

# GROWTH PARAMETERS AND YIELD PER RECRUIT ANALYSIS FOR THE ARMoured CATFISH *Pterygoplichthys pardalis* SAMPLED IN THE LOW REACH OF THE AMAZONAS RIVER

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## ABSTRACT

Armoured catfish *Pterygoplichthys pardalis* is an endemic fish from the Amazon basin (Brazil) and currently is the top ten target species in the regional fisheries. A total of 1,200 samples were collected monthly from March 2011 to February 2012 with an average length of  $28 \pm 2.57$  cm and average weight of  $441.57 \pm 103.37$  g. The growth stock parameters for this species ( $W_t = 0.431227 * L_t^{2.08637}$ ;  $M = 0.93$  year<sup>-1</sup>;  $F_{-Estimated} = 0.91$  year<sup>-1</sup>;  $F_{-10} = 3.02$  year<sup>-1</sup>;  $A_{0.95} = 7.31$  years;  $K = 0.41$  year<sup>-1</sup>;  $T_r = T_c = 1.92$  years;  $L_c = 21.14$  cm;  $L_\infty = 38.85$  cm;  $W_\infty = 869.76$  g) and exploitation rate ( $E_{-Estimated} = 0.50$ ;  $E_{-10} = 0.80$ ) reveal that its stocks are not being overfished in the study area. The baseline information obtained in this study can help support fisheries management strategies of *P. pardalis*, especially regarding the potential implementation of a policy to increase landings of individuals larger than 22.3 cm length. However, before making a final decision, it is necessary to carefully examine the available information and evidence aimed at sustainable fishing management and conservation of their stocks, which is of great cultural, social and economic importance for Amazonian peoples.

**Keywords:** acarí-bodó; Amazon basin; fisheries; native fish; yield per recruit; Tupinambarana Island.

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## PARÂMETROS DE CRESCIMENTO E ANÁLISE DA TAXA DE RECRUTAMENTO DO PEIXE CASCUDO *Pterygoplichthys pardalis* PESCADO NO TRECHO DO BAIXO RIO AMAZONAS

## RESUMO

O peixe cascudo *Pterygoplichthys pardalis* é uma espécie nativa da bacia Amazônica (Brasil), e atualmente está entre as dez espécies alvo nas pescarias regionais. Exemplos dessa espécie foram obtidos entre março de 2011 e fevereiro de 2012, em coletas mensais, agregando 1.200 espécimes, com média de comprimento de  $28 \pm 2,57$  cm, e média de peso de  $441,57 \pm 103,37$  g. Os parâmetros do crescimento do estoque do peixe cascudo ( $W_t = 0,431227 * L_t^{2,08637}$ ;  $M = 0,93$  ano<sup>-1</sup>;  $F_{-Estimado} = 0,91$  ano<sup>-1</sup>;  $F_{-10} = 3,02$  ano<sup>-1</sup>;  $A_{0,95} = 7,31$  anos;  $K = 0,41$  ano<sup>-1</sup>;  $T_r = T_c = 1,92$  anos;  $L_c = 21,14$  cm;  $L_\infty = 38,85$  cm;  $W_\infty = 869,76$  g) e taxa de exploração ( $E_{-Estimada} = 0,50$ ;  $E_{-10} = 0,80$ ) revelaram que a espécie não está em situação de sobre pesca na área do estudo. As informações obtidas neste estudo, são pioneiras e gerais, e podem embasar medidas para a gestão da pesca, especialmente com a possibilidade de aumentar o esforço de captura sobre os indivíduos de *P. pardalis* com comprimento em torno de 22,3 cm. No entanto, é necessário ter cautela durante as tomadas de decisões, objetivando o manejo sustentável da atividade pesqueira e a conservação de seus estoques, que são de grande importância cultural, social e econômica para as populações amazônicas.

**Palavras-chave:** acarí-bodó; pescarias amazônicas; Bacia Amazônica; peixe nativo; taxa por recruta; Ilha Tupinambarana.

