992	113	12.30	26.50	24.83	288.09	0.00818 (0.00694–0.00962)	3.209 (3.152–3.265)	0.97
		Acestrorhynchus falcirostris (Cuvier, 1819)	735	10.00	45.00	19.40	1000.84	0.00547 (0.00502–0.00594)	3.172 (3.146–3.198)	0.95
		Acestrorhynchus heterolepis (Cope, 1878)	564	13.00	40.80	33.51	960.12	*0.00644* (*0.00586–0.00706*)	3.184 (3.154–3.213)	0.95
		Acestrorhynchus microlepis (Schomburgk, 1841)	928	7.90	22.00	4.90	141.80	0.00724 (0.00679–0.00772)	3.177 (3.153–3.200)	0.95
	Alestidae	*Chalceus epakros* Zanata & Toledo-Piza, 2004	33	9.50	15.10	16.86	72.37	0.01710 (0.01313–0.02226)	3.072 (2.961–3.182)	0.96
		Chalceus guaporensis Zanata & Toledo-Piza, 2004	187	9.00	**17.40**	12.82	122.00	0.01001 (0.00893–0.01120)	*3.302* (*3.258–3.346*)	0.97
	Anostomidae	*Laemolyta proxima* (Garman, 1890)	138	9.20	28.50	14.65	415.00	0.01353 (0.01186–0.01541)	3.126 (3.080–3.172)	0.97
		Laemolyta taeniata (Kner, 1859)	113	10.00	24.50	19.00	222.10	0.01174 (0.01006–0.01368)	3.119 (3.063–3.174	0.97
		Leporinus fasciatus (Bloch, 1794)	88	11.00	30.50	24.28	698.00	0.01215 (0.01033–0.01429)	3.172 (3.118–3.226)	0.98
		Leporinus friderici (Bloch, 1794)	170	8.60	33.00	13.01	1053.30	0.01722 (0.01609–0.01842)	3.119 (3.094–3.143)	0.99
		Rhytiodus argenteofuscus Kner, 1859	91	12.20	**32.00**	25.21	537.75	0.00510 (0.00402–0.00645)	3.296 (3.220–3.372)	0.95
		Rhytiodus microlepis Kner, 1859	36	12.20	33.20	21.73	460.00	*0.01286* (*0.00893–0.01850*)	2.998 (2.887–3.107)	0.95
		Schizodon fasciatus Spix & Agassiz, 1829	439	9.40	31.90	14.73	846.62	0.02231 (0.02084–0.02387)	2.925 (2.902–2.947)	0.97
	Characidae	*Brycon amazonicus* (Spix & Agassiz, 1829)	43	11.80	40.60	37.78	1890.99	0.02887 (0.02194–0.03797)	2.944 (2.859–3.029)	0.96
		Brycon melanopterus (Cope, 1872)	39	11.00	**38.00**	34.42	1332.80	0.01744 (0.01287–0.02362)	3.098 (3.000–3.195)	0.96
		Bryconops alburnoides Kner, 1858	97	7.00	**15.00**	4.00	48.35	0.00853 (0.00711–0.01021)	3.199 (3.124–3.272)	0.95
		Roeboides affinis (Günther,1868)	29	6.30	10.80	4.30	22.00	0.01647 (0.01246–0.02175)	3.035 (2.908–3.162)	0.95
		Roeboides myersi Gill, 1870	118	7.00	16.70	5.40	124.14	0.01150 (0.01004–0.01316)	3.245 (3.190–3.299)	0.97
		Triportheus albus Cope, 1872	394	9.30	21.60	11.98	154.00	0.01709 (0.01569–0.01861)	2.947 (2.914–2.980)	0.95
		Triportheus angulatus Cope, 1872	1282	6.30	**23.50**	6.32	211.00	0.02603 (0.02482–0.02728)	2.897 (2.878–2.915)	0.95
