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Stock Estimation Trial From Spatio-temporal Limited Data of Six Commercial Species in the Middle Madeira River, Southwest Amazon

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Abstract

This short communication note is an attempt to evaluate the fish stocks of six commercially significant species in the middle Madeira River, Southwest Amazon, by using refined fisheries data and an adapted catch effort method. Through daily monitoring at the Humaitá station from May 2018 to April 2019, it examines the catchability and stock estimates for S*emaprochilodus insignis, Mylossoma aureum, Mylossoma duriventre, Prochilodus nigricans, Brycon amazonicus,* and *Pseudoplatystoma fasciatum*. Despite the observed low model adjustments and the influence of capture site diversity, significant p-values indicate less than 7% exploitation of the estimated fish populations, suggesting under-exploration and potential for sustainable growth in the region's fishing activities. However, the study emphasizes cautious interpretation due to unaccounted factors like seasonality, highlighting the necessity for longer data series and consideration of Amazonian peculiarities in future research. This effort contributes to understanding the sustainable management and conservation needs of Amazonian fish resources amidst environmental and human impacts.

Keywords: Amazon fish stocks, Catch effort method, Fish population assessment, Madeira River, Sustainable fishing.

1. Introduction

Fishing is a crucial activity in the Amazon region, providing income, food security, and leisure to local populations (MEGGERS, 1977). This activity is also the primary and most easily accessible source of protein for people living in the region (CERDEIRA et al., 1997; BATISTA et al., 2004). Given its importance, recent studies have emphasized the need to discuss its sustainability and responsible management (SANTOS & SANTOS, 2005; COUX et al., 2010; SANTOS, FERREIRA & VAL, 2010; WELCOMME, 2011; PRYSTHON, 2021).

These studies highlight a critical problem that must be addressed immediately - the lack of refined data about fisheries. This limitation restricts the use of advanced analyses. However, recent studies have introduced new and feasible methodologies to generate more refined fishery monitoring data (Lourenço et al., 2020). These studies have also provided fresh perspectives on the Amazon's fishery resources in light of increased exploration (Lourenço et al., 2024) and large hydroelectric projects' impact on fishery resources (Lourenço et al., 2023).

Among the possibilities opened with a more refined fisheries database, fish stock estimations deserve a prominent position, especially when considering the fish stock depletions of several commercial species reported across the Amazon in the last decades (PETRERE, 1983; ALAN et al., 2005; CASTELLO et al., 2014; ROBINSON et al., 2020; SU et al., 2021).

Several methods are available to estimate fish stocks in inland waters (FRITZGERALD, DELANTY & SHEPHARD, 2018). When choosing, it is crucial to consider several factors that can influence the decision-making process. Hoyle et al. (2024) argue that despite the attractiveness of more powerful models, such as Structural Topic Models (STMs), more straightforward approaches should be used before exploring complex models.

A recent study by Silva Júnior et al. (2017) in Amazon estimated fish stocks using an adapted version of the catch effort method proposed by Mao (2007). While the approach seems feasible, due to the lack of refined data in the region, the authors violated a statistical assumption in Mao's method by considering the total biomass instead of the total number of individuals in the regressions, which led to partially unreliable, or at least overestimated results.

This study uses the adaptation made by Silva Júnior et al. (2016) to Mao's (2007) method using refined fisheries data produced by the Lourenço et al. (2020) method to estimate fish stocks of six commercial species in the middle Madeira region, Southwest Amazon.

2. Material and Methods

2.1. Study area and data collection

We gathered the data used in this study from May 2018 to April 2019 by daily monitoring the landings that arrived at the monitoring station in Humaitá, Amazonas, Brazil, middle Madeira River (GIBBS, 1967; McCLAIN et al., 1995; GOULDING et al., 2003; QUEIROZ et al., 2013), following the method proposed by Lourenço et al., (2020).

