RASGOS DE VIDA DE LAS ESPECIES AMAZÓNICAS: *Calophysus macropterus* (SILURIFORME: PIMELODIDAE) Y *Mylossoma albiscopum* (CHARACIFORMES: SERRASALMIDAE) EN LA CUENCA ALTA DE LOS RIOS AMAZONAS Y PUTUMAYO

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Jurado

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en poder

alcanzar un sueño.

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Introducción

La cuenca amazónica alberga la ictiofauna dulceacuícola con mayor diversidad el mundo (Val, de Almeida, 1995) con 2406 especies descritas aproximadamente (Jézéquel *et al*., 2020) y esta cifra va en aumento día tras día. Ante tal abundancia de organismos, las comunidades locales y centros urbanos en la Amazonia, se han visto beneficiados de ellas de formas distintas, algunas son comercializadas como ornamentales (por ejemplo, el pez escalar o ángel, disco y arawana) (Ortega-Lara *et al*., 2015), otros como peces de consumo comercial (grandes bagres del género *Brachyplatystoma* y siluros medianos como *Pinirampus* y *Calophysus*) tal como lo confirma Agudelo, (2015). Una última categoría son las especies de subsistencia, conocidas popularmente como pescado menudo, que son importantes en la socioeconomía local, no trascienden las fronteras de la región y dentro este grupo se destacan el bocachico (*Prochilodus nigricas*) y la palometa (*Mylossoma albiscopum*).

Actualmente, los recursos pesqueros en la Amazonia, enfrentan diversos riesgos que ponen en peligro el estado natural de las poblaciones, como la sobrepesca, contaminación de las fuentes hídricas, construcción de represas, cambio climático, introducción de especies exóticas entre otras (Doria *et al*., 2021; Frederico *et al*., 2016; Melack, Coe, 2021; Velásquez Ramírez *et al*., 2021). Investigadores de la Amazonia colombiana y peruana han identificado a *C. macropterus* y *M. albiscopum* como dos especies de gran relevancia en la pesca artesanal con potencial prometedor en la acuicultura (Bonilla-Castillo *et al*., 2012; García Vásquez, 2016). La presente propuesta de investigación busca llenar vacíos de información sobre aspectos poblacionales y pesqueros de esas dos especies, las cuales son relevantes en la región por los servicios ecosistémicos que ofrecen en la cuenca alta de los ríos Amazonas y Putumayo.

Aspectos metodológicos

La investigación se llevó a cabo en la región occidental de la cuenca Amazónica en las localidades de Leticia e Iquitos (Perú) para el río Amazonas o alto Solimões y Puerto Leguízamo (Colombia) en la cuenca alta del río Putumayo. Para la estimación de los parámetros poblacionales de *C. macropterus* se dispuso de los registros biológicos y pesqueros del grupo de Ecosistemas Acuáticos del Instituto Amazónico de Investigaciones Científicas-SINCHI para el sector colombiano (Alto Putumayo: 8.064), y del Instituto de Investigaciones de la Amazonia Peruana-IIAP para la localidad de Iquitos (1.710 registros). En cuanto a *Mylossoma albiscopum*, el Instituto Sinchi dispuso de la información de la especie para ambas cuencas hidrográficas (Alto Solimões: 4.793 registros; Alto Putumayo: 7.960 registros).

Los peces analizados provenían de la pesca artesanal que son comercializados en los centros de acopio o puerto de desembarque fluvial. Los individuos examinados fueron capturados con artes de pesca como redes de enmalle y palangres. A los peces se les tomó talla y en el mejor de los casos peso total e identificación de sexo. La información biométrica usada para los análisis fue longitud estándar- Le en unidades de centímetros, peso total y peso eviscerado en gramos, al igual que peso de la gónada con ayuda de balanzas analíticas. La madurez gonadal se definió usando la escala propuesta por Núñez, Duponchelle (2009).

Se estimaron los parámetros relación peso-longitud mediante transformado a Log_{10} para obtener una relación lineal (Hoeinghaus et al., 2006). Fue calculado la longitud de primera madurez-L_{m50}, definido como la longitud en la cual el 50% de todos los individuos son sexualmente maduros. Para la determinación de L_m se consideraron los registros de machos y hembras maduros e inmaduros. Para la identificación de las temporadas reproductivas, se determinó mensualmente la proporción de hembras maduras combinado con los valores promedio mensual del índice gonadosomático (IGS) (Nikolsky, 1963) y su relación con el régimen hidrológico de los ríos.

Las características de crecimiento y edades fueron estimados utilizando el análisis de frecuencias de longitudes estándar a lo largo del tiempo con ayuda del programa FISAT II (FAO-ICLARM Stock Assessment Tools) para *C. macropterus* y el paquete TropFishR (Mildenberger *et al*., 2017) del software R para *M. albiscopum* con la rutina de análisis de frecuencia-ELEFAN (Electronic LEngth Frecuency ANalysis) para ambas especies. Para calcular el crecimiento en función del tiempo, se tuvo presente el modelo exponencial de von Bertalanffy (VBGF) que hace parte de la rutina de ELEFAN. El cálculo de t_0 se obtuvieron a partir de la relación empírica de Pauly (1980).

Los parámetros de mortalidad fueron estimados de la rutina de FISAT II. La mortalidad total (Z) se calculó con la rutina de la curva de captura modificada a partir de longitudes por el método length-converted catch curves (LCCC) (Pauly, 1983). Para la mortalidad natural (M) se utilizaron modelos empíricos para estimar M mediante la edad de de madurez y crecimiento utilizando la ecuación empírica de Pauly (Pauly, Morgan, 1987), también se calculó la mortalidad mediante la fórmula de Rikhter and Efanov`s (Sparre, Venema, 1998) Jensen (Jensen, 1996) y Gislason *et al*., (2010). La mortalidad por pesca (F) fue estimada de F=Z-M (Pauly, 1980). La tasa de explotación (E) se calculó como el cociente de la división entre la mortalidad por pesca sobre la mortalidad total (Eberhardt & Ricker, 1977) como $E= F.Z^{-1}$.

Para evaluar el estado del stock en *M. albiscopum* se utilizaron dos métodos, el primero fue Thomson & Bell (Sparre, Venema, 1998) con la estimación del rendimiento relativo por recluta (YPR) y el rendimiento relativo por biomasa (BPR), y el segundo método fue LB-SPR o proporción potencial de desove basado en longitud que busca estimar el potencial de desove mediante la composición de las tallas de capturas registradas en la pesquería (Hordyk *et al*., 2015).

1. Contribución de publicaciones

2.1 Artículos científicos aprobado y sometido

Bonilla-Castillo CA, Vasquez AG, Córdoba EA, Hurtado GG, Vargas G, Duponchelle F. Life history trait variations and population dynamics of *Calophysus macropterus* (Siluriformes: Pimelodidae) in two river systems of the Colombian and Peruvian Amazon. Neotropical Ichthyology. 2022; 20(1). https://doi.org/10.1590/1982-0224-2021-0082

Bonilla-Castillo CA, Córdoba EA, Canchala D, Peña LC, Gómez G, Duponchelle F. Estimation of growth parameters and stock status of *Mylossoma albiscopum* (Characiformes: Serrasalmidae) in two tributaries of the Amazon River. Sometido a Neotropical Ichthyology **ID NI-2022-0042**

2.2 Presentaciones en eventos

XVI Congreso Colombiano de Ictiología y VII Encuentro Suramericano de Ictiólogos. 23 al 29 de julio de 2022. Barranquilla, Atlántico-Colombia.

- **Bonilla-Castillo, C. A.**; García, A.; Agudelo, E.; Gómez, G.; Vargas, G.; Duponchelle, F. Rasgos de *Calophysus macropterus* (Siluriformes: Pimelodidae) en dos sistemas fluviales de la Amazonia colombiana y peruana. **Modalidad Oral**
- **Bonilla-Castillo, C. A.**; Agudelo, E.; Gomez, G. Parámetros poblacionales y evaluación pesquera de *Mylossoma albiscopum* (Serrasalmidae: Characiforme) en los ríos Amazonas y Putumayo colombiano. **Modalidad Oral**

2. Life history trait variations and population dynamics of *Calophysus macropterus* (Liechtenstein, 1819) in two river systems of the Colombian and Peruvian Amazon

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Abstract

The catfish *Calophysus macropterus* is heavily exploited in the Amazon basin, yet its life history characteristics are poorly documented, hampering proper fisheries management. In order to fill this gap, monthly sampling in the upper Putumayo River and in the Amazonas, lower Marañón and Ucayali (AMU) rivers were carried out over several years (2013-2015 in the UMA, 2013-2017 in the Putumayo) to provide detailed information about its reproduction, growth and mortality patterns (using length frequency data). Reproduction, which occurs during the dry and early flooding season, was only observed in the upper Putumayo River and not in the sampled portion of the AMU system, suggesting that the species reproduces closer to the Andes than other pimelodid catfishes. Size at first sexual maturity did not differ significantly among sex or among river systems, ranging from 25-28 cm SL. In both river systems, females had a faster growth than males and both gender also tended to have a better growth in the AMU than in the upper Putumayo. Mortality and exploitation estimates all indicated overexploitation of the species in both river systems. The implications of these results for fisheries management and conservation are discussed.

