ACTA ICHTHYOLOGICA ET PISCATORIA (2018) 48 (3): 303–313 DOI: 10.3750/AIEP/02346

ESTIMATION OF GROWTH PARAMETERS OF FIVE FISH SPECIES (ACTINOPTERYGII) CAUGHT IN THE CENTRAL AMAZON

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Guerreiro A., Amadio S., Fabré N., Batista V. 2018. Estimation of growth parameters of five fish species (Actinopterygii) caught in the central Amazon. Acta Ichthyol. Piscat. 48 (3): 303–313.

Abstract. For some tropical fishes, the information on growth parameters is still scarce, and few or no records are available in FishBase. Therefore, the objective of this study was to estimate the growth curves for *Brycon amazonicus* (Spix et Agassiz, 1829), *Piaractus brachypomus* (Cuvier, 1818), *Prochilodus nigricans* Spix et Agassiz, 1829, *Semaprochilodus insignis* (Jardine, 1841), and *Semaprochilodus taeniurus* (Valenciennes, 1821), and to build the auximetric plots for each of the families to which these species belong: Characidae, Prochilodontidae, and Serrasalmidae. Samples were obtained from commercial catches landed in the Port of Manaus. Growth parameters were estimated using the Electronic Length Frequency Analysis (ELEFAN) routine of the Length Frequency Distribution Analysis (LFDA) program. Twenty-six sets of growth parameters were thus estimated, and 66 further sets were located in the literature and FishBase. Prochilodontidae and Serrasalmidae showed a strong inverse relation between the variables composing the auximetric plots.

Keywords: tropical fishes, commercial fishery, length frequency data, growth coefficient, asymptotic length

INTRODUCTION

Growth is one of the most critical measurable characteristics of individuals, stocks, and species, and it is fundamental to our understanding of the life histories, demographics, ecosystem dynamics, and sustainability of fisheries (Pardo et al. 2013). Fishes are the primary food source of the Amazon's local inhabitants, with some areas showing the highest consumption rates in the world (with fish consumed six out of every seven days, at a mean rate of 169 kg per person per year) (Isaac et al. 2015). The dynamics of fish stocks may alter due to environmental changes (Barletta et al. 2010), overfishing, climate change, pollution, deforestation, etc. (Li et al. 2011, Freitas et al. 2013). However, growth parameters of fishes from the central Amazon—key indicators that will enable the assessment of the impact of such processes on fish populations—are still scarce for *Brycon amazonicus* (Spix et Agassiz, 1829), *Piaractus brachypomus* (Cuvier, 1818), *Prochilodus nigricans* Spix et Agassiz, 1829, *Semaprochilodus insignis* (Jardine, 1841), and *Semaprochilodus taeniurus* (Valenciennes, 1821). This study aimed to estimate the von Bertalanffy growth parameters for five fish species of significant commercial interest within six rivers in the Amazon region. In addition, the study built auximetric plots of each of the three families to which these species belong (Characidae, Prochilodontidae, and Serrasalmidae).

MATERIAL AND METHODS

The samples were obtained from the catches of commercial fisheries along the Amazon, Japurá, Juruá, Madeira, Negro, and Purus rivers that landed at the Port of Manaus, Brazil (03º08′47′′S, 60º06′35′′W). The sampling protocol was designed to measure the fish length of a total of 300 individuals per month. Thus, 30 individuals per species per night had their fork length (FL, cm) measured (as the caudal fin was often damaged) on 10 randomly selected days within a month-long period. To ensure a 'knife-edge' selection, only those fish captured with 20 mm mesh seine net were used in this analysis (see Batista and Freitas (2003) for technological fishing details). Five out of the 10 species with the highest catches in the

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database were examined, namely *Prochilodus nigricans*, *Semaprochilodus insignis*, *Semaprochilodus taeniurus*, *Brycon amazonicus*, and *Piaractus brachypomus*.

Growth parameters were estimated using the seasonal growth curve proposed by Hoenig and Hanumara (1990). The equation is:

$$L(t) = L\infty\left\{1 - e^{-\left[K\,(t - t0) + \frac{KC}{2\pi}SIN\,2\pi\,(t - ts) - \frac{KC}{2\pi}SIN\,2\pi\,(t0 - ts)\right]}\right\}$$

where K is the growth coefficient, L_∞ the asymptotic size, t_0 the theoretical age at zero length, C the relative amplitude of seasonal oscillations, and the t_s describes the phase of seasonal oscillations.

Finally, the Winter Point (WP) (García-Berthou et al. 2012) was determined using the following equation:

$$\mathrm{WP} = t\mathrm{s} + 0.5$$

The ELEFAN routine of the LFDA program (Kirkwood et al. 2001) was used with sets of between two and six years, depending on data availability. A growth curve was fitted using any arbitrary 'seed' input values of L_∞ and K (Pauly and David 1981).