		Triportheus auritus (Valenciennes, in Cuvier & Valenciennes, 1850)	100	7.80	**25.50**	12.06	277.24	*0.03555* (*0.02956–0.04275*)	*2.666* (*2.604–2.727*)	0.95
	Ctenoluciidae	*Boulengerella cuvieri* (Agassiz, 1829)	50	20.20	44.40	51.45	906.53	0.00078 (0.00057–0.00107)	3.674 (3.575–3.771)	0.97
		Boulengerella maculata (Valenciennes, 1850)	23	18.80	29.90	42.00	228.50	0.00109 (0.00070–0.00170)	*3.578* (*3.439–3.715*)	0.97
	Curimatidae	*Curimata roseni* Vari, 1989	141	8.50	**19.50**	14.76	209.70	0.02934 (0.02652–0.03245)	2.995 (2.957–3.032)	0.98
		Curimata vittata (Kner, 1858)	82	8.10	**19.60**	12.18	231.64	0.02558 (0.02133–0.03067)	3.018 (2.951–3.085)	0.96
		Curimatella alburna (Müller & Troschel, 1844)	335	5.80	**18.80**	8.20	220.33	0.03230 (0.03035–0.03437)	2.997 (2.970–3.023)	0.97
		Curimatella meyeri (Steindachner, 1882)	45	8.20	**17.20**	16.00	152.50	0.01902 (0.01474–0.02452)	3.131 (3.034–3.227)	0.96
		Cyphocharax notatus (Steindachner, 1908)	75	6.90	14.70	9.80	72.09	0.03955 (0.03445–0.04540)	*2.813* (*2.754–2.870*)	0.97
		Potamorhina altamazonica (Cope, 1878)	1032	7.20	23.50	9.09	330.40	0.03409 (0.03241–0.03584)	2.869 (2.851–2.886)	0.96
		Potamorhina latior (Spix & Agassiz, 1829)	1807	6.50	**24.00**	7.77	271.00	0.02237 (0.02149–0.02328)	2.929 (2.915–2.943)	0.96
		Psectrogaster amazonica Eigenmann & Eigenmann, 1889	375	7.20	17.30	10.47	174.53	0.02615 (0.02413–0.02833)	3.086 (3.054–3.117)	0.96
		Psectrogaster rutiloides (Kner, 1858)	794	6.40	17.80	8.20	147.62	0.03724 (0.03534–0.03923)	2.874 (2.853–2.895)	0.96
		Steindachnerina bimaculata (Steindachner, 1876)	105	7.50	17.30	12.16	150.14	0.01910 (0.01616–0.02257)	3.130 (3.064–3.196)	0.96
	Cynodontidae	*Cynodon gibbus* Agassiz, in Spix & Agassiz, 1829	193	13.20	**32.20**	23.80	487.66	*0.00582* (*0.00492–0.00687*)	3.241 (3.188–3.293)	0.95
		Hydrolycus armatus (Schomburgk, 1841)	97	14.20	75.00	42.14	8500.00	*0.00998* (*0.00869–0.01146*)	3.109 (3.069–3.149)	0.98
		Hydrolycus scomberoides (Cuvier, 1816)	212	12.00	46.70	14.96	1670.00	0.00599 (0.00521–0.00687)	3.284 (3.240–3.328)	0.96
		Rhaphiodon vulpinus Agassiz, in Spix & Agassiz, 1829	600	20.50	55.80	51.22	1368.24	0.00387 (0.00350–0.00427)	3.146 (3.118–3.174)	0.96
		Roestes molossus (Kner, 1858)	155	10.60	**21.60**	25.48	209.61	0.01564 (0.01363–0.01792)	3.117 (3.067–3.166)	0.96