## INTRODUCTION

The Amazon basin is the largest freshwater basin in the world (ANA, 2018), consisting of a huge and complex system of rivers with adjacent floodplains (Junk et al., 2007). This ecosystem hosts the highest ichthyofauna diversity on Earth (Reis et al., 2016), totaling approximately 2,500 fish species already described (Junk et al., 2007; Lévêque et al., 2008). Consequently, this abundance of fish is exploited by more than

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330,000 fishers in the Brazilian Amazon basin (BRASIL, 2016), both for subsistence and commercial means. These fisheries are also important in terms of social, economic and cultural (traditional practices) aspects for the riverine communities that inhabit the banks of Amazonian rivers and lakes (Barthem and Fabr e, 2004; Isaac et al., 2015; Souza et al., 2015).

In the last four decades, the equilibrium between fisher (resource user) and fish (exploited resource) has changed, with the number of fishers increasing, while the number of fish has decreased. Therefore, overexploitation has occurred with some fish stocks, mainly popular commercial fish species like tambaqui (Campos et al., 2015). Concomitantly, loss of fish habitat predominantly caused by the construction of hydroelectric dam installations, has intensified in recent years, thereby negatively impacting fish stocks (Doria et al., 2017).

Amazonian fishery yields are strongly dependent on the seasonal dynamics of the hydrological flood pulse (Garcez et al., 2017). Specifically, the hydrological pattern has been shown to directly affect the diversity and composition of fish assemblages (Souza et al., 2015), whose abundances or scarcities ultimately dictate fisheries' successes or failures (Souza et al., 2015; Garcez et al., 2017).

Several fish species present morphological adaptations to survive in floodplain areas during the low water or drought season, when environmental conditions are adverse. Consequently, these characteristics allow certain fish assemblages to stay in these areas throughout the entire annual hydrological period (Garcez and Freitas, 2008). For example, some fish species that belong to the Siluriformes family have taxonomical adaptations that allow the individuals to survive in anoxic environments, which is the case of the armored catfish *Pterygoplichthys pardalis* (Castelnau, 1855).

*P. pardalis*, known locally as acari-bod o by the riverine communities, is a medium-sized fish that belongs to the Loricariidae Family, reaching a maximum total length of approximately 49 cm and 550 g of total weight (Neves and Ruffino, 1998; Jumawan and Seronay, 2017). Acari-bod o is benthic in nature and occurs exclusively in the Amazon basin (Weber, 1992), being found in different aquatic habitats, including floodplain areas, lakes, and on the margins of black, clear and white waters rivers. It has detritivorous feeding habits, feeding mainly on amorphous organic material, sediments and algae (Santos et al., 2006). *P. pardalis* also has air-breathing capability, with a high level of anaerobic metabolism, and can live in water with low dissolved oxygen (Bailey et al., 1997). *P. pardalis* does not migrate and shows an equilibrium reproductive strategy (Winemiller, 1989), which results in a prolonged reproductive period, spanning approximately eight months of every year (Neves and Ruffino, 1998).

*P. pardalis* is among the top ten fish species consumed by people in the Central Amazon region (Cerdeira et al., 1997; Neves and Ruffino, 1998), as it's a very tasty fish with high protein quality and low fat (Ferreira et al., 1998). Its muscle tissue is used to produce fish-meal powder, locally known as "piracui", which is widely consumed by Amazonian riverine communities (Loure o et al., 2011). Due to its popularity as a food fish, as well as its ability to survive for more than 30 hours outside of the water (Val and Almeida-Val, 1995), Amazonian artisanal fishermen catch and commercialize live specimens of acari-bod o at marketplaces in urban

centers, due to quick degradation after mortality (Loure o et al., 2011). Commercial landings of acari-bod o have been observed in many cities along the Solim es-Amazonas River, including in Parintins municipality in Amazonas State, mainly for consumption purposes (personal observation).

Many studies have investigated different aspects of *P. pardalis*, including its reproductive biology (Neves and Ruffino, 1998; Winemiller, 1989), air-breathing capability (Bailey et al., 1997), its potential for use in developing commercial food products, (Loure o et al., 2011), and also as an environment bio-indicator species (Freitas and Siqueira-Souza, 2009). However, there is not one study that has investigated the populations dynamics of *P. pardalis*, especially in relation to fish stocks and impacts from fishing. Furthermore, the lack of fisheries data compromises the ability to implement conservation management strategies, which also need to take into consideration both socioeconomic and ecological importance of this species for Amazonian populations. In this way, the present research aims to estimate the population dynamics and growth parameters of *P. pardalis* compiled from seasonal fish landing data in Parintins municipality, in order to try and determine the sustainability of the fishery in that region and support future management plans for its conservation.