We selected six commercial fish species that were landed more than 50 times during the sampled period, namely *Semaprochilodus insignis, Mylossoma aureum, Mylossoma duriventre, Prochilodus nigricans, Brycon amazonicus,* and *Pseudoplatystoma fasciatum.*

2.2. Statistical analyses

To estimate the fish stocks of the six selected species, we applied the adaptation of Silva Júnior et al. (2016) of Mao's (2007) method, but using number of captured individuals instead of total captured biomass. This adaptation is based on the hypothesis that a population "N" that undergoes a sampling process "g" with a standardized effort "f" has a catch probability that is related to time "t". The catchability "π" is determined by:

$$g_{\pi}(t) = p_{\mathrm{q}}\left(f_t\right)\prod_{k=1}^{t-1}\left\{1 - p_{\mathrm{q}}\left(f_{\mathrm{k}}\right)\right\}$$

where: "q" is the catchability, "$p_q(f_t)$" represents the probability of an individual be captured given an amount of effort "f", and the "$\prod_{k=1}^{t-1}\left\{1 - p_{\mathrm{q}}\left(f_{\mathrm{k}}\right)\right\}$" represents the probability that it was not captured in previous events.

That way, the remaining population, following the catch probability of each individual is provided by "θ":

$$\theta = \frac{1 - \sum_{k=1}^{W} g_q(k)}{\sum_{k=1}^{W} g_q(k)}$$

Considering "n" individuals captured, the likelihood estimator of the original population is given by:

$$B = b + b\theta$$

where: "b" is the number of captured individuals, and "B" is the total population.

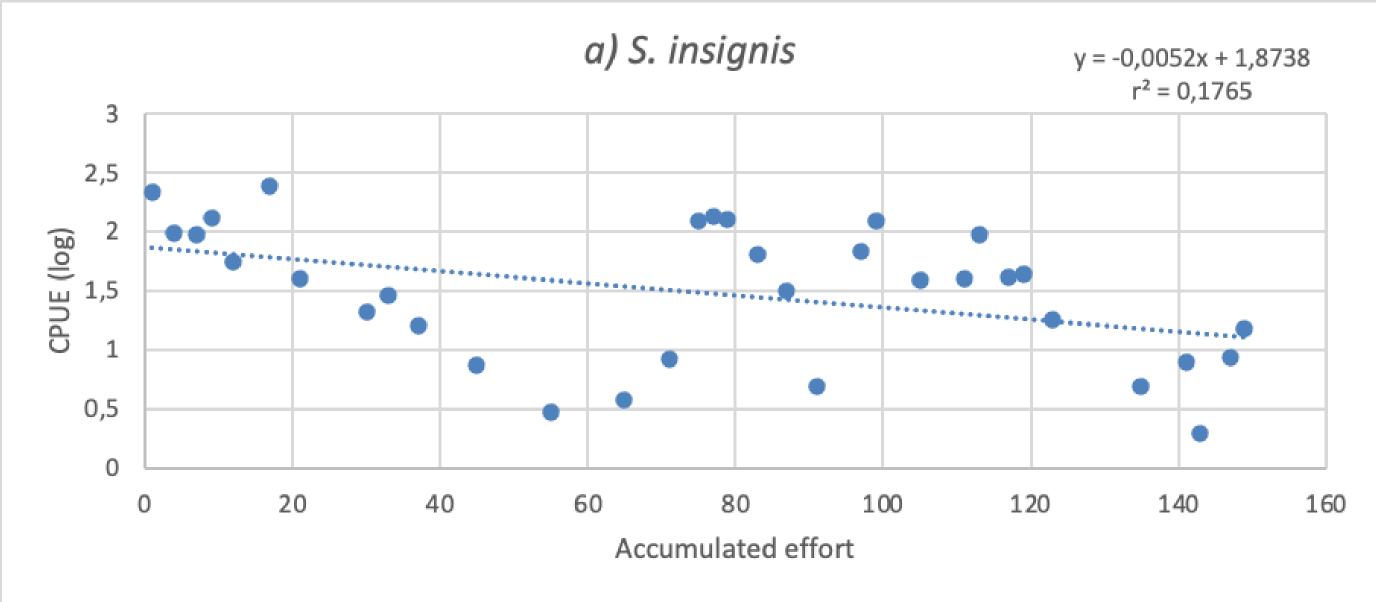
Finally, the function that relates the catch probability is linearly related to effort and parameterized by catchability:

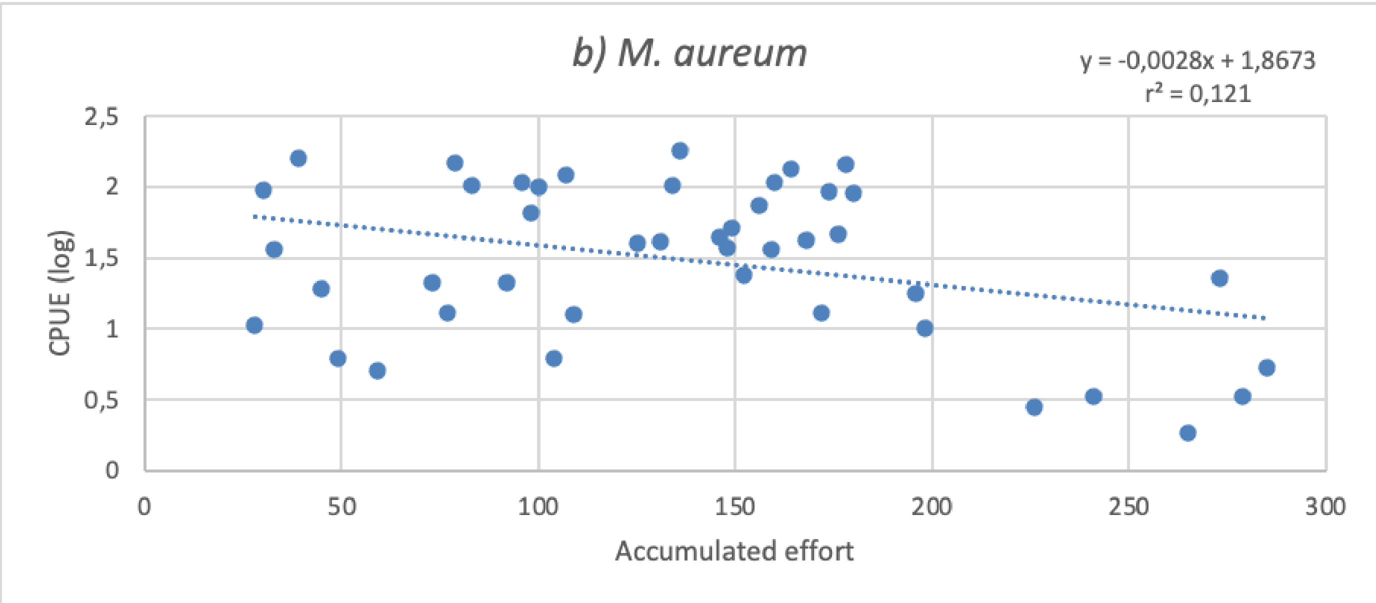
$$p_q(f) = qf$$

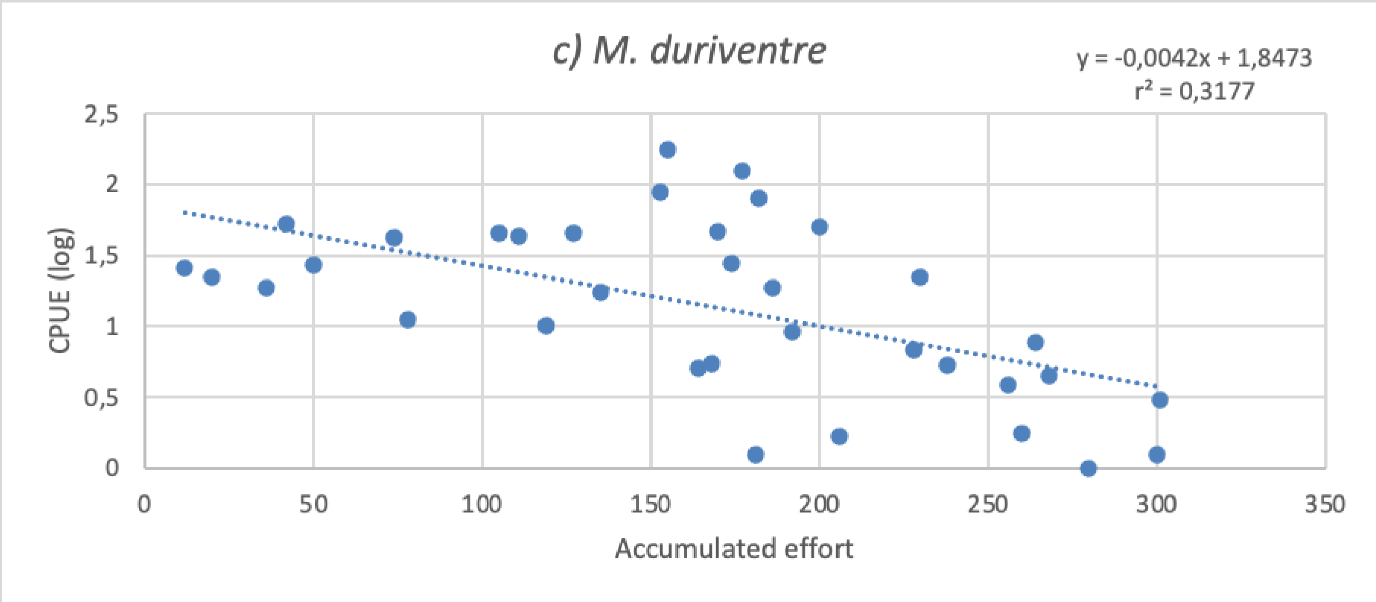
Basically, the method involves counting and removing individuals from a population while applying a given effort repeatedly. An estimative of catchability, known as "q", is determined based on the trend line obtained from the regression between the CPUE and cumulated effort. By replacing the captured individuals' number, effort, and catchability values in Equation 4, it is possible to estimate the fish stock of the analyzed population. In other words, the population size is estimated by modeling the decrease of catchability after successive tries (MAO, 2007).