Table 1
(Continued)

Order	Family	Species	N	SL (cm) Min	SL (cm) Max	Wt (g) Min	Wt (g) Max	*a*	*b*	r^2
Characiformes	Erythrinidae	*Hoplias malabaricus* (Bloch, 1794)	314	10.90	40.30	21.50	1351.41	0.01157 (0.01072–0.01247)	3.164 (3.140–3.186)	0.98
	Hemiodontidae	*Anodus elongatus* Agassiz, 1829	335	12.60	26.00	21.85	278.90	*0.00161 (0.00140–0.00185)*	*3.672 (3.625–3.717)*	0.95
		Anodus orinocensis (Steindachner, 1887)	104	14.10	26.70	31.00	319.31	*0.00097 (0.00077–0.00119)*	*3.856 (3.785–3.926)*	0.97
		Hemiodus immaculatus Kner, 1858	98	7.20	22.00	8.01	182.44	0.01873 (0.01575–0.02227)	2.957 (2.895–3.017)	0.96
		Hemiodus microlepis Kner, 1858	321	9.00	21.20	13.70	222.00	0.02318 (0.02127–0.02524)	2.958 (2.925–2.990)	0.96
		Hemiodus unimaculatus (Bloch, 1794)	508	8.50	22.00	13.34	259.00	0.01162 (0.01096–0.01230)	*3.232 (3.210–3.253)*	0.98
		Hemiodus sp. "rabo de fogo"	38	12.00	20.00	22.00	121.00	0.00282 (0.00196–0.00403)	3.543 (3.417–3.668)	0.96
	Prochilodontidae	*Prochilodus nigricans* Agassiz, 1829	639	7.20	38.20	9.84	1175.09	*0.02972 (0.02753–0.03207)*	2.933 (2.909–2.957)	0.96
		Semaprochilodus insignis (Jardine, 1841)	180	10.00	27.50	22.30	560.08	0.01573 (0.01353–0.01827)	3.193 (3.143–3.242)	0.96
		Semaprochilodus taeniurus (Valenciennes, 1817)	48	9.00	27.20	18.00	605.50	0.02953 (0.02275–0.03831)	2.886 (2.795–2.976)	0.95
	Serrasalmidae	*Metynnis guaporensis* Eigenmann, 1915	146	4.30	**16.00**	4.85	180.10	*0.06475 (0.06040–0.06939)*	2.881 (2.851–2.910)	0.98
		Metynnis lippincottianus (Cope, 1870)	45	8.20	**16.40**	22.25	205.37	*0.04470 (0.03462–0.05770)*	3.039 (2.937–3.140)	0.95
		Metynnis luna Cope, 1878	57	4.50	**12.90**	3.92	102.00	*0.04406 (0.03742–0.05187)*	3.091 (3.015–3.165)	0.97
		Myleus setiger Müller & Troschel, 1844	37	9.70	23.00	30.20	670.00	0.02049 (0.01581–0.02653)	*3.328 (3.231–3.424)*	0.97
		Myloplus asterias (Müller & Troschel, 1844)	39	6.60	19.10	13.78	360.40	*0.04465 (0.03687–0.05407)*	3.034 (2.960–3.108)	0.98
		Mylossoma aureum (Agassiz, 1829)	136	8.50	17.70	20.30	230.30	0.02266 (0.01985–0.02585)	3.183 (3.131–3.235)	0.97
		Mylossoma duriventre (Cuvier, 1818)	1298	5.40	24.90	6.60	736.00	0.02920 (0.02781–0.03065)	3.118 (3.099–3.137)	0.96
		Piaractus brachypomus (Cuvier, 1818)	51	9.00	31.50	22.47	1171.43	0.02891 (0.02345–0.03563)	3.116 (3.038–3.193)	0.97
		Pygocentrus nattereri Kner, 1858	822	7.00	21.40	13.77	543.41	0.03546 (0.03350–0.03753)	3.125 (3.103–3.146)	0.96
		Serrasalmus compressus Jégu, Leão & Santos, 1991	50	8.10	18.80	13.38	259.70	0.01639 (0.01325–0.02028)	3.245 (3.163–3.327)	0.97