Keywords: Amazonas-Marañon-Ucayali, Catfish, Growth, Overfishing, Putumayo

3.1 Introduction

The migratory catfish *Calophysus macropterus* is largely distributed in rivers and floodplains of the Amazon and Orinoco basins (Pérez, Fabre, 2009). Being a single species genus in the family Pimelodidae, it was traditionally not a prime target in Amazonian fisheries (Agudelo *et al*., 2000; Pérez, Fabré, 2002), except in the Putumayo River in Colombia where it has long been one of the main landed species (Bonilla-Castillo *et al*., 2011). In the last two decades, however, landings of *C. macropterus* have greatly increased in Colombia and Peru, possibly owing to the decreasing abundance of the main catfish targets such as the large *Brachyplatystoma* and *Pseudoplastystoma* species and to the growing demand in Colombian big cities, where it is sold fraudulently as the 'capaz', *Pimelodus grosskopfii*, a highly appreciated and now endangered catfish species from the Magdalena River (Bonilla-Castillo *et al*., 2011; Bonilla-Castillo *et al*., 2012; García Vasquez *et al*. 2009, 2012; Mosquera-Guerra *et al*., 2015). While its catches barely accounted for 0.3% of total landings in the Loreto region (Peru) in 2000, *C. macropterus* was the 7th most landed species in 2016, accounting for ~ 4% of total landings in the Loreto and > 6% in the Ucayali region (García Vasquez *et al*., unpublished data). In the Putumayo River, Colombia, it already accounted for ~ 21% of total landings in 2000 (Bonilla-Castillo, *et al*., 2012) and in 2016, it accounted for ~ 50% of total landing, together with *Pinirampus pirinampu*, another pimelodid species (Bonilla-Castillo and Agudelo, unpublished data).

Although its diet can be classified as opportunistic omnivorous to piscivorous, based on its main food items: fish (dominant item), plant material (including seeds) and invertebrates (García Vasquez *et al*., 2017), the species also have a pronounced necrophagous tendency, which explains why it was traditionally rejected in central Amazonia (Pérez, Fabré 2009; Cunha *et al*., 2015). Additionally, the feeding habits of *C. macropterus* often result in methyl-mercury bioaccumulation largely exceeding the maximum reference value (0.5 $mg.kg^{-1}$) established by the World Health Organisation (Mosquera-Guerra *et al*., 2015). As a consequence, its fishing has been banned for 5 years (2016-2020) by normative actions in Brazil (Franco *et al*., 2016) and indefinitely in Colombia since 2017 (resolution Nº1710/2017, AUNAP). In Brazil, using mtDNA sequencing, Cunha *et al*., (2015) evidenced that *C. macropterus* processed as fillet was frequently sold by fish-processing plants and markets under deceptive names, in spite to the rejection of scavenger fishes by Brazilian consumers. Although fishing *C. macropterus* has been officially banned in Brazil, several factors suggest that its fisheries might still be operating: the existence of an established production chain that largely exports to Colombia (Franco *et al*., 2016) together with a widespread retail market in Brazil (Cunha *et al*., 2015), the fact that it yields important income with much less effort than other fisheries in the Amazon (Iriarte, Marmontel, 2013) and the lack of enforcement by government agencies (Cunha *et al*., 2015). Yet, in spite of its recently acquired economic importance and popularity, albeit infamous, in most Amazonian countries, the few studies about the life history characteristics of *C. macropterus* are geographically restricted to Central Amazonia (Pérez, Fabré, 2002, 2009) and a portion of the Colombian Amazon (Agudelo *et al*., 2000). Apart from some information about its reproduction in the Putumayo River (Camacho *et al*., 2006), little is known about its life history traits and population dynamics in the Putumayo and in the Peruvian Amazon, where this species strongly contributes to fisheries landings. The present study aimed at characterising important life history traits (reproductive, growth and mortality patterns) for fisheries management and conservation in the main landing site of the Peruvian Amazon, Iquitos, and in Puerto Leguízamo, located in the upper Putumayo River, shared by Colombia and Perú. Indeed, previous studies have shown important differences in the life history traits of different species between the two river systems (Duponchelle *et al*., 2012, 2015; Bonilla-Castillo *et al*., 2018).

3.2 Materials and Methods

3.2.1 Sampling area

The city of Puerto Leguízamo (00°11'53.2"S - 74°46'42.7"W) is located in the upper part of the Putumayo River at a height of 220 m.a.s.l. its climate is hot and humid (Bonilla-Castillo *et al*. 2018) (Fig. 3-1). Iquitos (03°44'56.83"S - 73°15'13.79"W), on the other hand, is located at ~ 90 m.a.s.l., slightly below where the Marañón and Ucayali, two of the major tributaries of the Amazon basin, meet to form the Amazonas River. We will thereafter refer to the lower Marañon, lower Ucayali and Amazonas around Iquitos as the AMU system. The AMU is mainly constituted of nutrient-rich white waters originating from the Andes (Hanek, 1982). The hydrological conditions in the AMU produce flood pulses that inundate large, highly productive areas responsible for the best fisheries production of the Peruvian Amazon (Tello, Bayley, 2001). The Marañón River has a length of 1707 km, its average velocity on the lower portion is 1.65 $m.s^{-1}$ with flow ranging between 7000 to 25000 m^3.s-1 (MINAM, 2011). The Ucayali River has a length of 2670 km, its average velocity is between 1.5 to 2.5 $m.s^{-1}$, with a flow ranging from 2700 to 20000 $m^3.s^{-1}$ in the lower portion (MINAM, 2011). The Putumayo is one of the two major affluents of Colombia flowing into the Amazon River. It has a length of 2000 km, of which 1,500 travels the Colombian territory and 450 km in Brazil (Alonso *et al*., 2006). The Putumayo river is a white water system of Andean origin. At the Puerto Leguízamo is has a flow of 268 $m^3.s^{-1}$ average, with a maximum value of 417 $m^3.s^{-1}$ in the month of May. The transparency of the water is approximately 16 cm, the conductivity of the river is 36.96 μS/cm, pH of 6.26 average, dissolved oxygen of 7.85 mg/L and average water temperature of 27.2ºC. (Nuñez-Avellaneda *et al*., 2006).

Figure 3-1. Geographic location of biological monitoring points for *Calophysus macropterus* at Puerto Leguízamo in the Putumayo River (Colombia) and Iquitos (Amazonas, lower Marañón and Ucayali rivers, AMU).

3.2.2 Fish sampling

In the Putumayo, fish were sampled monthly between 2013 and 2017 in the main landing sites of the city of Puerto Leguízamo (Colombia), where fishermen exert their activity ~140 km around the city (Fig. 3-1).

In Iquitos (Peru), fish were sampled monthly between 2013 and 2015 in the main landing sites of the city, where fishermen land their products from the Amazonas, the lower Marañón and the lower Ucayali rivers (AMU system).

In both sampling sites, fishermen mainly use two methods for the capture of *C. macropterus*. The first is using bait, usually blood and decomposing meat (mainly beef and pork viscera and grease) that is submerged near the boat along the river preferably during the hours of night and early morning. Once the fish have concentrated around the bait, they are caught by purse seines of 2 inches mesh-size. This method is used during all hydrological periods, although less frequently on nights with full moon. It is non selective, as all sizes get caught.

The second fishing method uses a nylon line with 30 to 50 hooks size #6, submerged perpendicularly to the main river channel. Hooks are baited with fish parts (see García Vásquez *et al*., 2017 for further details). This method is more selective as hook size determines bait size and hence the size of fish caught. But as the same size of hooks is used in both the AMU and the Putumayo, selectivity should not impact the size distribution of fish caught in the two sampling areas.

Specimens were compared with reference collections of this species in the Amazon Icthyological Collection of Instituto Amazónico de Investigaciones Científicas Sinchi (*e.g*., voucher Sinchi: CIACOL:455, Leticia, 04º12'30.5''S - 69º56'0.5''W, Amazon River, Amazonas, Colombia) to verify identification.