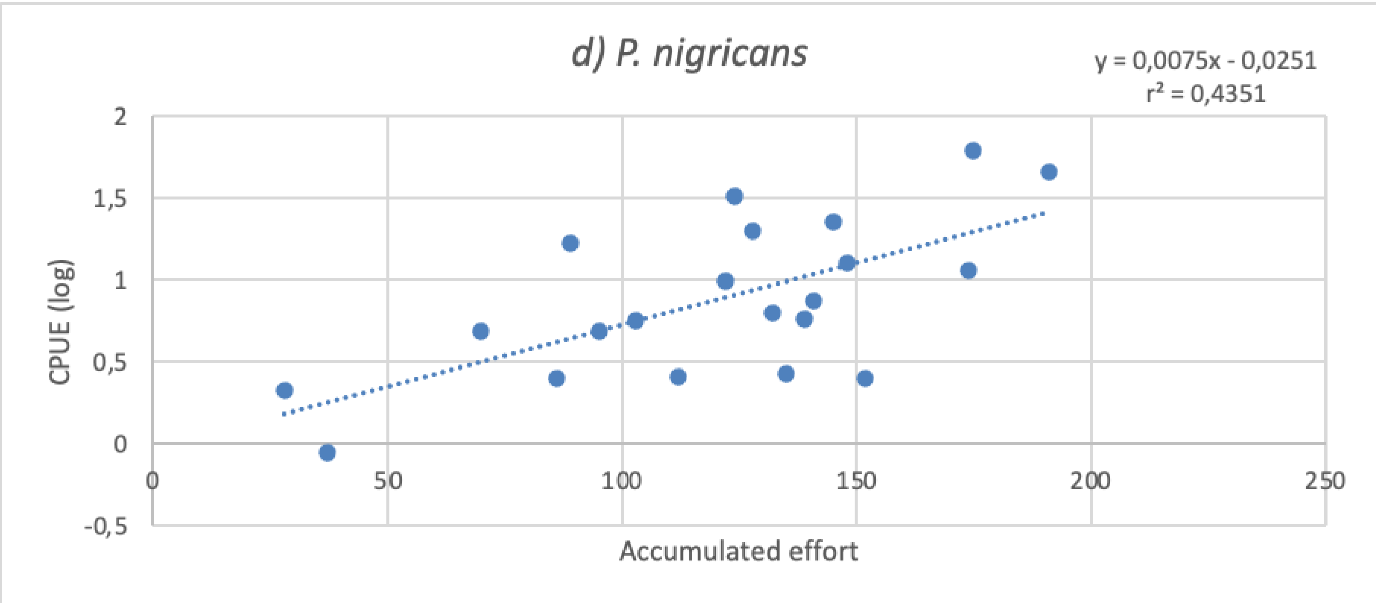
3. Results

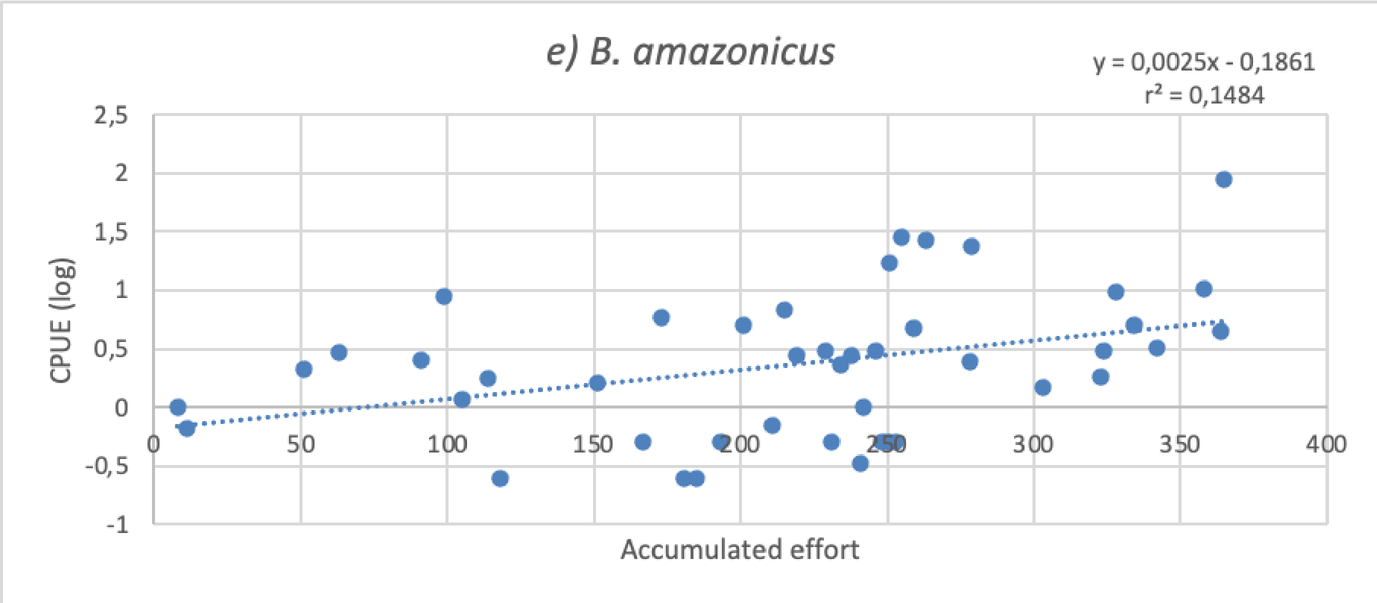
The regressions obtained are presented next (Figure 1). The tendency lines presented a downward bias for*S. insignis*, *M. aureum*, *M. duriventre,* and *F. fasciatum* and an upward bias for *P. nigricans* and *B. amazonicus*.