RESULTS

In some years, only juveniles were caught. Thus, the length at first maturity available in the literature, as well as the maximum length found here, were used to ensure that the data used—and, consequently, the estimates found—were reliable. Thus, we only used years in which data were available for both juveniles and adults. Moreover, we used the age at first maturity available in the literature to evaluate the reliability of the growth curve estimates for each species (Table 1).

Finally, as Pauly (1998) reported an inverse pattern between the asymptotic lengths and the growth coefficients of tropical fish, auximetric plots were built for each of the three families to which the species studied here belong: Characidae, Prochilodontidae, and Serrasalmidae. In addition, we utilised other growth parameters found in FishBase (Froese and Pauly 2018), and 21 other studies (Ruffino and Isaac 1995, Isaac and Ruffino 1996, Lizama and Ambrósio 2003, Penna et al. 2005, Silva and Stewart 2006, Cunha et al. 2007, Gomiero et al. 2007, Peixer et al. 2007, Santos Filho and Batista 2009, Carmassi et al. 2011, Bevilaqua and Soares 2010, Isaac et al. 2012, Lourenço et al. 2012, Tondato et al. 2012, Vicentin et al. 2012, Pérez-Lozano and Aniello 2013, Sousa et al. 2013, Ambrósio et al. 2014, Catarino et al. 2014, Vaz unpublished*, Villacorta-Corrêa unpublished**) (Table 2), for these same families. The correlation between the two variables of each of the auximetric plots ($\log_{10}$ asymptotic length and $\log_{10}$ growth coefficient) was tested using the non-parametric Spearman rs test.

The growth parameter estimates are shown in Table 3, and the LFDA growth curves in Figs. 1–7. Additional information used in the estimation of these parameters is available in Table 1.

DISCUSSION

Fish exhibit differences in growth as a result of being subjected to environmental fluctuations (King 2007). Amazonian fish are also subject to the annual flood regime, as well as periodical natural climatic phenomena (Junk 1983, Tomasella et al. 2012, Camacho Guerreiro et al. 2016, Guerreiro 2017). The variations observed in the growth parameters of some of the species sampled appear to accord with the high degree of environmental variation observed in this type of ecosystem.

No trend was observed in the auximetric plot of Characidae (Spearman rs test, $r_s = -0.14$, $P = 0.60$) (Fig. 8A). However, for the Prochilodontidae (Spearman rs test, $r_s = -0.67$, $P < 0.001$) (Fig. 8B) and Serrasalmidae (Spearman rs test, $r_s = -0.65$, $P < 0.001$) (Fig. 8C) families, a significant and inverse relation was found between the growth parameters. Growth parameters were found in the literature for only 10 species out of the 1113 species belonging to the Characidae (Froese and Pauly 2018). Thus, great effort is required to fill this research gap before it will be possible to build an auximetric plot for this family.

Finally, the pattern observed here between the growth parameters of Prochilodontidae and Serrasalmidae was similar to that recorded by Pauly (1998), supporting the reliability of the estimates obtained. In fact, the clusters of points on the auximetric plot seem to reflect similarities between the various species within these families.

ACKNOWLEDGEMENTS

We thank all fishers that provided information about catches and the team that collected this information; Elsa Guerreiro for reviewing the English of this paper; and Victor Silva for editing figures in Adobe Illustrator. This study was funded by Coordination for the Improvement of Higher Education Personnel (CAPES) (AICG grant), the Brazilian Innovation Agency (FINEP), and the [Brazilian] Ministry of Fisheries and Aquaculture (MPA) (grant No. 01.10.0770.00).