## METHODS

### Study area

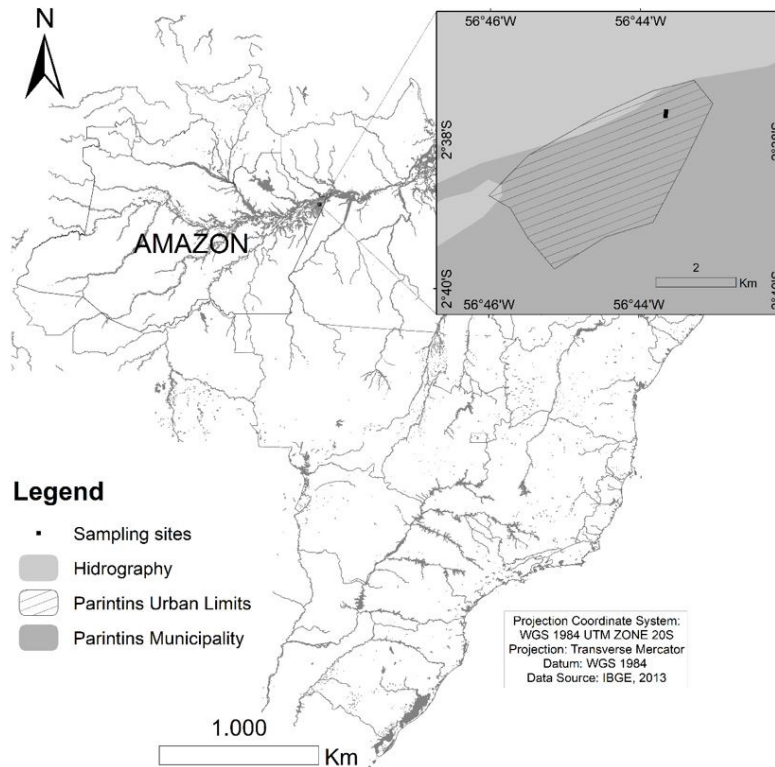
The present research was conducted in the small city of Parintins (Tupinambarana island, 02° 37' 42" S and 56° 44' 09" W), which is situated on the southern margin of the Amazon River in eastern Amazonas State, Brazil (Figure 1). The municipality of Parintins encompasses an area of 5,952 km<sup>2</sup>, which reported a population of 113,832 people in 2016 (IBGE, 2017).

### Sample collections

Samples of *P. pardalis* were collected monthly from March 2011 to February 2012 (n = 100 per month) from commercial fish landings at Baga o and Zezito Assayag markets in the city of Parintins. Fish specimens were preserved in coolers with ice and transported to the Fish Ecology Laboratory at the Federal Institute of Education, Science and Technology of Amazonas State, where measurements of total length ( $L_t$  - cm) and total weight ( $W_t$  - g) were taken.

### Data analyses

All of the biometric values ( $L_t$  and  $W_t$ ) of *P. pardalis* individuals were compiled using Statistica 9.0 software (STATSOFT Inc., 2009) to analyze the length-weight relationship. This relationship is determined from a nonlinear regression using Levenberg-Marquardt's algorithm (Fan, 2013), which consider the parameters "a" (curve intercept) and "b" (allometry coefficient), as displayed in the equation of  $W_t = a * L_t^b$  (Le Cren, 1951), where  $W_t$  is the total weight and  $L_t$  is the total length. Consequently, the biometric dataset was then employed in the FISAT II analysis (FAO-ICLARM



**Figure 1.** Locations of sampling sites in Parintins municipality, Amazonas State, Brazil.

Stock Assessment Tools: Gayanilo Junior et al., 2005), in order to assess the stocks of *P. pardalis* in the region from derived maximum theoretical weight or asymptotic length ( $W_{\infty}$ ) values of *P. pardalis* individuals.