a) S. insignis
y = -0,0052x + 1,8738
r² = 0,1765
CPUE (log)
3
2,5
2
1,5
1
0,5
0
0
20
40
60
80
100
120
140
160
Accumulated effort


b) M. aureum
y = -0,0028x + 1,8673
r² = 0,121
CPUE (log)
2,5
2
1,5
1
0,5
0
0
50
100
150
200
250
300
Accumulated effort


c) M. duriventre
y = -0,0042x + 1,8473
r² = 0,3177
2,5
2
1,5
1
0,5
0
CPUE (log)
0
50
100
150
200
250
300
350
Accumulated effort


d) P. nigricans
y = 0,0075x - 0,0251
r² = 0,4351
2
1,5
1
0,5
0
-0,5
CPUE (log)
0
50
100
150
200
250
Accumulated effort



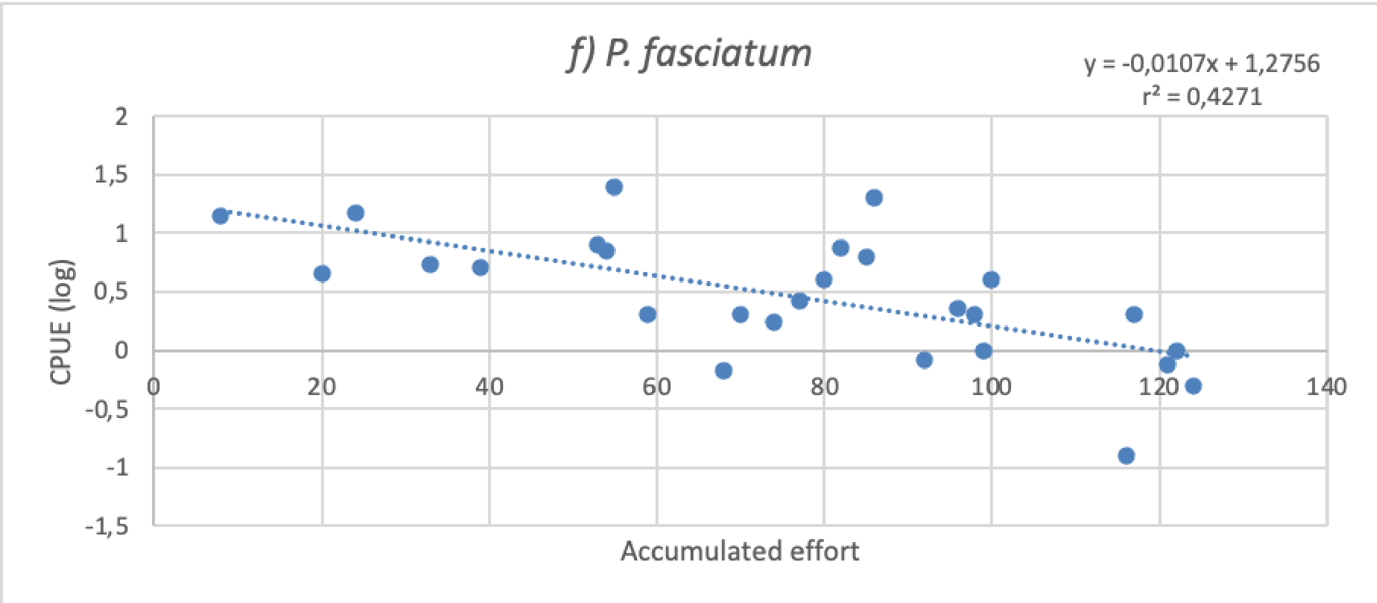


Figure 1. Regressions between the CPUE and the cumulated effort of six commercial species landed in Humaitá, Amazonas, from May 2018 to April 2019.

Despite the low adjustment of the models (r^2), the regression's p-values were all significant (Table 1). In addition, by analyzing the total estimated population for each species, we observe that less than 7% is currently being explored, complicating the interpretation of the tendency lines.