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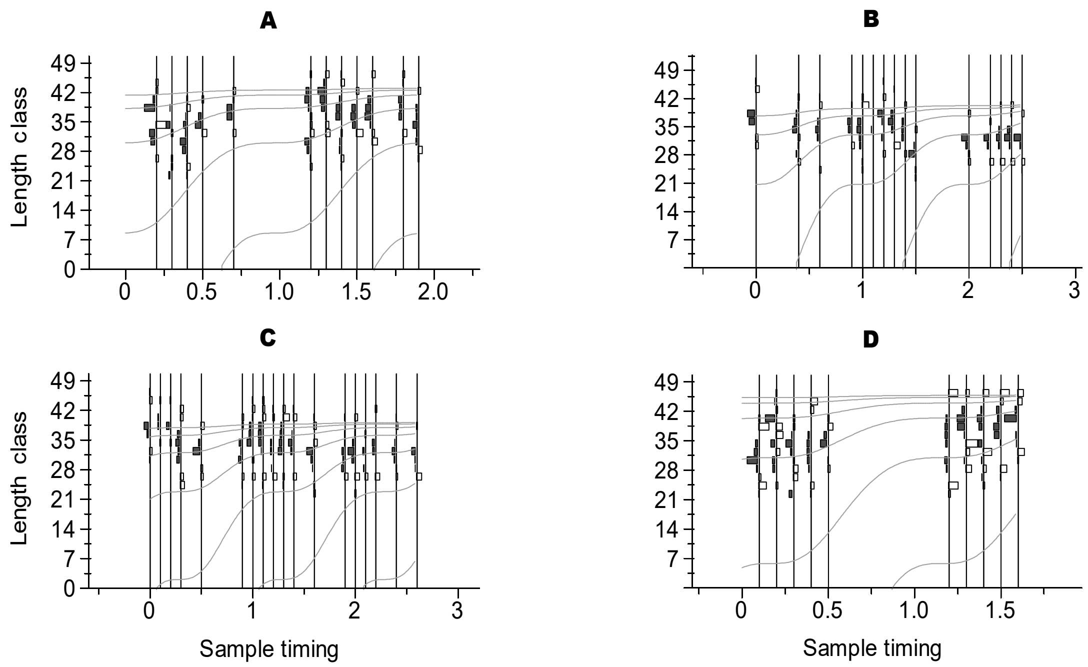

Fig. 1. Growth curves of *Brycon amazonicus* caught in three Amazonian rivers: (**A**) Amazonas 2003–2004, (**B**) Japurá 1998–2000, (**C**) Juruá 1998–2000, and (**D**) Purus 2003–2004

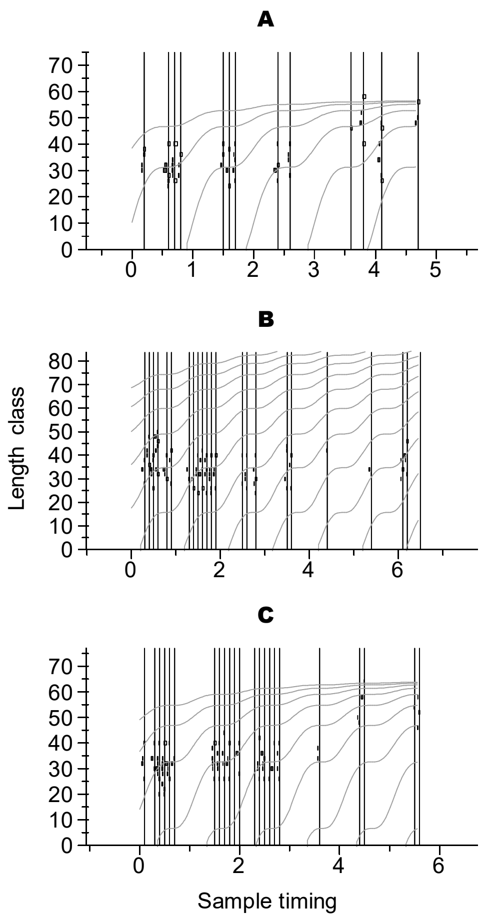

Fig. 2. Growth curves of *Piaractus brachypomus* caught in three Amazonian rivers: (**A**) Amazonas 2000–2004, (**B**) Japurá 1998–2004, and (**C**) Purus 1999–2004