For each fish, standard length (SL) was recorded to the nearest cm, and when possible total and eviscerated body mass (to the nearest g, Wt and We, respectively). When the fish were not eviscerated, gonads were photographed and macroscopically checked for gender and maturity stage determination, then weighed to the nearest 0.1 g. The gonadal maturation scale used was that of Núñez, Duponchelle (2009). Briefly, males at stage 1 are immature, at stage 2 they are either maturing or resting and at stage 3 they are ripe. Females at stage 1 are also immature; at stage 2 they are maturing; at stage 3 they are in advanced maturation; at stage 4 they are ripe; at stage 5 they have just spawned and at stage 6 they are resting.

3.2.3 Reproductive aspect

The reproduction period was estimated from the monthly proportions of gonadal maturation stages and of the gonado-somatic index (GSI = gonad mass/total body mass *100) in adult females.

The average size at first sexual maturity (L_{50}) is defined as the standard length at which 50% of the individuals are at an advanced stage of the first sexual cycle during the breeding season (Sparre, Venema, 1998). Practically, this is the size at which 50% of the fish have reached stage 2 of the maturity scale for females and males (Núñez, Duponchelle, 2009). For each river system and for each gender, the mean S_L at first maturity (L_{50}) was estimated by fitting the fraction of mature individuals per 5 mm S_L intervals to a logistic regression function weighted by the total number of individuals in each size class (Bonilla-Castillo *et al.*, 2018):

$$\%M = \frac{100}{1+e^{(-a\times(L-L50))}}$$

where %M = percentage of mature individual by size class, L = central value of each size class, and a and L_{50} = constants of the model.

3.2.4 Growth aspect

Age and growth characteristics were calculated from the modal progressions of standard length frequency distributions (King, 2007) using the ELEFAN (Electronic Length Frequency Analysis) routine (Pauly, David, 1981) provided in the FiSAT II (FAO-ICLARM Fish Stock Assessment Tools) package package (http://www.fao.org/fi/statist/fisoft/fisat/index.htm) (Gayanilo *et al*., 2005). The set of parameters that best corresponded to the breeding patterns observed for the species (i.e., which gave an estimated birth date corresponding to the breeding peak) and that best described the distributions (i.e., which went through the largest number of large modes and yielded the largest Score = "goodness-of-fit" parameter of the ELEFAN routine) was selected (García Vásquez *et al*., 2009). This process also permitted to diminish the tendency of ELEFAN method to underestimate K and overestimate L_∞ (Sparre, Venema, 1998). The growth parameters were calculated by the von Bertalanffy Growth Function (VBGF) equation fitted by the ELEFAN method:

$$L_t = L_\infty(1-e^{(-K\,(t-t0)})$$

where L_t is the mean length at age t, L_∞ is the asymptotic length, K the growth coefficient and t_0 the theoretical age at size 0.

t_0 was calculated using the empirical formula proposed by Pauly (1980):

$$\log_{10}(t_0) = -0.392 - 0.275 \log_{10} L_\infty - 1.038 \log_{10} K$$

The estimated L_∞ and K values were used to calculate the growth performance index (phi prime, ǿ) defined by Pauly, Munro, (1984) as

$$ǿ = \log K + 2\log L_\infty.$$

The age at first sexual maturity (A_{50}) was calculated from the VBGF as follows (Duponchelle *et al*., 2007):

$$A_{50} = \{-\ln[1-(L_{50}.L_\infty-1)]K-1\} + to$$

where L_{50} is the size at first sexual maturity and L_∞ and K are parameters from the VBGF.

The longevity (t_{max}) was estimated as the age at 95% of L_∞ from the equation of Taylor, (1958):

$$Ap = to-[\ln(1-p)K^{-1}]$$

where t_0, and K are the VBGF parameters and p is a fraction of L_∞ (in this case 0.95). The longevity was also calculated from the equation of Froese, Binohlan (2000):

$$\log_{10} t_{max} = 0.5496 + 0.957 \log_{10} (A_{50})$$

where A_{50} is the age at first sexual maturity.

3.2.5 Mortality

Mortality parameters were also estimated using procedures provided in the FISAT II package. Total mortality (Z) was estimated by the method of the length-converted catch curves (LCCC) (Pauly, 1983). Natural mortality (M) is one of the most complicated life history parameters to estimate in natural populations (Pauly, 1980) and several empirical models linking M to life history attributes such as age at maturity or growth were proposed for fish (reviews in Gislason *et al*., 2010). These empirical relationships assume that M is a species- or stock-specific constant, and users generally apply the estimate to all exploited ages and sizes of the species or stock under study. Several of these relationships were calculated in order to provide a range of natural mortality values and assess their effect on the estimation of fishing mortality and exploitation rate (E). Hence, natural mortality was evaluated using Pauly (1980)'s equation, as implemented in the FiSAT package, for a mean annual temperature of 27°C (Bonilla-Castillo *et al*., 2018):

$$-0.006-0.270*Log_{10}(L_{\infty})+0.6543*Log(K)+0.4634*Log_{10}(T^{o}),$$

where L_{∞} and K are the VBGF parameters and T° the mean annual temperature.

Other empirical methods were used to estimate natural mortality (M), among them: Equation of Gislason *et al*., (2010) with the mathematical expression 0.55 - 1.61Ln (L) + 1.44Ln (L_{∞}) + Ln (K); Rikhter, Efanov (1976): $1.521/(L50)^{0.72} - 0.155$; Charnov *et al*., (2013): $[(L/L_{\infty})^{-1.5})]$ x K; Jensen, (1996) using K: 1.6*K; Jensen, (1996) using A_{50}: $1.65/A_{50}$ (A_{50}: Age at which 50% of the population reaches sexual maturity.

For the equations of Gislason *et al*., (2010) and Charnov *et al*., (2013) “L” was established as the average length in immature and for mature individuals.

Fishing mortality (F) was calculated as F = Z-M (Pauly, 1980). The exploitation rate was estimated as $E = F.Z^{-1}$.

For comparison purposes, both F and E were calculated for the different estimates of M.

3.2.6 Biometric indicator

The weight-length relationship was estimated by expression $Wt=a*SL^{b}$, after logarithmic transformation log(Wt)=log(a)+b*log (SL), Wt the total weight, SL the standard length, “a” the intercept of the curve and “b” the allometry coefficient of the weight-length ratio (Zar, 2010).

3.2.7 Statistical analyses

Differences in mean Ls, Wt and We between sexes were tested with a Mann–Whitney rank-sum test. Parametric tests could be carried out as either normality of distributions or homocedasticity were not met. Differences in size at first sexual maturity were tested using t-test.

3.3 Results

A total of 8064 specimens of *C. macropterus* were analysed from Puerto Leguízamo (upper Putumayo River), 3.2% (254) in 2013 (November and December), 26.9% (2161) in 2014, 28.9% (2319) in 2015, 31.1% (2528) in 2016 and 10% (802) in 2017 (January to June). A total of 1710 specimens were analysed from Iquitos, 37% (634) in 2013, 40% (688) in 2014 and 23% (388) in 2015. The smallest size class observed in the Putumayo River was 22 cm, whereas individuals of 16 cm were caught in commercial fisheries of the AMU system around Iquitos (Figs. 2A-B). Overall, in both river systems females were significantly larger (Mann–Whitney Rank Sum test: $U = 401256$, $P<0.001$ in the Putumayo River; $U = 18224$, $P<0.001$ in the AMU rivers) and heavier ($U = 466462.5$, $P<0.001$ in the Putumayo River; $U = 17729.5$, $P<0.001$ in the AMU) than males in commercial landings (Tab. 3-1).

Table 3-1. Mean length of catch and range of standard length (SL), total weight (Wt), range of weight, length-weight relationship (*a* and *b*), 95% confidence interval (CI), r^2 determination coefficient of females (F), males (M) and all individuals (sex and unsexed, T) combined of *Calophysus macropterus* specimens analysed from Puerto Leguízamo (upper Putumayo River) and Iquitos (Amazonas, lower Marañón and Ucayali rivers, AMU). N=number of fish analysed.

River	Sex	N	S_L mean (cm)	(S_L cm) range	Wt Mean (g)	Wt Range (g)	*a* ($CI_{95\%}$)	*b* ($CI_{95\%}$)	r^2
Upper Putumayo	F	2706	39.0	23.0-47.5	807	128-1453	0.010 (0.009-0.011)	3.08 (3.04-3.12)	0.9014
	M	4115	31.0	22.0-45.8	395	140-1254	0.014 (0.012-0.015)	2.99 (2.95-3.02)	0.8898
	T	8064	34.0	22.0-47.5	550	128-1454	0.011 (0.010-0.011)	3.06 (3.04-3.07)	0.9578
AMU	F	1112	35.0	23.0-46.6	588	61-1312	0.009 (0.008-0.011)	3.08 (3.04-3.12)	0.9656
	M	597	28.4	22.0-45.8	304	74-1020	0.011 (0.009-0.013)	3.04 (2.98-3.09)	0.9510
	T	1710	32.7	16.5-46.6	489	61-1312	0.010 (0.009-0.010)	3.08 (3.07-3.10)	0.9623

Although maximum observed length (Lmax) only varied by 4% and 2% between females and males in the Putumayo and AMU, respectively, maximum observed body mass (Wmax) varied by 14% and 22% in the Putumayo and AMU, respectively. However, when looking at mean observed lengths and masses, differences between males and females varied by 20% in length and 51% in mass for the Putumayo and by 19% in length and 48% in mass in the AMU (Tab. 3-1, Figs. 3-2A-B).