Total length frequencies were used in the Von Bertalanffy growth function (VBGF) (Sarr et al., 2012) to plot the cohort distribution of *P. pardalis* during the sampled period in relation to river water level, in order to verify some patterns with both biological and environmental variables. The asymptotic length ( $L_{\infty}$ ) and the specific individual growth rate (K, curvature parameter) can be assessed from:  $K = -\log(b)$  and  $L_{\infty} = \frac{a}{1-b}$  (Ford, 1933; Walford, 1946), in order to initiate the algorithms used in the FISAT II. Also, the mean annual surface water temperature (T) in the Amazon River floodplain lakes was estimated.

The size at first sexual maturity ( $L_m$ , cm) for *P. pardalis* was estimated using the empirical equation proposed by Froese and Binohlan (2000), which was expressed as:  $\log L_m = 0.8979 * \log(L_{\infty}) - 0.0781$ . Natural mortality (M) was estimated using an empirical equation that establishes a relationship between natural mortality, growth parameters, and water surface temperature, as suggested by Pauly (1983) in the following equation:

$\log M = -0.0066 - 0.279 * \log L_{\infty} + 0.6543 * \log K + 0.4634 * \log T$ . Total mortality (Z) was estimated using the linearized catch curve method (Pauly, 1983), which incorporates fish length data frequencies by class (samples are converted into percentage rates) and growth parameter distribution values obtained from a regression curve,

to determine a size when more than 50% of the individuals from the fish population are vulnerable to fisheries. The analysis also considered the equation:  $\frac{dN}{dt} = -Zt$ , where the number of surviving fish from a cohort at a given time ( $N_t$ ) is:  $N_t = N_0 e^{-Zt}$ . Then, after the values of M and Z were obtained, fishing mortality (F) was estimated using the equation  $F = Z - M$  (Rikhter and Efanov, 1976).

The values of age of recruitment ( $T_r$ ) and first catch ( $T_c$ ), were estimated using an adaptation of the VBGF (King, 1995; Sparre and Venema, 1997), which is as follows:

$$T_r = t_0 - \left(\frac{1}{K}\right) * Ln * \left[1 - \frac{L_r}{L_{\infty}}\right], \text{ and}$$

$$T_c = t_0 - \left(\frac{1}{K}\right) * Ln * \left[1 - \frac{L_c}{L_{\infty}}\right].$$

Where  $L_t$  = length of fish at age t (t = age), and  $t_0$  = theoretical age at zero length. As the fish at birth has no significant length or weight (Moreau, 1987; King, 1995) and  $L_r$  = average length at the time of recruitment and  $L_c$  = length at first capture, for this analysis it was assumed that  $L_c = L_r$  (Sparre and Venema, 1997).

To assess the maximum theoretical weight ( $W_{\infty}$ ), the equation  $W_{\infty} = a * L_{\infty}^3$  was applied (Sparre and Venema, 1997). Likewise, longevity ( $A_{0.95}$ ) was estimated using the equation proposed by Taylor (1958):

$A_{0.95} = \frac{t_0 = 2.996}{k}$ , where  $t_0$  and  $K$  are parameters from the Von Bertalanffy model.

To adjust the fish stock scenario, the value of  $L_c$  was changed to  $L_a$ , which corresponds to the average length ( $L_a = 28$  cm) of fish caught during this study. Therefore, to observe the Y/R of *P. pardalis*, the  $T_c$  values were changed, applying different combinations of  $L_c$ ,  $L_m$  and  $L_a$  values. These parameter values also were used to build a hypothetical background of yield per recruit (Y/R) for the Beverton and Holt models (Sparre and Venema, 1997):

$$\frac{Y}{R} = F * \exp[-M * (T_c - T_r)] * W_{\infty} * \left[ \left( \frac{L}{Z} \right) - \left( \frac{3S}{Z+K} \right) + \left( \frac{3S^2}{Z+2K} \right) - \left( \frac{3S^3}{Z+3K} \right) \right].$$

The fisheries exploitation rate (E) is the fraction of fish stock exploitation (Sparre and Venema, 1992), which was acquired applying the equation:

$E = \frac{F}{Z}$ . Consequently, F was estimated from the E values, as expressed in the equation:  $F = \frac{M * E}{1 - E}$ . The estimated exploitation rate (termed here as  $E_{-Est.}$ ) is optimized when  $E_{-50}$ , considering  $F = M$  as an ideal model for a sustainable fishery (Gulland, 1983; Caddy and Mahon, 1996). Therefore, the relative Yield per Recruit was applied to Knife-edge selection from the FISAT model, considering  $L_c/L_{\infty}$  and  $F/K$  as the parameters to be used in the analysis, in order to find the exploitation ratios (e.g.  $E_{-10}$  and  $E_{-50}$ ) and their relation to relative Yield per recruits. Thus, the  $F_{-10}$  value was estimated using the  $E_{-10}$  rate.

The estimated biological reference values that were applied in the analysis were based on the estimated mortality of the fishery ( $F_{-Est.}$ ), where the reference point was  $F = M$ . It was expected that the rate of fishing mortality at the maximum sustainable yield ( $F_{MSY}$ ) is approximately equal to the natural mortality (Caddy and Mahon, 1996), which happens when the inclination curve of yield per recruit diminishes 10% ( $F_{-10}$ ) from its original rate.

## RESULTS

A total of 1,200 specimens of *P. pardalis* were sampled over a period of 12 months. The individuals had a total average length ( $L_a$ , cm) of  $28.00 \pm 2.57$  cm (ranging from 21.00 to 37.00 cm), and total average weight of  $441.57 \pm 103.37$  g (ranging from 210.00 to 835.00 g). This data was applied to the length-weight relationship grouping males and females' individuals in the equation:  $W_t = 0.431227 * L_t^{2.08637}$ , allowing a standard error of  $a = 0.054$  and  $b = 0.037$ , with a  $r^2 = 0.72$  (Figure 2).

The growth parameters  $L_{\infty}$  (38.85 cm) and  $K$  (0.41 year<sup>-1</sup>) obtained from the Ford-Walford equation for *P. pardalis* were applied in the VBGF and used to adjust the length frequency plot in the ELEFAN I method, which permitted estimation of the  $L_m$  value (22.3 cm) for the *P. pardalis* fish stocks. In total, only 0.3% ( $n = 4$ ) of the specimens were found to have a length below this value. Furthermore, four cohorts of this species were identified, suggesting the presence of adults throughout the entire

year, while the youngest individuals were only found between the falling water and low water periods, from October to February (Figure 3).

The natural mortality rate for *P. pardalis* was estimated at  $M = 0.93$  year<sup>-1</sup>. Subsequently, fishing mortality ( $F = 0.91$  year<sup>-1</sup>) was determined as the difference between the total mortality ( $Z = 1.84$  year<sup>-1</sup>) and the natural mortality (M) rates ( $F = Z - M$ ). Therefore, with the mortality values it was possible to calculate the exploitation rate ( $E_{-Est.}$ ), which was 0.5.

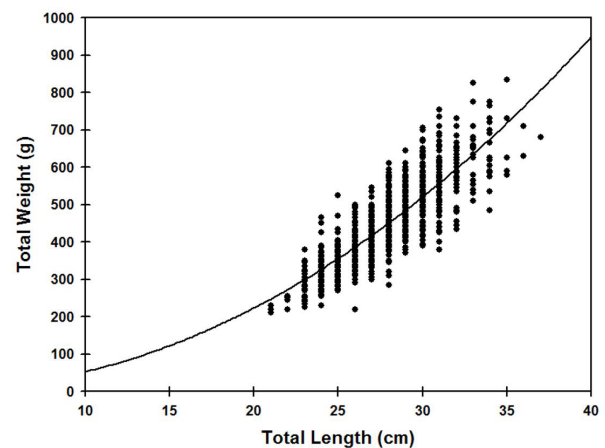
The maximum theoretical weight obtained was  $W_{\infty} = 869.76$  g. Thus, the actual growth parameters ( $W_{\infty}$ ,  $L_{\infty}$  e  $K$ ) were applied in the Growth performance index ( $\emptyset = \log K + 2/3 \log W_{\infty}$  and  $\emptyset' = \log K + 2 \log L_{\infty}$ ) using ELEFAN I, showing differences in the values of  $\emptyset = 1.57$  and  $\emptyset' = 2.79$ , which suggests different populations of *P. pardalis*. Also, with the adapted VBGF, of the age at recruitment ( $T_r$ ) and at point of first capture ( $T_c$ ) were estimated at 1.92 years, as these variable were considered to be equivalent.