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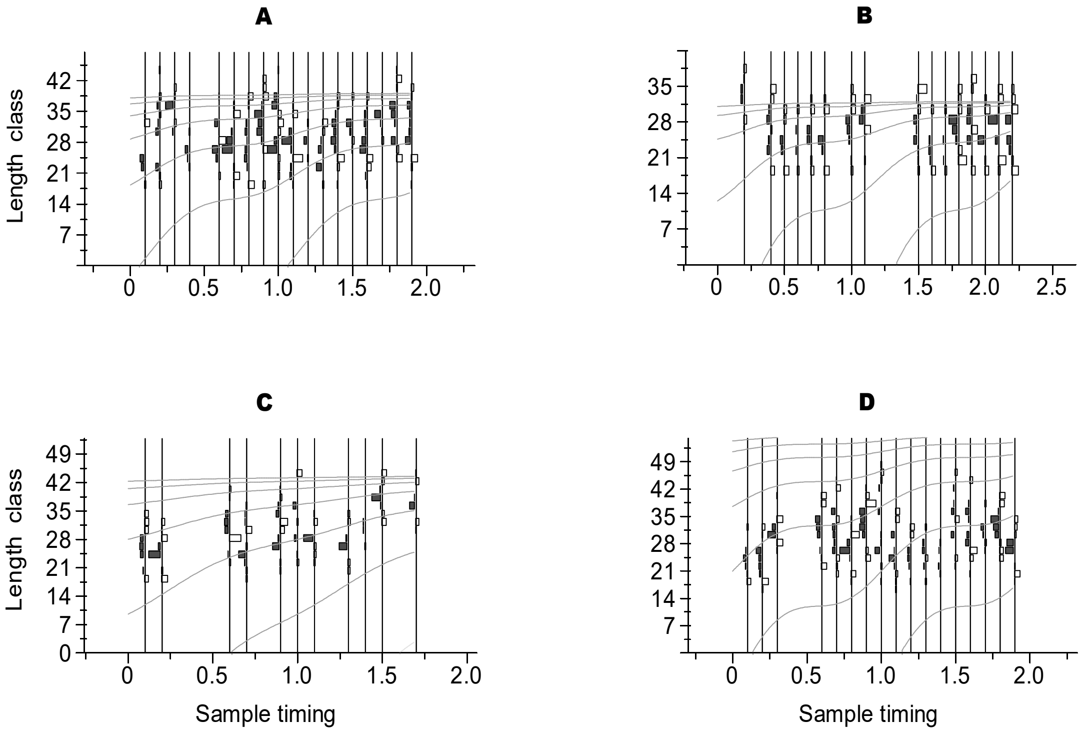

Fig. 3. Growth curves of *Prochilodus nigricans* caught in four Amazonian rivers: (**A**) Amazonas 1995–1996, (**B**) Japurá 1998–2000, (**C**) Madeira 1995–1996, and (**D**) Purus 1995–1996

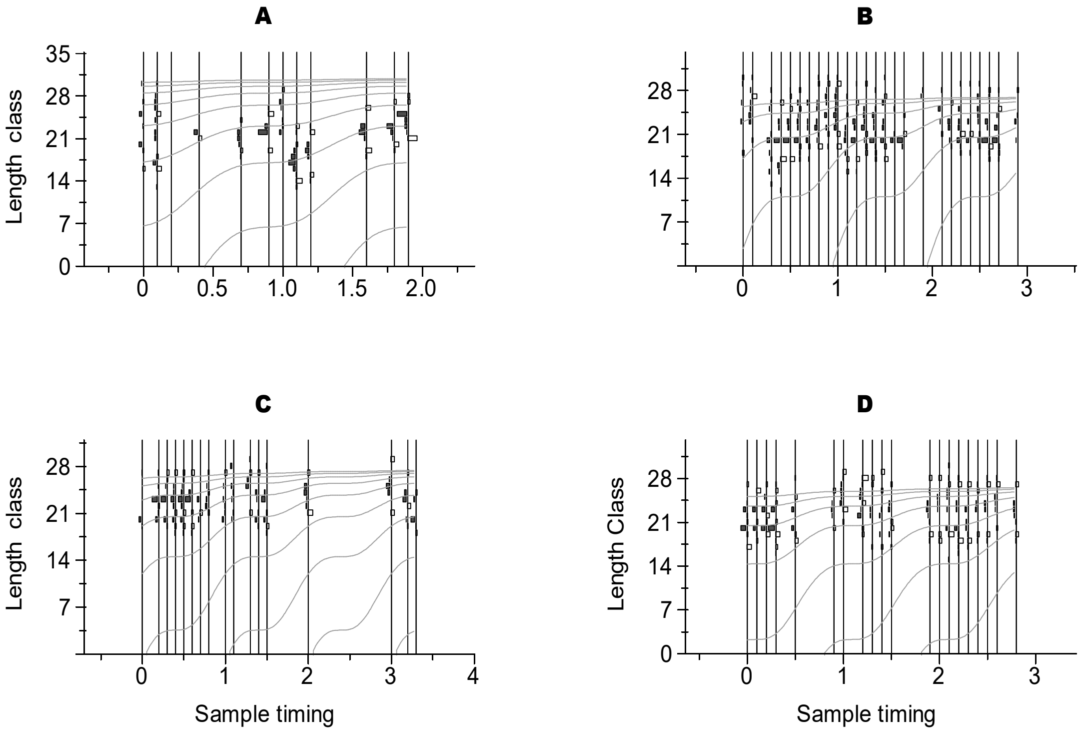

Fig. 4. Growth curves of *Semaprochilodus insignis* caught in two Amazonian rivers: Negro (**A**) 1995–1996, (**B**) 1998–2000, and (**C**) 2001–2004; and (**D**) Purus 2002–2004