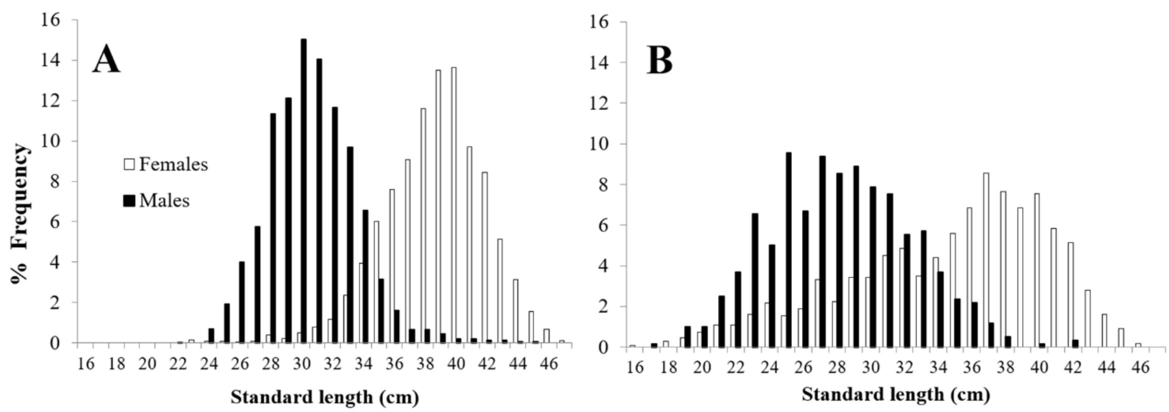


Figure 3-2. Size frequency distribution of *Calophysus macropterus* females and males caught over the study period in the Putumayo River (**A**) and the Amazonas, lower Marañón and Ucayali rivers (**B**).

Over the study period, standard length (SL) – total mass relationships (M_t) were Wt = 0.0099 $SL^{3.078}$ (R^2 = 0.901, P<0.001) and Wt = 0.0135 $SL^{2.988}$ (R^2 = 0.890, P<0.001) in the Putumayo for females and males, respectively and Wt = 0.0093$SL^{3.081}$ (R^2 = 0.966, P<0.001) and Wt = 0.0109 $SL^{3.037}$ (R^2 = 0.951, P<0.001) in AMU for females and males, respectively.

3.3.1 Reproduction

In the upper Putumayo River, both the gonado-somatic index (GSI) and the monthly proportions of ripe females indicated a breeding period between December and March, corresponding to the low water and early flooding period (Fig. 3-3A). This pattern was consistent across years. On the other hand, not a single ripe female or even a female with developed gonads was observed in the AMU (Iquitos area) during the two and a half years of study. This is also reflected in the constantly very low GSI values (Fig. 3-3B).

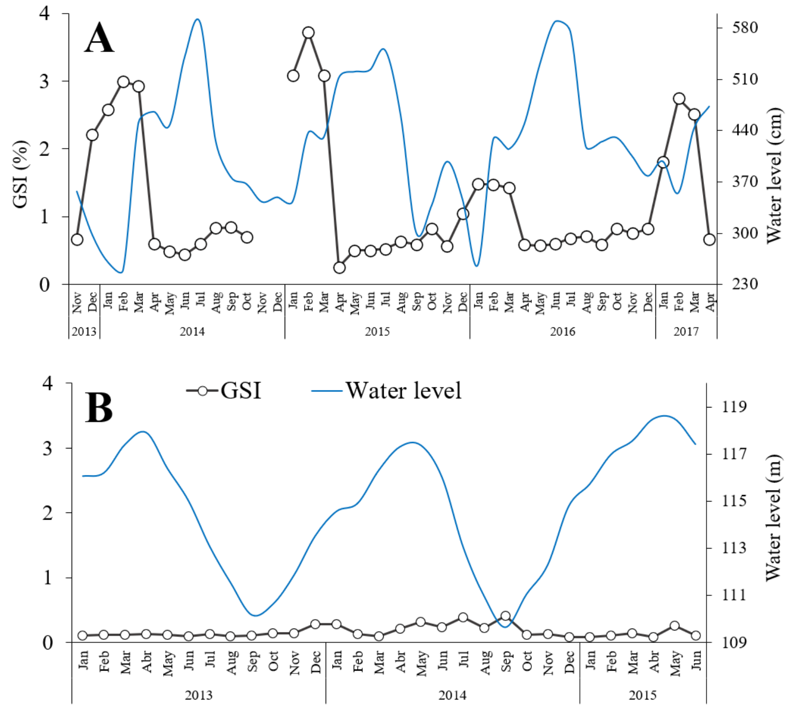


Figure 3-3. Mean monthly GSI values (circles) of *Calophysus macropterus* females between 2013 and 2017 in relation with the water level (dotted line) in the upper Putumayo River (A) and the Amazonas, lower Marañón and Ucayali rivers (B).

3.3.2 Age and growth

The S_L frequency histograms and the corresponding VBGF curves for the whole time series are presented for all individuals (sexed and unsexed pooled together). The best fitting models obtained from the ELEFAN routine gave mean birth dates corresponding to the peak of the breeding season in the upper Putumayo River (Fig. 3-4A). As no single reproductively active individuals could be observed in the AMU around Iquitos during the period of study, the best fitting model giving a mean birth date during the low-water season, beginning of the rising water period (corresponding to the observed breeding period in the upper Putumayo) was selected (Fig. 3-4B). The corresponding VBGF parameters for males, females and all individuals (sexed and unsexed) pooled together, are presented in Tab. 3-2.

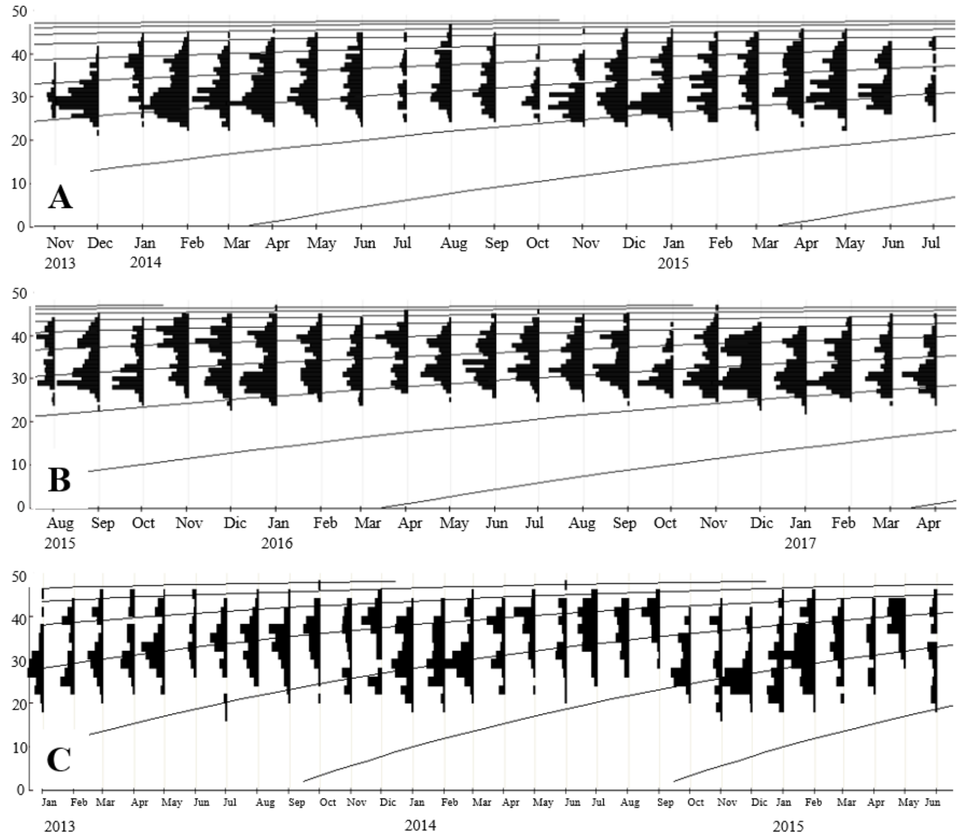


Figure 3-4. Standard length frequency histograms and the corresponding von Bertalanffy growth function for *Calophysus macropterus* (sexed and unsexed individuals combined) in (A, B) the upper Putumayo River and in (C) the AMU (the Amazonas, lower Marañón and Ucayali rivers).