In addition, the biological and environmental variables were essential to assess the longevity ( $A_{0.95}$ ) of *P. pardalis* populations at 7.31 years, indicating that the specimens had already achieved 95% of their  $L_{\infty}$  at this age, which corresponded to a growth gain of approximately 5.31 cm year<sup>-1</sup> (Figure 4A).

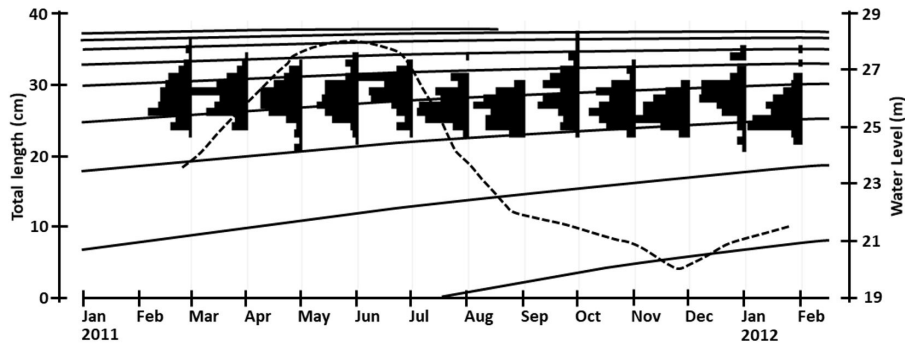
Additionally, the relative yield per recruit analyses (Y/R) was arranged allowing  $F$  and  $L_r = L_c (= 21.0$  cm, corresponding to the smallest fish caught in this study) as a function for the model. Based on the estimated F values, the yield per recruit was calculated at 110.70 g. recruit<sup>-1</sup>, when considering that  $T_r = T_c = 1.92$  years (Figure 4B). In addition, the biomass per recruit was estimated at 121.64 g. recruit<sup>-1</sup>.

When the  $L_m$  value was applied to the Y/R relationship, an increase of 44% was observed, indicating that is possible to maintain actual  $F_{-Est.}$  values, considering that fish specimens would likely be caught after spawning. Besides, from using the  $L_a$  as  $T_c$  in the Y/R calculations, an increase of 17% was observed, suggesting a better yield when the  $L_a$  value is closer to the  $L_m$  value (Figure 4B).

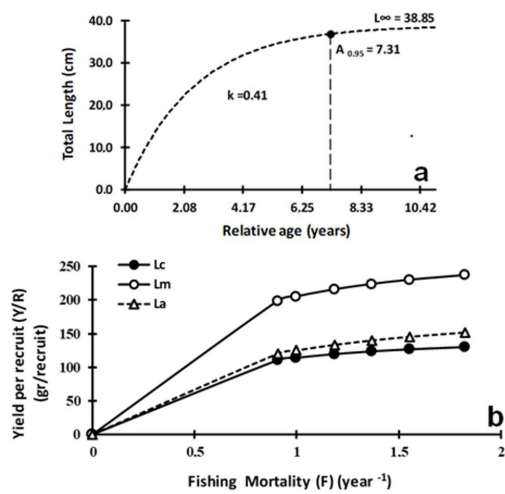
The parameter values resulting from the equations  $L_c/L_{\infty} = 0.54$  and  $M/K = 2.26$  were applied to the Knife-edge selection from



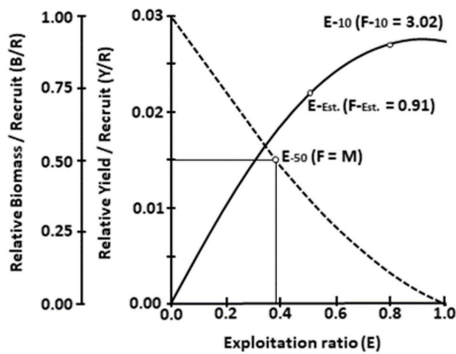
**Figure 2.** Length-weight relationship for *Pterygoplichthys pardalis* commercially caught in Parintins municipality, Amazonas State, Brazil.