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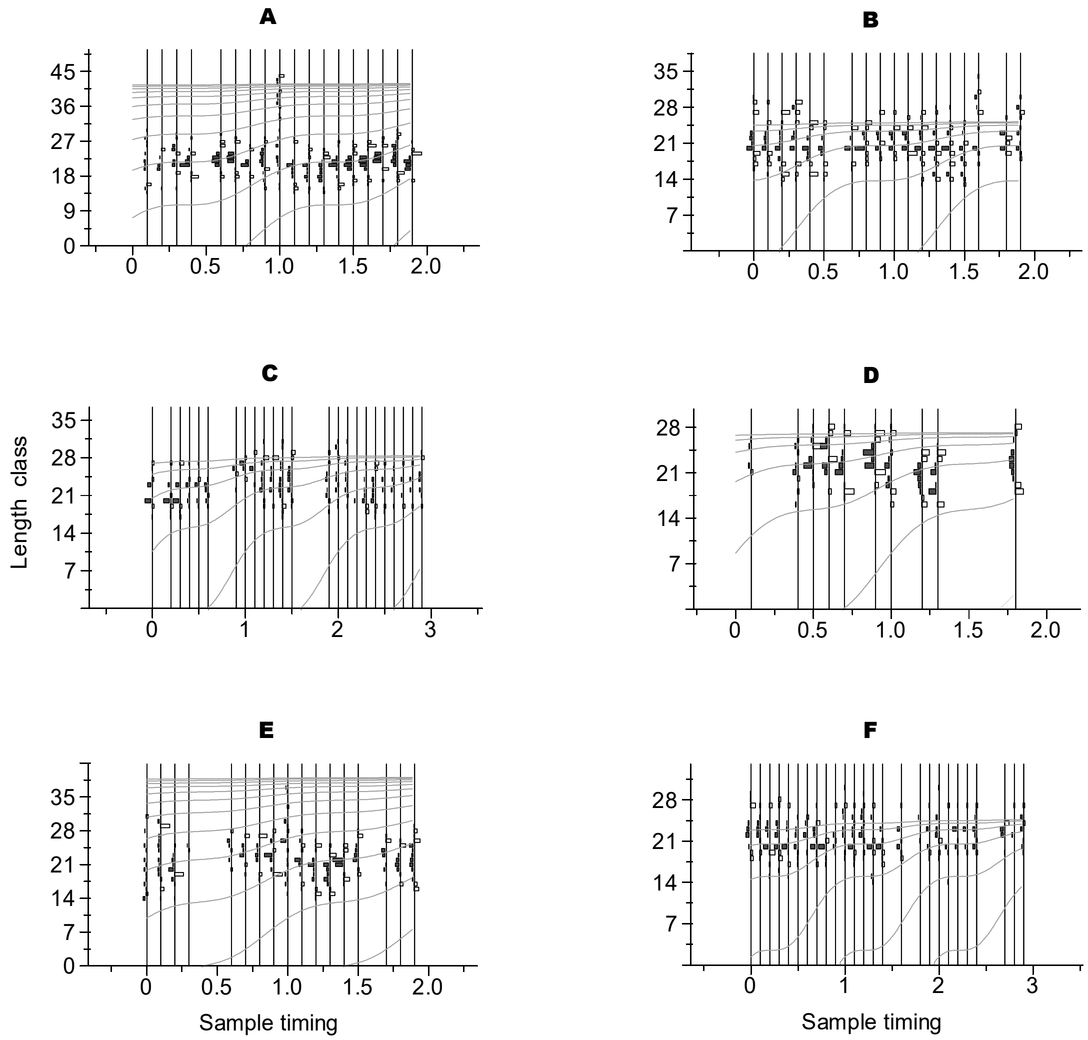

Fig. 5. Growth curves of *Semaprochilodus insignis* caught in three Amazonian rivers: Amazonas (**A**) 1995–1996, (**B**) 1999–2000, and (**C**) 2002–2004; (**D**) Juruá 1995–1996; and Madeira (**E**) 1995–1996, and (**F**) 1999–2001

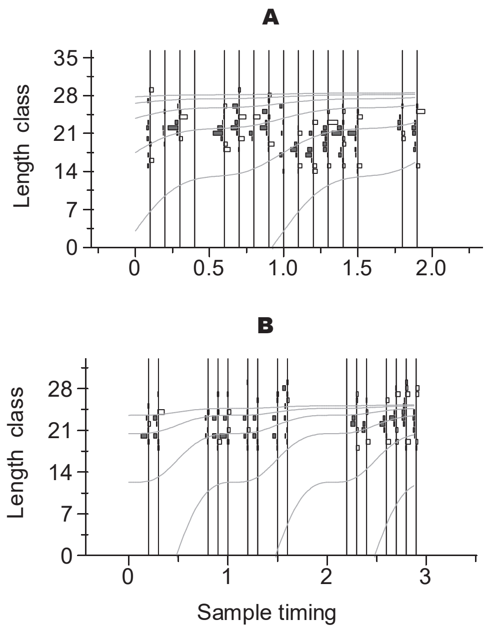

Fig. 6. Growth curves of *Semaprochilodus taeniurus* caught in the Amazonas river: (**A**) 1995–1996, and (**B**) 2001–2003