Table 3-2. Parameters of the von Bertalanffy growth function (L_∞, k, t_0), growth performance index (ǿ) and longevity (t_{max}) of *Calophysus macropterus* in the upper Putumayo River and in the AMU, as modelled in FISAT II using the ELEFAN procedure. Longevity t_{max}^1 and t_{max}^2 were calculated form Taylor, (1958) and Froese, Binohlan (2000), respectively

	Sex	L_∞ (cm)	K ($Year^{-1}$)	t_0 ($Year^{-1}$)	ǿ	Score	t_{max}^1 (Year)	t_{max}^2 (Year)
Upper Putumayo	Females	50.4	0.40	-0.357	3.007	0.146	7.1	5.8
	Males	48.4	0.45	-0.319	3.023	0.150	6.3	5.3
	Total	50.1	0.42	-0.340	3.023	0.141	6.8	5.1
AMU	Females	49.9	0.68	- 0.21	3.229	0.394	4.2	3.9
	Males	43.9	0.80	- 0.35	3.188	0.255	3.6	3.2
	Total	50.0	0.6	- 0.29	3.176	0.171	4.7	3.9

In both the upper Putumayo and in the AMU, females tended to have a better growth than males as indicated by the calculated SL-at-age (Tab. 3-3). Females were systematically larger than males and the size difference tended to increase with age. This among-gender difference, however, tended to be greater in the AMU than in the upper Putumayo.

Fish also tended to have a better growth in the AMU than in the upper Putumayo: this difference ranged from > 21% at age one to 2% at age 8 (see # Total, Tab. 3-3). The youngest individuals sampled were ~ 1 year old (22 cm male) in the upper Putumayo and ~ 4 month old (16.5 cm female) in the AMU.

Table 3-3. Standard length-at-age (cm, calculated from the VBGF) for females (F), males (M) and the combination of sexed and unsexed individuals (Total) of *Calophysus macropterus* in the upper Putumayo River and in the AMU. (# F – M): growth difference between females and males. # Total: growth difference between the fish (all individuals combined) from the upper Putumayo and the AMU. P&F (2009): length-at-age data calculated from the VBGF parameters provided in a previously published study (Pérez, Fabré, 2009).

	Upper Putumayo				AMU					P&F
Age (t)	F	M	Total	# F-M	F	M	Total	# F-M	#	Total
1	21.1	21.7	21.6	- 2.6%	27.9	26.8	26.2	4.0%	21.3%	18.6
2	30.8	31.4	31.3	- 1.9%	38.8	36.2	36.9	7.0%	19.9%	26.8
3	37.2	37.5	37.8	- 0.8%	44.2	40.5	42.8	9.4%	13.2%	32.1
4	41.6	41.5	42.0	0.3%	47.0	42.4	46.1	11.0%	9.8%	35.7
5	44.5	44.0	44.8	1.2%	48.4	43.2	47.8	12.1%	6.7%	38.1
6	46.4	45.6	46.6	1.9%	49.1	43.6	48.8	12.8%	4.7%	39.6
7	47.7	46.6	47.8	2.4%	49.5	43.8	49.3	13.1%	3.1%	40.7
8	48.6	47.3	48.6	2.9%	49.7	43.8	49.6	13.4%	2.1%	41.4

The calculated life span for *C. macropterus* varied according to the model used (Tab. 3-2). Froese, Binohlan's (2000) model resulted in life span estimates of 5.8 and 5.3 years for females and males, respectively, in the upper Putumayo, and of 3.9 and 3.2 years in the AMU. Taylor's model (1958) gave higher estimations of 7.1 and 6.3 years for females and males, respectively in the upper Putumayo, and of 4.2 and 3.6 years in the AMU. Computing age from the VBGF, the largest fish sampled (47.5 cm unsexed individual) was ~ 7 years old in the upper Putumayo and ~ 4 years old (46.6 cm female) in the AMU (Tab. 4-3).

3.3.3 Growth and mortality patterns

Over the study period, males and females reached maturity at remarkably similar sizes in the upper Putumayo and AMU (Fig. 3-5): 28.2 cm (±0.15 SD) and 25.6 cm (± 4.45 SD) for females and males, respectively in the upper Putumayo; 27.9 cm (± 8.55 SD) and 24.6 cm (± 8.15 SD) in the AMU. Consequently, there was no significant difference in size at maturity between the upper Putumayo and AMU for both females (t = 0.090, df = 28, P = 0.993) and males (t = 0.108, df = 26, P = 0.915). Similarly, among-sex differences were not significant either in the upper Putumayo (t = 0.530, df = 26, P = 0.596) or in the AMU (t = 0.279, df = 28, P = 0.782).

Given the observed growth differences, however, age at maturity differed more markedly between the upper Putumayo (1.7 years old for females and 1.4 years old for males) and the AMU (1 year old for females and 0.8 year old for males).

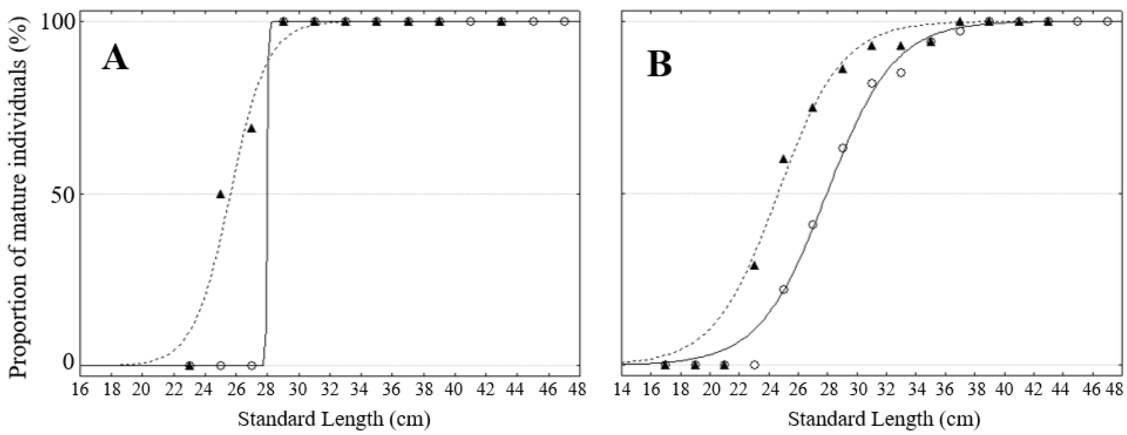
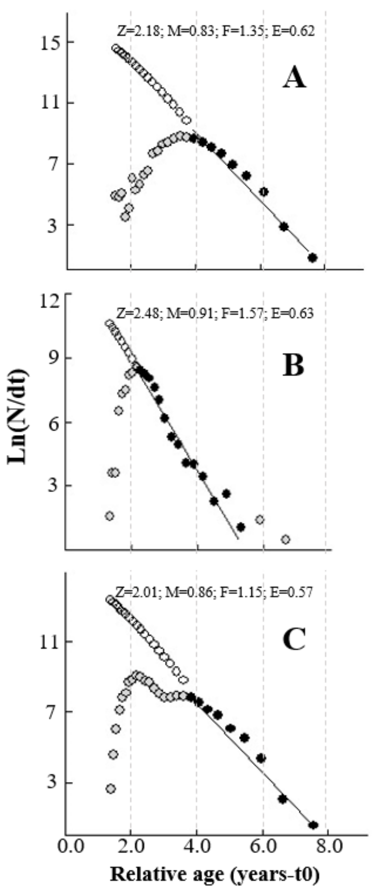


Figure 3-5. Standard length at first sexual maturity for males (black triangles) and females (white circles) of *Calophysus macropterus* (A) in the upper Putumayo River and (B) in AMU (the Amazonas, lower Marañón and Ucayali rivers).

Length converted catch curves resulted in total mortality (Z) estimates of 2.18 year^{-1} for females, 2.48 for males and 2.01 for sexed and unsexed individuals combined in the upper Putumayo (Fig. 3-6) and of 2.81 for males and 2.67 for sexed and unsexed individuals combined in the AMU (Fig. 3-7). Natural mortality (M) estimates, using both size-independent (assuming a constant M for all age and size classes) and size-dependant models (taking into account two size classes: mean length of immature fish and mean length of mature fish in the population) are presented in Tab. 3-4 for both the upper Putumayo and the AMU.