Table 1. Number of captured individuals, mean effort, catchability, regression's p-value between CPUE and cumulated effort, estimated population, and percentage of explored population of six commercial fish species landed in Humaitá, Amazonas, from May 2018 and April 2019.

Species	N Individuals	Mean effort	Catchability	p-value	Estimated population	Explored %
Semaprochilodus insignis	6380	4.52	-5.20E-03	1.49E-02*	271734.64	2.35
Mylossoma aureum	9108	6.48	-2.80E-03	2.07E-02*	502195.49	1.81
Mylossoma duriventre	8079	8.60	-4.20E-03	4.22E-04*	223671.10	3.61
Prochilodus nigricans	1914	9.10	7.50E-03	1.14E-03*	28058.64	6.82
Brycon amazonicus	1259	8.30	2.50E-03	9.81E-03*	60707.95	2.07
Pseudoplatystoma fasciatum	583	4.59	-1.07E-02	2.19E-04*	17879.37	3.26

*Effort: fishermen.days^{-1}; *: significance < 0.05%.*

4. Discussion

The low adjustment of the models can be explained by the inclusion of different capture sites and, consequently, environments. The ideal would be to generate one regression for each capture site separately; however, given the small historical series, there are not enough entries to do so.

As Lorenzen et al. (2016) pointed out, the tendency lines can hold critical information about the exploration levels of each species. Theoretically, given a certain amount of cumulated effort, the regression's tendency lines (our capturability index) will tend to go up until we reach our maximum sustainable yield (MSY). After reaching the MSY, the catchability will tend to decrease, even if we continue to increase the effort, marking the point where fishermen should stop the activity and give time for the stocks to recover (Martell and Froese, 2012).

In light of this, our results suggest that the species*P. nigricans* and *P. fasciatum* still haven't reached the MSY; in other words, the more effort we apply to capture these species, the more the catch. Parallelly, this logic can be applied to the species that presented a downward tendency line, suggesting an exceeding of the MSY.

However, we must interpret these results carefully since we didn't consider the effect of the seasonality over the catch, which has a close relation with the hydrological seasons (SOUSA et al., 2017; LOPES & FREITAS, 2018), a fact consolidated in the studies developed by Issac, Milstein & Ruffino (1996) and Barthem & Fabré (2003). When we take into consideration, for instance, the capture of the genera *Mylossoma* over the year (LOURENÇO, ANJOS E BARREIROS, 2020), the catchability will naturally tend to decline, since the data used (starting in May 2018) coincides with the beginning of the captures, reaching a peak around September, and tending to decline again after that. The same logic can be applied to the other analyzed species, not necessarily meaning that they reached the MSY.

A more accurate analysis would require a longer data series, preferably several years, so we can plot the Lorenzen et al. (2016) parable and have a better glimpse into the conservation status of the analyzed species. A longer data series would also allow us to isolate the effects of the seasonality and environment over the estimates, reinforcing the importance of the continuity of the monitoring method employed here.

The results raised a few questions: What is the support capacity of fish stocks in Amazon inland waters? How much can we extract without compromising the activity and the ecosystem services? How much time do we need to let the stocks rest? At first, the information generated here suggests that the activity can still grow since the number of captured individuals didn't reach 7% of the total population.

When comparing the catch from our study with the catch data from the closest capital in the Madeira River, Porto Velho (approximately two hundred kilometers upstream from Humaitá), we can see that the production here is almost inexpressive (DORIA & LIMA, 2008; DORIA et al., 2012; DORIA, LIMA & ANGELINI, 2018)—opening space for the discussions around the under-exploration of the region, and what factors are influencing it.

Finally, it is worth mentioning that the method developed by Mao (2007) doesn't consider the seasonality, diversity of environments, migration cycles, specificities of the explored species, and fishing gear used, among other factors not considered in this study. Further studies considering these nuances are required for a better understanding of the exploration of this resource and, much likely, adaptions to Mao's (2007) method which will cover the Amazonian peculiarities. Future studies aiming to incorporate each species size are currently under construction and welcoming collaborators and orientations.

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