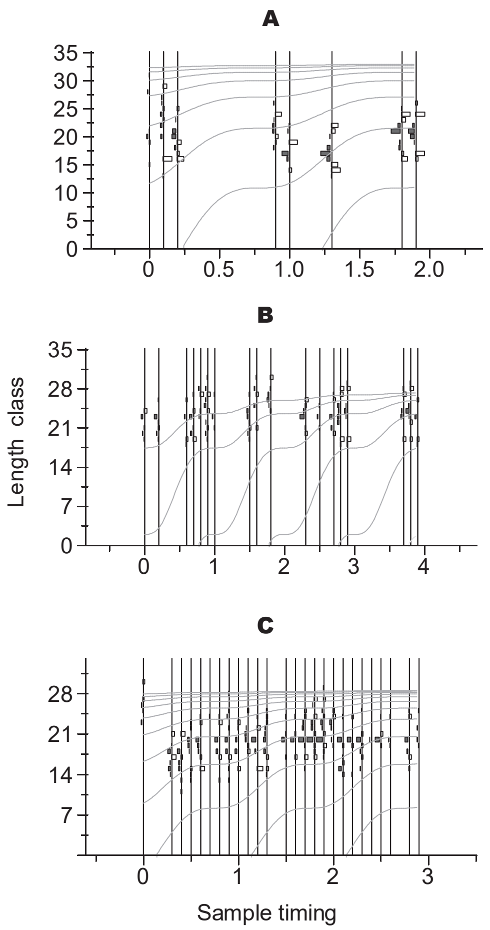

Fig. 7. Growth curves of *Semaprochilodus taeniurus* caught in three Amazonian rivers: (**A**) Madeira 1995–1996; (**B**) Negro 2001–2004; and (**C**) Purus 1998–2000

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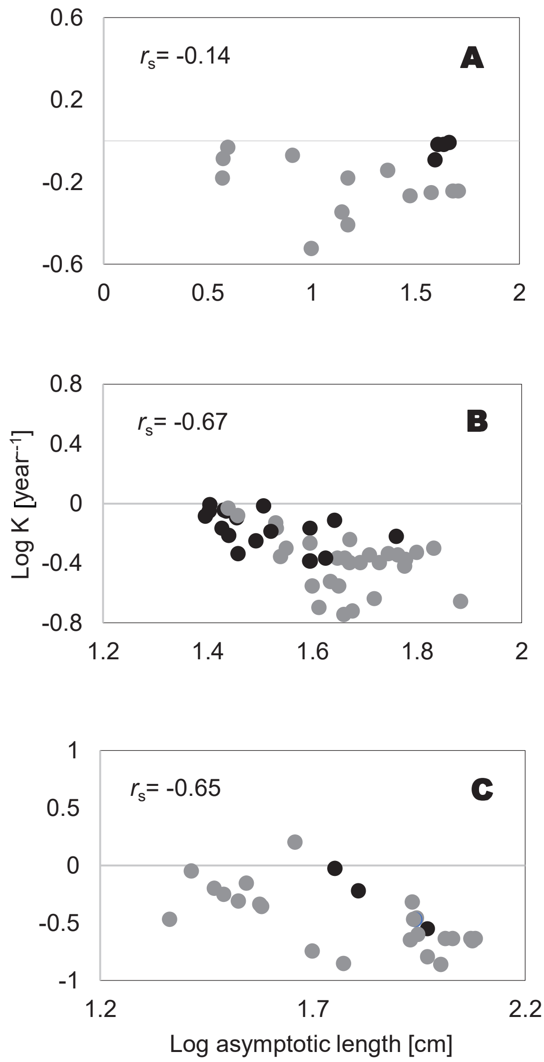

Fig. 8. Auximetric plots of (**A**) Characidae, (**B**) Prochilodontidae, and (**C**) Serrasalmidae; growth parameters: black circles, this study; grey circles, other studies

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Table 1

Complementary information, for the estimation of growth parameters of five species from six Amazonian rivers

