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

Ana GUERREIRO 1*, Sidineia AMADIO 2, Nídia FABRÉ 3, and Vandick BATISTA 3

1 Pós-graduação em Biologia de Água Doce e Pesca Interior, Instituto Nacional de Pesquisas da Amazônia, Petrópolis, Manaus, Amazonas, Brazil
2 Coordenação de Biodiversidade, Instituto Nacional de Pesquisas da Amazônia, Petrópolis, Manaus, Amazonas, Brazil
3 Instituto de Ciências Biológicas e da Saúde, Universidade Federal de Alagoas, Campus A. C. Simões, Tabuleiro dos Martins, Maceió, Alagoas, Brazil

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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 (03°08′47″S, 60°06′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
database were examined, namely *Prochilodus nigricanus*, *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:

\[
L(t) = L_\infty \left(1 - e^{-\left(\frac{K}{2(\pi C)^2} \sin \left(\frac{2\pi t}{s}\right) \sin \left(\frac{2\pi t}{s} - \frac{\pi}{2}\right)\right)}\right)
\]

where \( K \) is the growth coefficient, \( L_\infty \) 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) (Garcia-Berthou et al. 2012) was determined using the following equation:

\[
WP = t_s + 0.5
\]

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 \( L_\infty \) 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 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.

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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

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**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

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] |
|--------------------------|----------------|-----------|------------|------------------------|
| *Brycon amazonicus*     | 37³  2²         | Amazonas  | 2003–2004  | 46                     |
|                          |                | Japurá    | 1998–2000  | 48                     |
|                          |                | Juruá     | 1998–2000  | 46                     |
|                          |                | Purus     | 2003–2004  | 46                     |
| *Piaractus brachypomus* | 59³  3⁴         | Amazonas  | 2000–2004  | 68                     |
|                          |                | Japurá    | 1998–2004  | 76                     |
|                          |                | Purus     | 1999–2004  | 70                     |
| *Prochilodus nigricans* | 27³  2²         | Amazonas  | 1995–1996  | 44                     |
|                          |                | Japurá    | 1998–2000  | 38                     |
|                          |                | Madeira   | 1995–1996  | 48                     |
|                          |                | Purus     | 1995–1996  | 50                     |
| *Semaprochilodus insignis*| 23³  2⁶       | Amazonas  | 1995–1996  | 46                     |
|                          |                | 1999–2000  | 35                     |
|                          |                | 2002–2004  | 34                     |
|                          |                | Juruá     | 1995–1996  | 28                     |
|                          |                | Madeira   | 1995–1996  | 38                     |
|                          |                | Negro     | 1999–2001  | 31                     |
|                          |                | 1995–1996  | 32                     |
|                          |                | 1998–2000  | 31                     |
|                          |                | 2001–2004  | 29                     |
| *Semaprochilodus taeniurus* | 22³  2⁶       | Amazonas  | 1995–1996  | 32                     |
|                          |                | Purus     | 2002–2004  | 31                     |
|                          |                | 1995–1996  | 32                     |
|                          |                | 1998–2000  | 31                     |
|                          |                | Madeira   | 2001–2004  | 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); ¹Santos et al. 2006, ²Lopes et al. 2016, ³Froese and Pauly 2018, ⁴Escobar et al. 2015, ⁵Santana and Freitas 2013, ⁶Vieira 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 dichrous* (Kner, 1858) | 8.1        | 0.85 | Cunha et al. 2007          |
| *Moenkhausia intermedia* Eigenmann, 1908 | 10.0       | 0.30 | Lizama and Ambrósio 2003   |
| *Odontostilbe pequiri* (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 magdenae* 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 |                            |

* See footnote on page 309.

Table continues on next page.
Table 2 cont.

| Species                        | $L_\infty$ | $K$  | Reference                   |
|-------------------------------|------------|------|----------------------------|
| *Semaprochilodus taeniurus* (Valenciennes, 1821) | 27.0       | 0.90 | This study                 |
|                               | 27.6       | 0.61 |                            |
|                               | 26.8       | 0.68 |                            |
| *Colossoma macropomum* (Cuvier, 1816) | 28.7       | 0.83 | Isaac et al. 2012          |
|                               | 25.4       | 0.98 |                            |
|                               | 33.2       | 0.65 |                            |
|                               | 27.5       | 0.93 |                            |
|                               | 28.7       | 0.46 |                            |
|                               | 35.5       | 0.50 |                            |
| *Myloplus rhomboidalis* (Cuvier, 1818) | 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* |
| *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 |                            |
|                               | 102.9      | 0.23 |                            |
|                               | 88.0       | 0.35 |                            |
| *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          |

$L_\infty =$ asymptotic length, $K =$ growth coefficient.

* See footnote on page 309.
| Species              | River         | Year          | N   | Results |
|---------------------|---------------|---------------|-----|---------|
|                     |               |               |     | $L_\infty$ | $K$ | $t_0$ | 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        | 1998–2000     | 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* | Amazonas | 1995–1996     | 2920| 42.21    | 0.43 | −0.24 | 1.00 | May   |
|                     |                | 1999–2000     | 6667| 25.29    | 0.89 | −0.83 | 0.83 | May   |
|                     |                | 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    |
|                     |                | 2002–2004     | 2927| 26.75    | 0.68 | −0.20 | 1.00 | Feb    |
| *Semaprochilodus taeoniurus* | 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    |

$L_\infty$ = 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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