**Figure 3.** Distribution of total length frequencies for *Pterygoplichthys pardalis* commercially caught in Parintins municipality in the middle Amazon River basin. The spotted line represents the river water level, while the full line shows the plotted VBGF.



**Figure 4. a** = Growth curve distribution of *P. pardalis* showing the relationship between total length and relative age, which is associated with Longevity ( $A_{0.95}$ ), Growth rate ( $K$ , year<sup>-1</sup>), and Asymptotic length ( $L_{\infty}$ , cm). **b** = Different scenarios showing the relation between Yield per recruit and Fishing Mortality, using as reference points Length at first capture ( $L_c$ ), Length at first sexual maturation ( $L_m$ ), and average capture length ( $L_a$ ).



**Figure 5.** Yield per Recruit of *P. pardalis* with Relative Biomass per Recruit (B/R) and Relative yield per recruit (Y/R) as a function of the Exploitation rate. The dotted line represents the relative Biomass per Recruit.

**Table 1.** Parameters of population dynamics, Exploitation rates and fishing mortality for specimens of *P. pardalis* captured between March 2011 and February 2012 in Parintins municipality, Amazonas State, Brazil.

Population parameters of <i>Pterygoplichthys pardalis</i>	
Natural mortality (M) (year <sup>-1</sup> ); F = M	0.93
Fishing mortality (F) (year <sup>-1</sup> )	0.91
Total mortality (Z) (year <sup>-1</sup> )	1.84
Age at recruitment ( $T_r$ ) and (years)	1.92
Age at first capture ( $T_c$ ) (years)	1.92
Length at first capture ( $L_c$ ) (cm)	21.14
Length at first sexual maturation ( $L_m$ , cm)	22.30
Average caught length ( $L_a$ , cm)	28.00
Asymptotic length ( $L_{\infty}$ ) (cm)	38.85
Maximum theoretical weight ( $W_{\infty}$ ) (g)	869.76
Growth rate (K) (year <sup>-1</sup> )	0.41
Longevity ( $A_{0.95}$ )	7.31
Exploitation rates and fishing mortality values	
$F_{-Estimated}$	0.91
$E_{-Estimated}$	0.50
$E_{-10}$	0.80
$F_{-10}$	3.02

the FISAT model. The results from the Relative Yield per Recruit analyses show Exploitation ratio values of  $E_{-10} = 0.80$ ;  $E_{-50} = 0.38$ ; and  $E_{-Est.} = 0.50$  (Figure 5). As a result, the F rate values for *P. pardalis* were  $F_{-Est.} = 0.91 < F=M=0.93 < F_{10}=3.02$  (Figure 5 and Table 1).

The population growth parameters of *P. pardalis* estimated in the present study are presented in Table 1.

## DISCUSSION

The results showed that a distribution of adult acari-bodó individuals throughout the year, with greater numbers of adult fish during peak flood and low water periods. This phenomenon was corroborated by Winemiller (1989), who reported that adults of *P. pardalis* use the flood period for reproduction purposes. In addition, the flooded forests that are seasonally inundated with rising water levels serve as important feeding and nursery areas for juveniles. Strong *P. pardalis* parental care helps to reduce juvenile mortality in the early stages, which offsets losses by fishing recruitment all year round (Samat et al., 2016). Also, variations in fishing yields could be a result of variances in fishing effort, recruitment, natural mortality and growth rates.

The allometry value estimated for *P. pardalis* (grouping both males and females) in the present study was  $b = 2.09$  (s.d. = 0.04), which is characteristic of an individual with negative allometric growth. Although this  $b$  value was different from the values found by Neves and Ruffino (1998), which were 2.70 (males) and 2.61 (females), both studies found that it was associated with negative growth.