Species	First maturity		River	Year	Maximum size (FL) [cm]
	Length (FL) [cm]	Age [year]			
Brycon amazonicus	37[1]	2[2]	Amazonas	2003–2004	46
			Japurá	1998–2000	48
			Juruá	1998–2000	46
			Purus	2003–2004	46
Piaractus brachypomus	59[3]	3[4]	Amazonas	2000–2004	68
			Japurá	1998–2004	76
			Purus	1999–2004	70
Prochilodus nigricans	27[1]	2[5]	Amazonas	1995–1996	44
			Japurá	1998–2000	38
			Madeira	1995–1996	48
			Purus	1995–1996	50
Semaprochilodus insignis	23[1]	2[6]	Amazonas	1995–1996	46
				1999–2000	35
				2002–2004	34
			Juruá	1995–1996	28
			Madeira	1995–1996	38
				1999–2001	31
			Negro	1995–1996	32
				1998–2000	31
				2001–2004	29
			Purus	2002–2004	31
Semaprochilodus taeniurus	22[1]	2[6]	Amazonas	1995–1996	32
				2001–2003	30
			Madeira	1995–1996	32
			Negro	2001–2004	32
			Purus	1998–2000	31

Values of the length at first maturity, available in the literature, were converted into fork length (FL) using the species-specific, length–length equation, which is available in Froese and Pauly (2018); [1]Santos et al. 2006, [2]Lopes et al. 2016, [3]Froese and Pauly 2018, [4]Escobar et al. 2015, [5]Santana and Freitas 2013, [6]Vieira unpublished[*].

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Table 2

Growth parameters of Characidae, Prochilodontidae, and Serrasalmidae

Species	$L\infty$	K	Reference
Astyanax altiparanae Garutti et Britski, 2000	14.0	0.45	Froese and Pauly 2018
	15.0	0.39	
	15.0	0.66	
Brycon amazonicus (Spix et Agassiz, 1829)	43.3	0.96	This study
	40.6	0.96	
	39.4	0.81	
	46.1	0.98	
	51.0	0.57	Santos Filho and Batista 2009
	48.0	0.57	Isaac et al. 2012
Brycon opalinus (Cuvier, 1819)	29.8	0.54	Gomiero et al. 2007
	37.7	0.56	
Hemigrammus marginatus Ellis, 1911	3.7	0.66	Lourenço et al. 2012
Moenkhausia dichroura (Kner, 1858)	8.1	0.85	Cunha et al. 2007
Moenkhausia intermedia Eigenmann, 1908	10.0	0.30	Lizama and Ambrósio 2003
Odontostilbe pequira (Steindachner, 1882)	4.0	0.93	Tondato et al. 2012
Oligosarcus hepsetus (Cuvier, 1829)	23.3	0.72	Carmassi et al. 2011
Prochilodus brevis Steindachner, 1875	47.0	0.57	Froese and Pauly 2018
Prochilodus lineatus (Valenciennes, 1837)	33.9	0.74	Froese and Pauly 2018
	34.0	0.68	
	39.5	0.41	
	44.5	0.43	
	45.9	0.43	
	47.5	0.19	
	49.2	0.40	
	51.2	0.45	
	52.3	0.23	
	53.5	0.40	
	76.5	0.22	
	55.7	0.46	Vicentin et al. 2012
Prochilodus magdalenae Steindachner, 1879	39.4	0.54	Froese and Pauly 2018
	43.1	0.30	
	44.7	0.28	
	59.8	0.38	
	60.0	0.42	
Prochilodus mariae Eigenmann, 1922	46.9	0.40	Pérez-Lozano and Aniello 2013
Prochilodus nigricans Spix et Agassiz, 1829	39.5	0.68	This study
	32.1	0.96	
	43.9	0.77	
	57.7	0.60	
	68.0	0.50	Ruffino and Isaac 1995
	58.0	0.45	
	34.6	0.44	Catarino et al. 2014
	45.8	0.18	Silva and Stewart 2006
	39.8	0.28	
	63.0	0.47	Isaac et al. 2012
Prochilodus reticulatus Valenciennes, 1850	41.0	0.20	Froese and Pauly 2018
Semaprochilodus insignis (Jardine, 1841)	42.2	0.43	This study
	25.3	0.89	
	28.6	0.80	
	27.3	0.89	
	39.4	0.41	
	24.9	0.82	
	31.1	0.56	

Table continues on next page.

[*] See footnote on page 309.

Table 2 cont.