		Serrasalmus eigenmanni Norman, 1929	192	5.20	19.60	3.27	394.00	0.01061 (0.00955–0.01179)	*3.458 (3.414–3.502)*	0.97
		Serrasalmus elongatus Kner, 1858	227	7.50	22.90	7.39	311.00	0.00890 (0.00831–0.00951)	*3.328 (3.302–3.353)*	0.99
		Serrasalmus hollandi Eigenmann, 1915	157	5.20	17.20	3.43	154.32	0.01829 (0.01681–0.01990)	3.247 (3.210–3.283)	0.98
		Serrasalmus maculatus Kner, 1858	28	6.50	18.80	8.90	288.17	0.02444 (0.02031–0.02939)	3.172 (3.093–3.249)	0.98
		Serrasalmus rhombeus (Linnaeus, 1766)	693	5.60	31.00	4.67	1277.00	0.01388 (0.01315–0.01465)	*3.314 (3.293–3.335)*	0.97
		Serrasalmus spilopleura Kner, 1858	129	5.20	19.30	5.01	277.41	0.02784 (0.02390–0.03242)	3.131 (3.068–3.194)	0.95
Clupeiformes	Engraulidae	*Jurengraulis juruensis* (Boulenger, 1898)	50	10.00	**17.90**	9.97	89.00	0.00327 (0.00256–0.00416)	*3.463 (3.368–3.557)*	0.97
		Lycengraulis batesii (Günther, 1868)	54	12.00	18.20	18.80	74.23	0.00630 (0.00495–0.00801)	3.222 (3.132–3.311)	0.96
	Pristigasteridae	*Ilisha amazonica* (Miranda Ribeiro, 1920)	32	13.80	19.70	31.90	98.39	0.00769 (0.00584–0.01011)	3.183 (3.084–3.282)	0.97
		Pellona castelnaeana (Valenciennes, 1847)	280	8.70	60.90	8.47	4000.30	0.01038 (0.00962–0.01119)	3.120 (3.098–3.142)	0.98
		Pellona flavipinnis (Valenciennes, 1836)	275	9.20	44.30	6.81	1347.00	0.01696 (0.01512–0.01901)	2.972 (2.934–3.008)	0.96
Perciformes	Cichlidae	*Astronotus crassipinnis* (Heckel, 1840)	39	12.00	21.00	75.00	484.54	*0.06911 (0.05542–0.08616)*	2.896 (2.817–2.974)	0.97
		Biotodoma cupido (Heckel, 1840)	62	5.50	**11.70**	5.42	55.32	0.01920 (0.01610–0.02288)	*3.293 (3.211–3.375)*	0.96
		Chaetobranchus flavescens Heckel, 1840	41	6.20	20.70	13.99	316.00	*0.18832 (0.16086–0.22047)*	*2.483 (2.421–2.544)*	0.98
		Cichla pleiozona Kullander & Ferreira, 2006	217	8.50	44.20	12.58	2400.00	0.01506 (0.01376–0.01647)	3.160 (3.131–3.189)	0.98
		Geophagus megasema Heckel, 1840	121	7.50	18.90	15.40	272.18	*0.04403 (0.03897–0.04974)*	2.908 (2.862–2.952)	0.97
		Heros spurius Heckel, 1840	77	6.20	15.00	13.32	192.30	*0.07634 (0.06393–0.09115)*	2.915 (2.843–2.987)	0.95
		Mesonauta festivus (Heckel, 1840)	60	3.50	12.10	2.00	97.41	0.03027 (0.02594–0.03532)	3.255 (3.184–3.325)	0.97
		Satanoperca jurupari (Heckel, 1840)	238	6.50	18.40	9.12	206.86	*0.03669 (0.03278–0.04106)*	2.989 (2.946–3.030)	0.95
Perciformes	Sciaenidae	*Plagioscion squamosissimus* (Heckel, 1840)	178	12.90	42.50	40.81	1576.34	*0.03217 (0.02766–0.03740)*	*2.855 (2.809–2.901)*	0.95
Pleuronectiformes	Achiridae	*Hypoclinemus mentalis* (Günther, 1862)	72	9.00	**21.60**	24.28	388.65	0.02807 (0.02448–0.03219)	3.099 (3.047–3.150)	0.98