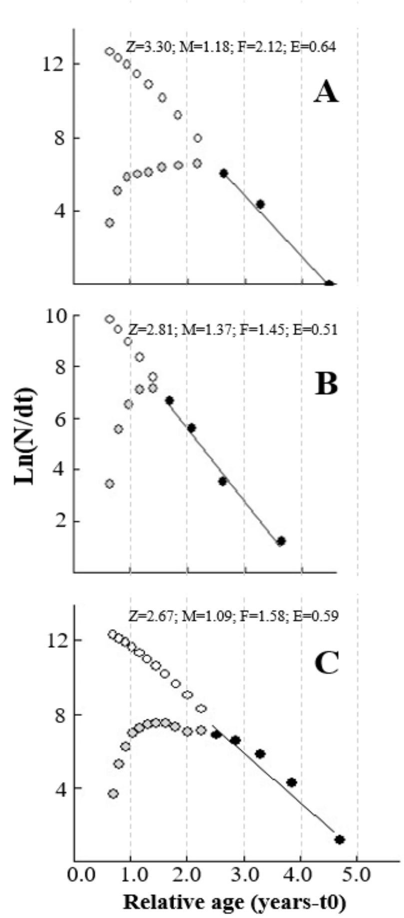


Figure 3-6. Standard length-converted catch curves (SL) and mortality estimates for *Calophysus macropterus* (A) females, (B) males and all individuals (sexed and unsexed) combined (C) in the upper Putumayo River, calculated from the VBGF parameters at a mean temperature of 27°C. Z, M and F represent the instantaneous rates of total, natural and fishing mortality, respectively. E is the exploitation rate (E = F.Z-1). Black dots = data points in the curve on which the regression was fitted.

Figure 3-7. Standard length-converted catch curves (SL) and mortality estimates for *Calophysus macropterus* (A) females, (B) males and all individuals (sexed and unsexed) combined (C) in the Amazonas, lower Marañón and lower Ucayali rivers, calculated from the VBGF parameters at a mean temperature of 27°C. Z, M and F represent the instantaneous rates of total, natural and fishing mortality, respectively. E is the exploitation rate (E = F.Z-1). Black dots = data points in the curve on which the regression was fitted.

Natural mortality estimates calculated from Pauly's (1980) equation, as implemented in FiSAT II, were within the range of values obtained from the other size-independent models for females and males in both the upper Putumayo and the AMU.

In the upper Putumayo, size-independent models (Richter and Efanov and Jensen) tended to give M estimates close to those observed for immature fish and superior to those obtained for mature fish using the size-dependent models (Gislason *et al.,* 2010; Charnov *et al*., 2013). All these natural mortality estimates resulted in high estimates of fishing mortality (F, 1.19 to 1.64 for females and 1.26 to 1.76 for males) and exploitation rate (E, 0.55 to 0.75 for females and 0.51 to 0.71 for males), excluding immature individuals. Immature individuals also had relatively high F and E values.

In the AMU, size-independent models (Richter and Efanov and Jensen) tended to give M estimates intermediate between those observed for immature and mature fish using the size-dependent models (Gislason *et al*., 2010; Charnov *et al*., 2013). Excluding immature individuals, all these natural mortality estimates resulted in higher estimates of fishing mortality (F, 1.64 to 2.31) and lower exploitation rate (E, 0.55 to 0.75) than in the Putumayo for females but lower estimates of fishing mortality (F, 0.37 to 1.53) and lower exploitation rate (E, 0.13 to 0.54) for males.

Table 3-4. Natural mortality (M, year-1) calculated using different models and corresponding fishing mortality (F, year^{-1}) and exploitation rate (E) for females, males and total (sexed and unsexed individuals combined) of *Calophysus macropterus* in the Putumayo and AMU rivers. Total mortality (Z) was calculated from length-converted catch curves illustrated in Fig. 3-6 and 3-7. Fishing mortality, F=Z-M. E=F/Z.

		Putumayo			**AMU**		
	Formulae used for estimating M	M	F	E	M	F	E
Females	Pauly, 1980.	0.83	1.35	0.62	1.18	2.12	0.64
	Richter, Efanov 1976	0.90	1.28	0.59	1.37	1.93	0.58
	Jensen, 1996. Using K	0.64	1.54	0.71	1.09	2.21	0.67
	Jensen, 1996. Using A_{50}	0.99	1.19	0.55	1.66	1.64	0.50
	Gislason *et al*., 2010. Immature	1.06	1.12	0.51	1.92	1.38	0.42
	Gislason *et al*., 2010. Mature	0.54	1.64	0.75	0.99	2.31	0.70
	Charnov *et al*., 2013. Immature	1.10	1.08	0.49	1.99	1.31	0.40
	Charnov *et al*., 2013. Mature	0.59	1.59	0.73	1.07	2.23	0.68
Males	Pauly, 1980.	0.91	1.57	0.63	1.37	1.45	0.51
	Richter, Efanov, 1976.	1.07	1.41	0.57	1.86	0.95	0.34
	Jensen, 1996. Using K	0.72	1.76	0.71	1.28	1.53	0.54
	Jensen, 1996. Using A_{50}	1.22	1.26	0.51	2.44	0.37	0.13
	Gislason *et al*., 2010. Immature	1.07	1.41	0.57	2.11	0.70	0.25
	Gislason *et al*., 2010. Mature	0.82	1.66	0.67	1.35	1.46	0.52
	Charnov *et al*., 2013. Immature	1.12	1.36	0.55	2.15	0.66	0.23
	Charnov *et al*., 2013. Mature	0.87	1.61	0.65	1.42	1.39	0.5
Total	Pauly, 1980.	0.86	1.15	0.57	1.09	1.58	0.59
	Jensen, 1996. Using K	0.67	1.34	0.67	0.96	1.71	0.64
	Gislason *et al*., 2010. Immature	1.06	0.95	0.47	1.70	0.97	0.36
	Gislason *et al*., 2010. Mature	0.65	1.36	0.67	0.87	1.80	0.67
	Charnov *et al*., 2013. Immature	1.11	0.90	0.45	1.76	0.91	0.34
	Charnov *et al*., 2013. Mature	0.71	1.30	0.65	0.95	1.72	0.65

3.4 Discussion

3.4.1 Reproduction

Published information about the reproductive biology of *C. macropterus* in the Amazon basin is scant and circumstantial. In the Caquetá River around La Pedrera, in Colombia, Agudelo *et al*., (2000) mentioned the presence of mature individuals in July, during the early decreasing water period, without showing data. Pérez and Fabré (2002, 2009) did not get any ripe female during their sampling in Central Amazonia (around Manaus) and most individuals were either immature or resting. They suggested, from the slightly higher gonado-somatic index values during the early rising waters, that reproduction probably occurred during that period. The same situation was observed in the present study around Iquitos, where no single ripe female or female with gonads in advanced maturation process was observed during the two and half year's sampling in the AMU, where the breeding cycles of many species (García Vasquez *et al*., 2015; Duponchelle *et al*., 2015), including pimelodid catfishes (García Vasquez *et al*., 2009) were successfully studied. This situation was also observed in Bolivia around Trinidad, where the breeding cycles of many species (Loubens, 2003), including pimelodid catfishes (Loubens, Panfili, 2000) were successfully studied. The only location in the Amazon basin so far where ripe individuals were officially reported is in the upper Putumayo around Puerto Leguízamo (Camacho *et al*., 2006, present study). The present study clearly demonstrates, during over three consecutive hydrological cycles, that the breeding season of *C. macropterus* occurs during the low water and early rising water periods. This is consistent with previous studies on fish larvae, collected using plankton nets and specifically identified by barcoding/metabarcoding (COI gene), which found *C. macropterus* larvae in the lower Marañon and lower Ucayali during the low water and early rising water periods (García-Dávila *et al*., 2015; Mariac *et al*., 2021). But larvae can travel long distances downstream.

The available evidence strongly suggests that environmental requirements for the reproduction of *C. macropterus* are met higher in the hydrographical networks, closer to the Andes. Although the elevation of the Putumayo in Puerto Leguízamo is only slightly higher than that of the Ucayali in Pucallpa (~177 m vs ~154 m, respectively), it is much closer to the Andean piedmont and the slope is much steeper upstream than in the Ucayali around Pucallpa. Similar topographical situations are found in 1) Puerto Maldonado in the upper Madre de Dios (Perú), where fishermen report the occurrence of ripe females between August and October (Chuctaya W., pers. comm. to

Duponchelle F.), corresponding to the low water - early rising water period (Cañas, Pine, 2011); 2) Puerto Villaroel in the upper Mamoré River (Bolívia), where ripe individuals are also observed (Van Damme P., pers. comm. to Duponchelle F.). Ripe individuals were also observed in the Portugues, Guanare, Bocono, Masparro rivers (tributaries of the Apure River) in the Andean foothills of Venezuela (300-150 m.a.s.l), during the period of rising waters (April – June; Castillo O., pers. com. to Bonilla Castillo C.).