Species	L∞	K	Reference
	27.0	0.90	
	27.6	0.61	
	26.8	0.68	
Semaprochilodus taeniurus (Valenciennes, 1821)	28.7	0.83	This study
	25.4	0.98	
	33.2	0.65	
	27.5	0.93	
	28.7	0.46	
	35.5	0.50	Isaac et al. 2012
Colossoma macropomum (Cuvier, 1816)	121.0	0.23	Ruffino and Isaac 1995
	118.0	0.23	
	119.9	0.23	Isaac and Ruffino 1996
	107.0	0.23	Froese and Pauly 2018
	88.7	0.25	Pérez-Lozano and Aniello 2013
	119.0	0.22	Isaac et al. 2012
	85.1	0.23	Penna et al. 2005
	100.4	0.14	
	93.3	0.16	Villacorta-Corrêa unpublished*
Myloplus rhomboidalis (Cuvier, 1818)	38.0	0.44	Froese and Pauly 2018
Mylossoma duriventre (Cuvier, 1818)	33.5	0.49	Pérez-Lozano and Aniello 2013
	31.0	0.56	Isaac et al. 2012
Piaractus brachypomus (Cuvier, 1818)	56.6	0.94	This study
	93.4	0.28	
	64.3	0.60	
	45.6	1.59	Froese and Pauly 2018
	102.9	0.23	Pérez-Lozano and Aniello 2013
	88.0	0.35	Isaac et al. 2012
Piaractus mesopotamicus (Holmberg, 1887)	50.0	0.18	Ambrósio et al. 2014
	59.2	0.14	
	87.2	0.34	Peixer et al. 2007
	86.5	0.34	
	86.0	0.48	Vaz unpublished*
Pygocentrus cariba (von Humboldt, 1821)	37.6	0.46	Pérez-Lozano and Aniello 2013
Pygocentrus nattereri Kner, 1858	26.0	0.89	Froese and Pauly 2018
	29.4	0.63	Bevilaqua and Soares 2010
	35.0	0.70	Isaac et al. 2012
Serrasalmus spilopleura Kner, 1858	23.1	0.34	Sousa et al. 2013

L∞ = asymptotic length, *K* = growth coefficient.

* See footnote on page 309.

Table 3

Growth parameters estimates for five species of six Amazonian rivers

Species	River	Year	N	Results				
				L_∞	K	t_0	C	WP
Brycon amazonicus	Amazonas	2003–2004	911	43.29	0.96	–0.39	0.99	Dec
	Japurá	1998–2000	819	40.63	0.96	–0.64	1.00	Dec
	Juruá	1998–2000	1942	39.38	0.81	–0.94	0.99	Apr
	Purus	2003–2004	736	46.07	0.98	–0.23	0.93	Jan
Piaractus brachypomus	Amazonas	2000–2004	591	56.57	0.94	–0.14	1.00	May
	Japurá	1998–2004	1147	93.43	0.28	–0.83	1.00	Oct
	Purus	1999–2004	1468	64.29	0.60	–0.61	1.00	Sep
Prochilodus nigricans	Amazonas	1995–1996	1643	39.45	0.68	–0.94	0.76	Sep
	Japurá	1998–2000	830	32.14	0.96	–0.71	0.99	Oct
	Madeira	1995–1996	696	43.90	0.77	–0.40	0.31	Nov
	Purus	1995–1996	1673	57.65	0.60	–0.87	0.96	Jul
Semaprochilodus insignis		1995–1996	2920	42.21	0.43	–0.24	1.00	May
	Amazonas	1999–2000	6667	25.29	0.89	–0.83	1.00	Nov
		2002–2004	4216	28.57	0.80	–0.38	0.83	May
	Juruá	1995–1996	423	27.29	0.89	–0.30	0.83	Mar
	Madeira	1995–1996	1331	39.39	0.41	–0.64	0.75	May
		1999–2001	3449	24.86	0.82	–0.08	1.00	Mar
		1995–1996	544	31.09	0.56	–0.56	0.94	Nov
	Negro	1998–2000	7109	27.00	0.90	–0.05	1.00	Jun
		2001–2004	1241	27.57	0.61	–0.90	1.00	May
	Purus	2002–2004	2927	26.75	0.68	–0.20	1.00	Feb
Semaprochilodus taeniurus	Amazonas	1995–1996	1122	28.69	0.83	–0.08	0.82	July
		2001–2003	1850	25.36	0.98	–0.53	1.00	Jan
	Madeira	1995–1996	563	33.17	0.65	–0.77	1.00	Oct
	Negro	2001–2004	1310	27.50	0.93	–0.23	1.00	Dec
	Purus	1998–2000	4346	28.73	0.46	–0.87	1.00	Oct

L_∞ = asymptotic length, K = growth coefficient, t_0 = theoretical age at zero length, C = relative amplitude of seasonal oscillations, WP = winter point.

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Received: 20 November 2017
Accepted: 24 May 2018
Published electronically: 30 September 2018