Table 1
(Continued)

Order	Family	Species	N	SL (cm)		Wt (g)		*a*	*b*	r^2
				Min	Max	Min	Max			
Siluriformes	Auchenipteridae	*Ageneiosus atronasus* Eigenmann & Eigenmann, 1888	50	8.70	14.90	10.93	65.50	0.00861 (0.00682–0.01086)	*3.282* (*3.185*–*3.377*)	0.96
		Ageneiosus inermis (Linnaeus, 1766)	206	12.70	45.00	31.54	1532.42	*0.01779* (*0.01530*–*0.02067*)	*2.970* (*2.925*–*3.015*)	0.95
		Ageneiosus ucayalensis Castelnau, 1855	92	13.10	32.50	21.02	276.00	*0.01922* (*0.01657*–*0.02229*)	*2.755* (*2.707*–*2.803*)	0.97
		Auchenipterichthys thoracatus (Kner, 1857)	2706	5.10	**13.80**	2.10	62.39	0.02138 (0.02073–0.02205)	3.066 (3.052–3.079)	0.95
		Auchenipterus ambyiacus Fowler, 1915	246	10.50	21.30	17.64	130.40	0.01332 (0.01194–0.01485)	2.967 (2.928–3.006)	0.96
		Auchenipterus nuchalis (Spix & Agassiz, 1829)	110	10.20	**22.70**	16.03	146.30	0.00852 (0.00730–0.00994)	3.136 (3.081–3.191)	0.97
		Centromochlus heckelii (De Filippi, 1853)	185	5.30	**13.90**	2.76	44.87	*0.01822* (*0.01616*–*0.02054*)	3.024 (2.972–3.076)	0.95
		Parauchenipterus galeatus (Linnaeus, 1766)	106	6.80	**23.70**	12.88	464.70	0.02506 (0.02180–0.02879)	3.071 (3.018–3.123)	0.97
		Tatia aulopygia (Kner, 1857)	27	7.10	15.30	7.92	95.00	0.01379 (0.01027–0.01850)	*3.256* (*3.122*–*3.388*)	0.96
	Cetopsidae	*Cetopsis coecutiens* (Lichtenstein, 1819)	62	12.80	23.80	41.49	280.39	0.01874 (0.01493–0.02351)	3.024 (2.946–3.101)	0.96
	Doradidae	*Hemidoras stenopeltis* (Kner, 1855)	40	8.70	19.40	8.00	86.52	0.01095 (0.00860–0.01393)	3.088 (2.988–3.187)	0.96
		Nemadoras humeralis (Kner, 1855)	98	7.00	13.50	6.60	55.90	0.01908 (0.01608–0.02264)	3.061 (2.990–3.131)	0.95
		Opsodoras boulengeri (Steindachner, 1915)	89	6.20	19.30	4.90	129.10	0.02198 (0.01934–0.02497)	2.858 (2.810–2.906)	0.97
		Oxydoras niger (Valenciennes, 1821)	73	14.50	57.00	54.71	2927.87	0.02010 (0.01640–0.02463)	2.951 (2.891–3.010)	0.97
		Pterodoras granulosus (Valenciennes, 1821)	21	14.60	43.00	103.90	2147.00	*0.06583* (*0.04567*–*0.09486*)	*2.739* (*2.618*–*2.860*)	0.96
		Trachydoras paraguayensis (Eigenmann & Ward, 1907)	82	6.00	13.80	5.60	67.97	0.03779 (0.03246–0.04398)	2.869 (2.798–2.938)	0.95
	Hypoptopomatinae	*Hypoptopoma incognitum* Aquino & Schaefer, 2010	202	6.20	**10.80**	4.35	26.66	*0.01599* (*0.01430*–*0.01789*)	3.115 (3.065–3.165)	0.95
	Hypostominae	*Aphanotorulus unicolor* (Steindachner, 1908)	24	10.30	13.50	24.01	55.59	0.02403 (0.01898–0.03042)	2.973 (2.877–3.069)	0.97
		Hypostomus pyrineusi (Miranda Ribeiro, 1920)	28	11.10	21.20	37.07	314.93	*0.03713* (*0.02751*–*0.05010*)	2.928 (2.823–3.032)	0.97
		Pterygoplichthys lituratus (Kner, 1854)	144	12.00	36.50	19.03	1204.36	0.02064 (0.01730–0.02462)	3.047 (2.991–3.101)	0.95
		Squaliforma cf. *emarginata* (Valenciennes, 1840)	36	10.00	**36.50**	22.19	550.66	*0.09131* (*0.07532*–*0.11067*)	*2.446* (*2.384*–*2.508*)	0.98
	Loricariidae	*Loricaria cataphracta* Linnaeus, 1758	35	13.60	26.60	12.70	117.90	0.00578 (0.00427–0.00780)	2.998 (2.897–3.097)	0.96
	Pimelodidae	*Brachyplatystoma filamentosum* (Lichtenstein, 1819)	517	49.00	196.00	2000.00	100000.00	0.02169 (0.01902–0.02472)	2.914 (2.885–2.943)	0.95
		Brachyplatystoma rousseauxii (Castelnau, 1855)	1102	8.70	147.00	5.23	60000.00	0.01233 (0.01143–0.01329)	3.032 (3.014–3.049)	0.96
		Brachyplatystoma vaillantii (Valenciennes, 1840)	444	29.00	69.00	300.00	6000.00	*0.00121* (*0.00104*–*0.00139*)	*3.629* (*3.590*–*3.667*)	0.95
		Calophysus macropterus (Lichtenstein, 1819)	120	12.20	38.60	21.66	689.80	0.01340 (0.01184–0.01516)	3.000 (2.962–3.037)	0.98
		Hypophthalmus edentatus Spix & Agassiz, 1829	85	17.20	39.00	51.22	884.86	0.00611 (0.00489–0.00762)	3.167 (3.101–3.232)	0.96
		Hypophthalmus marginatus Valenciennes, 1840	135	25.20	47.00	99.73	1014.06	0.00261 (0.00209–0.00326)	*3.328* (*3.263*–*3.393*)	0.95
		Pimelodus blochii Valenciennes, 1840	552	5.80	21.20	3.81	203.93	0.01945 (0.01800–0.02101)	2.983 (2.954–3.012)	0.95
		Pseudoplatystoma punctifer (Castelnau, 1855)	283	19.60	97.00	81.58	9500.00	0.00997 (0.00858–0.01157)	3.029 (2.992–3.065)	0.96
		Sorubim elongatus Littmann, Burr, Schmidt & Isern, 2001	104	16.20	**32.20**	28.39	260.00	0.00409 (0.00328–0.00509)	3.135 (3.065–3.204)	0.95
		Sorubim lima (Bloch & Schneider, 1801)	90	18.50	38.50	36.98	591.51	*0.00095* (*0.00072*–*0.00125*)	*3.636* (*3.553*–*3.719*)	0.95
		Sorubim maniradii Littmann, Burr, Schmidt & Isern, 2001	119	13.90	**25.60**	21.07	131.97	*0.00499* (*0.00412*–*0.00604*)	3.123 (3.060–3.185)	0.95