As the species is distributed in the whole Amazon basin, the available evidence indicating that it breeds only in the Andean foothills above ~150 m.a.s.l. suggest that its life cycle involves extensive migrations between the breeding areas and the distributing areas as far as Central or Lower Amazonia. Migrations at such a large scale are only known within another Pimelodid catfish genus, *Brachyplatystoma* spp. (Barthem *et al*., 1997, 2017; see Duponchelle *et al*., 2021 for review). This hypothesis, amenable to testing using natural tags such as otolith microchemistry (see review in Hermann *et al*., 2021), illustrate the large knowledge gaps remaining in the ecology of Amazonian species, including economically important fisheries resources such as *C. macropomum*.

Despite the important sexual dimorphism in both mean Lmax and Wmax in the Putumayo and in the AMU, L_{50} were remarkably similar among genders. Size at first sexual maturity did not differ either between the Putumayo and the AMU although age at first sexual maturity did differ, owing mainly to the observed growth differences among river systems.

3.4.2 Growth and mortality patterns

The important size dimorphism observed between females and males is a common feature in pimelodid catfishes (Agudelo *et al*., 2000; Loubens, Panfili, 2000; García Vasquez *et al*., 2009) and characids (Duponchelle *et al*., 2007), and was also reported for *C. macropterus* in Bolivia (Loubens, Aquim, 1986). Yet, Loubens and Aquim (1986) observed that sexual dimorphism was particularly pronounced in this species, reaching 20% in maximum observed length (Lmax) and 50% in maximum observed body mass (Wmax), which is consistent with our own observations. Lmax in this study (47.5 and 46.6 cm in the Putumayo and AMU, respectively) were smaller than those reported almost 20 years ago by Agudelo *et al*., (2000) in the same rivers (52 cm in the

Putumayo, 52 cm in the Amazonas close to Leticia, Colombia). Agudelo *et al*., (2012) also reported this Lmax reduction of *C. macropterus* in the Putumayo River and suggested it was likely due to the increased exploitation.

In both the upper Putumayo and the AMU, *C. macropterus* presents a fast growth during the first two years, as was also reported in Central Amazonia (Pérez, Fabré, 2009). In the two river systems, females had a faster growth than males and the difference increased with age, which was not observed in Pérez and Fabré (2009), where both sexes had similar growths. Growth dimorphism was reported in other species of the family Pimelodidae such as *Brachyplatystoma rousseauxii* (García Vásquez *et al*., 2009) or *Pseudoplatystoma tigrinum* and *P. fasciatum* (Loubens, Panfili, 2000). The among-sex difference, however, was much greater in the AMU than in the upper Putumayo. Fish also had a better growth in the AMU than in the upper Putumayo although this difference decreased with age from > 21% at age one to 2% at age 8. The growth rate observed in the present study were both better than that observed in Central Amazonia (Pérez, Fabré, 2009). The growth rate observed in the present study, however, remains low compared to growth rates obtained in captivity, where well fed and cared for specimens can reach in four to five months the length observed at one year old in the Putumayo and AMU, respectively (Kossowsky, 1998). The length calculated for one-year-old fish by Pérez and Fabré (2009, Tab. 3 present study) was reached after only two months in captivity (Kossowsky, 1998).

In both river systems, females tended to grow larger and faster than males, and the growth difference between females and males tended to be more important in the AMU than in the Putumayo. While we cannot rule out the possibility that the AMU would be a feeding site, while the Putumayo works as a spawning ground, the observed differences could also result from better trophic conditions in the AMU than in the Putumayo. When trophic conditions are less favourable, females cannot find enough energy to express their better growth potential to the maximum, which has already been observed for the red piranha, *Pygocentrus nattereri* (Duponchelle *et al*., 2007). Although there is no data providing direct evidence of less favourable conditions in the Putumayo, this hypothesis finds support in the fact that and fish generally tend to be smaller in the Putumayo than in the Caquetá (Bonilla-Castillo, Agudelo, pers. obs.) and that slower growth were already reported for other species in this river: *Prochilodus nigricans* (Bonilla-Castillo *et al*., 2018), *Osteoglossum bicirrhosum* (Duponchelle *et al*., 2015), *Pseudoplatystoma punctifer* (Armas *et al*., in press).

As previously emphasized (Bonilla-Castillo *et al*., 2018), however, inter-basin differences in fishery exploitation could also account for slower growth in fish populations of the Putumayo River, where the more heavily exploited populations tend to have smaller maximum sizes and slower growth. This phenomenon is known as tropicalization of stocks (Stergiou, 2002).

As natural mortality (M) is one of the most complicated life history parameters to estimate in natural fish populations (Pauly, 1980), estimations from several different methods were calculated in order to provide a measure of reliability. Natural mortality estimates calculated from Pauly's (1980) equation, as implemented in FiSAT II, were within the range of values obtained from the other size-independent models for females and males in both the upper Putumayo and the AMU. Whatever the method used for calculation, fishing mortality and exploitation rates were high for both the Putumayo and the AMU, indicating overexploitation of *C. macropterus* in both river systems. Fishery exploitation can therefore not be ruled out in the explanation of the observed slower growth in the Putumayo, although further studies will be needed to sort out its importance relative to the hypothesis of poorer trophic conditions in the Putumayo.

Calophysus macropterus has become quite infamous in most Amazonian countries in recent years because of the conservation and health issues associated with its exploitation and consumption. Yet, strong evidence suggests that in absence of proper enforcement, which is most challenging in the Amazon basin, its exploitation and fraudulent commercialization (i.e. Cunha *et al*., 2015) will likely continue, further endangering the natural populations of aquatic mammals and reptiles. Given its excellent potential for aquaculture (see Kossowsky, 1998 for further details) and its relatively low trophic level (Agudelo Córdoba, 2015), a complementary way of lowering its impact on natural populations of river dolphins, manatees and caimans, while providing healthy animal protein for the growing human populations, would be to encourage the development of its aquaculture in Amazonian countries, using local products as alternative to fish meal and oil. This solution would also allow relieving some of the harvesting pressure on natural populations of *C. macropterus*.

Life history traits of *Calophysus macropterus* varied importantly between the Putumayo and the AMU systems. Reproduction was only observed in the upper Putumayo, suggesting the species needs specific environmental conditions found close to the Andean piedmont and not available in our AMU sampling locations. Females tended to have a better growth than males in both river systems and fish of the AMU tended to grow faster in the AMU than in the Putumayo. The mortality data indicate overexploitation of the species in both river systems.

3. Estimation of growth parameters and stock status of *Mylossoma albiscopum* (Characiformes: Serrasalmidae) in two tributaries of the Amazon River

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Abstract

Mylossoma albiscopum is considered one of the main species for local consumption in the Amazon region; information on life traits and the current fishery status is poorly documented. Monthly monitoring of the capture sizes and registration of gonadal development of the species was carried out in the upper basin of the Putumayo River (2016-2019) and upper Solimões around Leticia (2007-2008). The reproductive season was recorded in the rising water season for both basins. The length at first maturity did not differ between rivers, ranging from 14.9 to 14.4 cm, respectively. Although upper Putumayo individuals showed a better growth rate, the growth parameters were very similar. The exploitation rate in upper Solimões was 0.67 and 0.54 in Putumayo. The potential spawning ratio varied between 0.19-0.23 in the upper Solimões and 0.35-0.58 for the Putumayo River. The state of exploitation of the resource indicates overfishing in the upper Solimões River and sustainable fishing in the Putumayo River. The results obtained provide elements for fishing management and conservation of this species.

Keywords: Artisanal fishing, Hydrological regime, Oscillatory Growth, LB-SPR, Migration lateral

Resumen

Mylossoma albiscopum es considerada una de las principales especies para el consumo local en la Amazonia; la información sobre rasgos de vida y estado actual de la pesquería está pobremente documentada. Mensualmente, se hizo seguimiento con respecto a las tallas de captura y desarrollo gonadal de la especie en la cuenca alta del río Putumayo (2016-2019) y alto Solimões a la altura de Leticia (2007-2008). La época reproductiva se registró en la temporada de aguas en ascenso para ambas cuencas. La longitud de primera madurez no difiere entre los ríos, presenta un rango desde 14,9 hasta 14,4 cm respectivamente. Los parámetros de crecimiento fueron muy similares, aunque los individuos del alto Putumayo presentaron un mejor índice de crecimiento. La tasa de explotación en el alto Solimões fue 0,67 y 0,54 en el Putumayo. La proporción potencial de desove varió entre 0,19-0,23 en el alto Solimões y 0,35-0,58 para el río Putumayo. El estado de explotación del recurso indica sobrepesca en alto río Solimões y pesca sustentable en el Putumayo. Los resultados obtenidos aportan elementos para el manejo pesquero y conservación de la especie.