In addition, the estimated length of acari-bodó at first sexual maturity ( $L_m$ : 22.3 cm) was smaller than the values reported by Neves and Ruffino (1998) from samples collected in Santarem, Amazonas State, which were 25 cm for male and 28 cm for female. In contrast, it was almost twice larger than that estimated by Samat et al. (2016) for individuals introduced in Langat River, Malaysia, which were 12.5 cm for males and 13 cm for females.

The divergence between the estimated  $L_m$  values noted above may be related to different fishing methods or smaller fish sizes used in the analyses. In the study by Neves and Ruffino (1998), the smallest fish was 26 cm in length, in the study of Samat et al. (2016) it was 16.0 cm for male and 10.8 cm for females, while in the present study the smallest fish had a length of 21.0 cm. Correspondingly, the  $L_m$  parameter may vary due to other factors, such as those related to environmental conditions, the multi-specificity of fishing equipment and differences in fishing effort exerted (Anderson et al., 2008). However, as gonadal maturation or gender differentiation of *P. pardalis* was not verifiable in this study, future studies could undergo such assessments.

In fish stock assessment analyses, where the stock and recruitment relationship is unknown, it is common to adopt an arbitrary limit ( $F_{10}$ ) of  $F$ , which represents a 10% increase in the  $Y/R$  of from its original rate at the estimated curve of yield per recruit and Fishing Mortality (Pauly, 1998). Therefore, the  $F_{10}$  value of adopted as a biological reference point (PRB) in the present study was chosen when *P. pardalis* stock was still under the exploited Yield and given a value of  $F_{-Est.}$  less than  $F_{MSY}$ , which was considered by Boerema and Gulland (1973) as the economic base for fish stock evaluation and protection from depletion (Clark, 1991).

In this context, the value at first capture ( $L_c$ , 21.1 cm) shows that acari-bodó is not being overfished, considering that a 100% increase in  $F_{-Est.}$  would only increase the yield per recruit ( $Y/R$ ) by 17%. These results may indicate that fishers are respecting the Length at first catch ( $L_c$ ) for *P. pardalis*, which bodes well for sustainable fisheries management, as only the largest specimens are

being exploited (Froese, 2004). Although the optimum situation is where the  $L_c$  and  $F$  values increase by the same proportion, more study is needed over a longer time period in order to accurately estimate the increase of fishing effort on fish stocks and ensure viable fisheries conservation over the long term.

The results showed that the yield of *P. pardalis* in the plotted fisheries scenarios varied for each  $T_c$  in relation to changes in the values of  $L_m$  and  $L_a$  in the adapted VBGF model. Therefore, changes in the  $L_c$  value due to variations in the  $L_m$  value (22.3 cm) result in better fisheries yield. However, this decision must be made carefully, as well as taking into consideration fluctuations in environmental parameters caused by natural (hydrological cycle) and anthropogenic factors (hydroelectric dams), which can directly influence fish population dynamics.

Therefore, in order to keep a robust database, it is essential to maintain fish landing statistics for the Amazon region. Concomitantly, a basin-wide fisheries database should be established as a collaboration among different government agencies and fishery stakeholders. Fishermen could fill out questionnaires outlining fishing effort and capture information as a means to implement an effective monitoring tool, aimed at maintaining *P. pardalis* stocks for both sustenance and commercial purposes (Isaac et al., 2015).

## CONCLUSION

In conclusion, assessment of *P. pardalis* stocks and its exploitation rate revealed that the species is currently not being overfished in the region of Parintins Island in Amazonas State. Consequently, the current fisheries yield of *P. pardalis* could be increased approximately 20% from the current rate without posing any kind of risk to the fish stocks.

However, these results should be viewed cautiously, both from an ecological standpoint, since environmental equilibrium assumptions need to be taken into consideration, and also from a meso-scale sustainability perspective, as more broader-based study is required to reduce the uncertainty regarding this kind of conclusion. In addition, the fisheries stock assessment models adopted in this research still need to be improved to increase the accuracy associated with estimations of population dynamics.

On the other hand, this research offers a current, unprecedented analysis of acari-bodó stocks in an important fishing region in the Central Amazon, which can be used as a benchmark for implementing fishing management strategies, ultimately aimed at protecting the species and promoting conservation and sustainable exploitation.

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