N, number of individuals; SL, standard length; Wt, total weight. Bold = new length record, MaxSL. *Italics* = values of *a* and *b* outside range reported in FishBase. r^2, Pearson r-squared for log–logregression (all relationships significant at $P < 0.0001$).

the 28 species ($t_a = 3.77$, df = 27; P < 0.001); a similar result was obtained for the *a* set of species ($t_a = 5.49$, df = 103, P > 0.05). However, the angular coefficient '*b*' observed beyond the BHA range in FishBase could not be considered consistently different from the BHA mean for the 24 species ($t_b = 1.64$, df = 23, P < 0.05), or for the Madeira River *b* set of species ($t_b = 1.66$, df = 103, P > 0.05).

Discussion

This study provides new maximum length records for 27 species. *Colossoma macropomum* is a very important commercial fish in the Amazon. However, specimens landed at the Madeira River fish market were from Bolivia and mixed in with specimens from piscicultures, precluding our analysis for this species. The best information on the *C. macropomum* LWR is in Loubens and Panfili (1997), where $SL_{max} = 82.5$ cm ($a = -4.258$, $b = 2.903$, $r^2 = 0.99$, N = 864). *Pseudoplatystoma tigrinum* with $SL_{max} = 127$ cm ($a = -5.201$, $b = 3.15$, $r^2 = 0.99$, N = 551) in Loubens and Panfili (2000) was neither captured in our samples nor seen in the fish market. The LWRs calculated for *Pinirampus pirinampu* ($a = 0.0271$, $b = 2.81$, $SL_{max} = 74$ cm) and *Brachyplatystoma platynemum* ($a = 0.0462$, $b = 2.67$, $SL_{max} =$ 89 cm) were published in Sant'Anna et al. (2014) using data from our samples. Most specimens captured in the Madeira River were adults and with a few juveniles. Madeira River is known for its schools of fish that perform yearly reproductive migrations. It is possible that these fish schools were growing and feeding in the same downstream river area before migrating to Madeira River each year, explaining the absence of juveniles in our gillnets samples.

The *a* and *b* parameters of the LWRs given in FishBase arise from a compilation of estimates from different genus or species belonging to the same family having the same body shape (Froese and Pauly, 2015). Indeed, 63 of 104 species have *a* and *b* parameters in agreement with coefficient values in FishBase; the differences observed in the coefficient values were reported by Allard et al. (2015) in the literature for Amazonian fish. Here, were report direct estimates of LWRs and are confident that our means and ranges encompass all size ranges for the adult species considered. However, our study notes that the *a* values are smaller than those estimated in FishBase, whereas the *b* are consistent. This suggests that Madeira River fish have the same proportional weight increments but are thinner when compared to BHA results (e.g. Table 1). Thin individuals, most often with empty stomachs and having low visceral fat deposits, may indicate a lower quality of habitat (Torrente-Vilara et al., 2011). In fact, a remarkable characteristic regarding Madeira River fish is that a typical lowland migratory fish in the stretch of rapids in our study area was represented by adult specimens in poor condition, possibly a result of a loss in energy due to migration.

Hydropower plants will almost certainly change ecological patterns; at the same time, they will favor some species more adaptable to new environmental conditions, yet will cause disturbances in others. As such, continued observations of the LWRs in these fish species are fundamental.

Acknowledgements

We are thankful for the Santo Antônio Energia (SAE) partnership with the Universidade Federal de Rondônia (UNIR), Instituto de Estudos e Pesquisas Agroambientais e Organizações Sustentáveis (EPAGRO) and Instituto Nacional de Pesquisas da Amazônia (INPA) for the opportunity to conduct ichthyological studies along the Madeira River. ACR received a scholarship from Fapeam (Proc. N° 062.01947/2013) and MH received a scholarship from CAPES (Proc. N° 21/2012, Pro-Amazon Program: Biodiversity and Sustainability 047/2012). We thank Fabiane Gallucci, Fabio Cop Ferreira and Harald Rosenthal for the review of the English.

References

Albert, J. S.; Petry, P.; Reis, R., 2011: Major Biogeographic and Phylogenetic Patterns. In: Historical Biogeography of Neotropical Freshwater Fishes. J. S. Albert, R. E. Reis (Eds). University of California Press, London, England, pp. 289.

Allard, L.; Toussaint, A.; Vigouroux, R.; Brosse, S., 2015: Length–weight relationship of 58 fish species in French Guiana streams. J. Appl. Ichthyol. **31**, 567–570.

Bello, G., 1991: Growth by weight versus growth by length in cephalopods. In: Squid Age Determination using Statoliths. P. Jereb, S. Ragonese, S. V. Boletzky (Eds). Proceedings International Workshop, Mazara del Vello, Italy, NTR-ITPP Spec. Publ. 1, pp. 35–37.

Cella-Ribeiro, A.; Torrente-Vilara, G.; Hungria, D. B.; Oliveira, M., 2013: As corredeiras do rio Madeira. In: Peixes do rio Madeira. L. J. Queiroz, G. Torrente-Vilara, W. M. Ohara, T. Pires, J. A. Zuanon, C. R. C. Doria, (Eds), Dialeto, São Paulo, pp. 56–63.

Dias, J. F.; Fernandez, W. S.; Schmidtt, T. C. S., 2013: Length–weight relationship of 73 fish species caught in the southeastern inner continental shelf region of Brazil. Lat. Am. J. Aquat. Res. **42**, 127–136.

Froese, R., 2006: Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. J. Appl. Ichthyol. **22**, 241–253.

Froese, R.; Pauly, D. (Eds), 2015: FishBase, World Wide Web electronic publication. Available at: http://www.fishbase.org (accessed on 12 January 2014).

Froese, R.; Thorson, J. T.; Reyes, R. B., 2014: A Bayesian approach for estimating length–weight relationship in fishes. J. Appl. Ichthyol. **30**, 78–85.

García-Dávila, C.; Duponchelle, F.; Castro-Ruiz, D.; Villacorta, J.; Quérouil, S.; Chota-Macuyama, W.; Nuñez, J.; Römer, U.; Carvajal-Vallejos, F.; Renno, J.-F., 2013: Molecular identification of a cryptic species in the Amazonian predatory catfish genus *Pseudoplatystoma* (Bleeker, 1962) from Peru. Genetica **141**, 347–358.

García Vásquez, A.; Alonso, J.-C.; Carvajal, F.; Moreau, J.; Nuñez, J.; Renno, J.-F.; Tello, S.; Montreuil, V.; Duponchelle, F., 2009: Life-history characteristics of the large Amazonian migratory catfish *Brachyplatystoma rousseauxii* in the Iquitos region, Peru. J. Fish Biol. **75**, 2527–2551.

Giarrizzo, T.; Bastos, D.; Andrade, M., 2011: Length–weight relationships for selected fish species of Rio Trombetas Biological Reserve: a reference study for the Amazonian basin. J. Appl. Ichthyol. **27**, 1422–1424.

Giarrizzo, T.; de Sena Oliveira, R. R.; Costa Andrade, M.; Pedrosa Gonçalves, A.; Barbosa, T. A. P.; Martins, A. R.; Marques, D. K.; Brito dos Santos, J. L.; de Paula da Silva Frois, R.; Oliveira de Albuquerque, T. P.; Fogaça de Assis Montag, L.; Camargo, M.; Melo de Sousa, L., 2015: Length–weight and length–length relationships for 153 fish species from the Xingu River (Amazon Basin, Brazil). J. Appl. Ichthyol. **31**, 415–424.

Haimovici, M.; Velasco, G., 2000a: Length–weight relationships of marine fishes from southern Brazil. Fishbyte **23**, 19–23.

Haimovici, M.; Velasco, G., 2000b: Relações comprimento-peso de peixes teleósteos marinhos do sul do Brasil com uma avaliação de diferentes métodos de ajuste. Atlântica **22**, 131–140.
Ikeziri, A. A. S. L.; Queiroz, L. J.; Doria, C. R. C.; Fávaro, L. F.; Araújo, T. R.; Torrente-Vilara, G., 2008: Estrutura populacional e abundância do Apapá-Amarelo, *Pellona castelnaeana* (Valenciennes, 1847) (Clupeiformes, Pristigasteridae), na Reserva Extrativista do Rio Cautário. Rondônia **10**, 41–50.
Kimmerer, W.; Avent, S. R.; Bollens, S. M., 2005: Variability in length–weight relationship used to estimate biomass of estuarine fish from survey data. Trans. Am. Fish. Soc. **134**, 481–495.
Koutrakis, E. T.; Tsikliras, A. C., 2002: Length–weight relationships of fishes from three northern Aegean estuarine systems (Greece). J. Appl. Ichthyol. **19**, 258–260.
Le Cren, E. D., 1951: The length–weight relationship and seasonal cycle in gonad weight and conditions in the perch (*Perca fluviatilis*). J. Anim. Ecol. **20**, 201–219.
Le Guennec, B.; Loubens, G., 2004: Biologie de *Pellona castelnaeana* (Teleostei: Pristigasteridae) dans le bassin du Mamoré (Amazonie bolivienne). Ichthyol. Explor. Freshw. Fish. **15**, 369–383.
Loubens, G., 2003: Biologie de *Plagioscion squamosissimus* (Teleostei: Sciaenidae) dans le bassin du Mamoré (Amazonie bolivienne). Ichthyol. Explor. Freshw. Fish. **14**, 335–352.
Loubens, G.; Panfili, J., 1995: Biologie de *Prochilodus nigricans* (Teleostei: Prochilodontidae) dans le bassin du Mamoré (Amazonie bolivienne). Ichthyol. Explor. Freshw. Fish. **6**, 17–32.
Loubens, G.; Panfili, J., 1997: Biologie de *Colossoma macropomum* (Teleostei: Serrasalmidae) dans le bassin du Mamoré (Amazonie bolivienne). Ichthyol. Explor. Freshw. Fish. **8**, 1–22.
Loubens, G.; Panfili, J., 2000: Biologie de *Pseudoplatystoma fasciatum* et *P. tigrinum* (Teleostei: Pimelodidae) dans le bassin du Mamoré (Amazonie bolivienne). Ichthyol. Explor. Freshw. Fish. **11**, 13–34.
Loubens, G.; Panfili, J., 2001: Biologie de *Piaractus brachypomus* (Teleostei: Serrasalmidae) dans le bassin du Mamoré (Amazonie bolivienne). Ichthyol. Explor. Freshw. Fish. **12**, 51–64.
Merella, P.; Quetglas, A.; Alemany, F.; Carbonell, A., 1997: Length–weight relationship of fishes and cephalopods from the Balearic Islands (western Mediterranean). Naga, ICLARM Q. **20**, 66–68.
Queiroz, L. J.; Torrente-Vilara, G.; Ohara, W. M.; Pires, T.; Zuanon, J. A.; Doria, C. R. C., 2013: Peixes do rio Madeira, Vol. 1. Editora Dialeto, São Paulo, pp. 1163.
Sant'Anna, I. R. A.; Doria, C. R. C.; Freitas, C. E. C., 2014: Pre-impoundment stock assessment of two Pimelodidae species caught by small-scale fisheries in the Madeira River (Amazon Basin – Brazil). Fish. Manage. Ecol. **21**, 322–329.
Silva, A. M. O.; Tavares-Dias, M.; Fernandes, J. S., 2011: Helminthes parasitizing Semaprochilodus insignis Jardine, 1841 (Osteichthyes: Prochilodontidae) from the Central Amazonia (Brazil), and their relationship with the host. Neotrop. Helminthol. **5**, 225–233.
Sparre, P.; Ursin, E.; Venema, S. C., 1989: Introduction to tropical fish stock assessment. Part 1 manual. FAO Fish. Tech. Pap. **306**, 337.
Torrente-Vilara, G.; Zuanon, J.; Amadio, S. A.; Doria, C. R. C., 2008: Biological and ecological characteristics of *Roestes molossus* (Synodontidae), a night hunting characiform fish from upper Madeira River, Brazil. Ichthyol. Explor. Fresh. **19**, 103–110.
Torrente-Vilara, G.; Zuanon, J.; Leprieur, F.; Oberdorff, T.; Tedesco, P. A., 2011: Effects of natural rapids and waterfalls on fish assemblage structure in the Madeira River (Amazon Basin). Eco. Freshw. Fish. **20**, 588–597.
Vegh, S. L.; Lozano, I. E.; Dománico, A. A., 2014: Length–weight, length–length relationships and length at first maturity of fish species from the Parana and Uruguay rivers, Argentina. J. Appl. Ichthyol. **30**, 555–557.
Zar, J. H., 1998: Biostatistical Analysis. Prentice-Hall, Englewood Cliffs, NJ, pp. 663.

Author's address: Ariana Cella-Ribeiro, Programa de Pós-graduação da Rede de Biodiversidade e Biotecnologia da Amazônia Legal, Laboratório de Ictiologia e Pesca/ Departamento de Biologia, Universidade Federal de Rondônia. Rodovia BR 364, km 9.5, Porto Velho, Rondônia, 76801-059, Brazil.
E-mail: arianacella.ribeiro@gmail.com