Palabras clave: Crecimiento oscilatorio, Régimen hidrológico, LB-SPR, Migración lateral, Pesca artesanal

4.1 Introduction

The Amazon basin is estimated to be home to approximately 2,406 fish species, some of great importance for local and commercial consumption. Studies have estimated that 14.7% of the species present in the Putumayo river basin (705 species) and 9.6% in the upper Solimões (1,113 species) are used for consumption (Agudelo, 2015; Jézéquel *et al*., 2020). *Mylossoma* sp., together with *P. nigricans*, are the most representative species in consumption fishery in the Colombian-Peruvian Amazon (Agudelo *et al*., 2006; Bonilla-Castillo *et al*., 2018; Moya *et al*., 2020). *Mylossoma albiscopum* is widely distributed in the Amazon and Orinoquia basins (Mateussi *et al*., 2018). Altitudinally, individuals have been recorded between 51 m.a.s.l. in Santarén-Brazil (Zacardi *et al*., 2018) and 333 m.a.s.l. in the Caquetá river, the town of Puerto Limón, and San Juan River (a tributary of the Putumayo River) at 262 m.a.s.l. at the Amazonian foothills in Colombia (Leonel Vallejo-Yela, 2022, pers. comm.).

Mylossoma albiscopum is a herbivorous species with an omnivorous tendency (Tribuzy-Neto *et al*., 2017; van der Sleen, Albert, 2017). Adult individuals migrate and move laterally during the rising water season from jungle origin streams and lagoons to whitewater rivers (Araujo-Lima, Ruffino, 2004; Granado-Lorencio *et al*., 2005). After the laying season, the fish takes refuge and feeds in the flooded forest and marginal river areas for dispersal, colonization, and initial development (Saint-Paul *et al*., 2000; Zacardi *et al*., 2018). Genetic studies and morphological information established that the *Mylossoma* genus includes four species: *M. albiscopum* and *M. aureum*, which thrive in the Amazon and Orinoquia basins, and *M. duriventre* in the Paraguay River, lower Paraná River, and Uruguay river basin. Finally, *M. unimaculatum* is endemic to the Tocantins-Araguaia system (Mateussi *et al*., 2017, 2018).

Despite the economic and social importance that this resource represents for the Amazon region, there are few studies on the population dynamics and status of *Mylossoma albiscopum*. Accordingly, this research aims to provide information on the life history, population dynamics, and current status of this resource in the Putumayo and upper Solimões river basins on the border axis between Brazil, Colombia, and Peru.

4.2 Materials and Methods

4.2.1 Sampling area

Sampling was carried out in two areas, In the upper basin of the Putumayo River near the city of Puerto Leguizamo and the upper Solimões River around the city of Leticia. The city of Puerto Leguízamo (00°11'53.2"S, 74°46'42.7"W) is located in the upper part of the Putumayo River at an altitude of 220 m.a.s.l. with a hot and humid climate (Bonilla-Castillo *et al*., 2022) (Fig. 4-8). The Putumayo River is a white water system of Andean origin. It is one of the two major Colombian affluents flowing into the Amazon River. It has a length of 2,000 km, of which 1,500 travels through the Colombian territory and 450 km in Brazil (Alonso *et al*., 2006). In Puerto Leguízamo, it has a flow of 268 $m^3.s^{-1}$ on average, with a maximum value of 417 $m^3.s^{-1}$ in July. Water transparency is approximately 16 cm, with a conductivity value of 41.8 µS/cm and an average pH of 6.7. The average dissolved oxygen value is 5.2 mg/L, turbidity FNU 197.3, total dissolved solids [ppm] 21.2, and an average water temperature of 26.3ºC. (Núñez-Avellaneda *et al*., 2006; Bonilla-Castillo *et al*., unpublished data). The city of Leticia (04°13'20.81"S, 69°56'44.90"W) is situated on the banks of the Colombian Amazon River or upper Solimões river in the border area of Brazil and Peru. It is located at about 77 m.a.s.l. Hydrologically, this region exhibits a monomodal regime with high waters in March-May and low in August-October. Rising waters occur in November-February and falling waters between June-July. The physical and chemical variables of the river during low and rising waters show transparency between 21.5-10.2 cm, conductivity from 173.1 to 163.3 µS/cm, pH of 7.35-7.46, dissolved oxygen of 4.35-4.84 mg/L, and a water temperature between 28.6-28.3ºC (Palma *et al*., 2014).

Figure 4-8. Geographical location of *Mylossoma albiscopum* sampling points in Puerto Leguízamo on the upper Putumayo River and Leticia on the upper Solimões River.

4.2.2 Fish sampling.

In the Putumayo, fish were sampled monthly between October 2016 and July 2019 at the main fish landing centers in the city of Puerto Leguízamo. In Leticia, fish were sampled between August 2007 and September 2008 from the border towns of Tabatinga (Brazil), Santa Rosa (Peru), and the coastal fishing areas on the Colombian side.

In both localities, artisanal fishers used the same capture method, monofilament surface gillnets made of nylon (polyamide-PA) known locally as "*agalleras* or *plástica*" from 0.28 to 0.30 mm in diameter. The netting piece varies between 40 to 100 m long with 30 to 50 meshes in height. The sizes of the meshes are 2.5, 3, and 3.5 inches for the top rope; braided PA 4 mm diameter lines are used. They carry polystyrene floats and sometimes plastic bottles on the top rope. No rope in the lower part is utilized. This fishing gear is employed during all hydrological periods but more frequently in the high water season.

The specimens collected were determined taxonomically compared to individuals from the Amazonian ichthyological collection of Instituto Amazónico de Investigaciones Científicas SINCHI (e.g., Sinchi voucher: CIACOL: 496, 340, Puerto Leguízamo market place and lake I, Yahuarcaca lagoon system-Leticia). For each individual, the standard length (S_L) in cm and, when possible, the total weight (W_t), eviscerated weight (W_e), and gonads weight (W_g) in grams were recorded.

4.2.3 Biometric indicator

The weight-length relationship was estimated with the following potential equation.

$$W_t = a*S_L^b$$

Where W_t is the total weight expressed in grams (g), S_L is the standard length (cm), "*a*" is the intercept, and "*b*" is the slope (coefficient of determination). Parameters *a* and *b* were estimated by linearization according to Froese (2006) as follows.

$$_{\log}(W_t) = \log(a) + b*_{log}(S_L).$$

4.2.4 Reproductive aspects

The reproductive season was estimated using the gonad somatic index (GSI) in females as follows:

$$GSI = Wg/Wt*100$$

To estimate the length at first maturity (L_{m50}) in females, class intervals of 1 cm were assigned and fitted to a logistic function model to determine L_{m50} and L_{m95} corresponding to the sizes in which 50 and 95% of the population reach sexual maturity (King, 2007).

The following equation establishes the percentage of mature individuals by size class (%M).

$$\%M = \frac{1}{1 + e^{(-a*(L-L50))}}$$

Where *L* is the central value of each size class, and "*a*" and L_{50} are constant parameters of the model.

4.2.5 Growth parameters

For the estimation of the population parameters, the ELEFAN method (Electronic LEnght Frequency ANalysis) of the von Bertalanffy growth function (VBGF) was used through the length-frequency analysis (LFQ) of modal progression through time (Pauly, 1980), employing the TropFishR package found in the free software environment R Project for Statistical Computing (Mildenberger *et al*., 2017). Once the LFQ was built, a bootstrapped ELEFAN with the genetic algorithm function (bootstrapping ELEFAN_GA) proposed by Schwamborn *et al*. (2019) was applied to the LFQs, thus, allowing the evaluation of the uncertainty around the growth estimates. The von Bertalanffy function with stationary oscillation (soVBGF) (Somers, 1988) was applied to estimate the parameters.

The length of the fish at age "*t*" (L_t) was estimated using the following equation:

$$L_t = L_\infty (1 - \exp(-(K (t-t_0) + S(t) - S(t_0))))$$

Where L_∞ is the asymptotic length of the fish (cm), K is the growth rate, and "t_0" is the theoretical age when L_t equals zero (now t_{anchor}). S(t) is obtained using the following equation.

$$S(t) = (CK/2\pi) \sin 2\pi(t-ts)$$

Where *C* is the oscillation amplitude constant that varies between 0 to 1 (values >1 represent shrinkage in length), and summer point "*ts*" is the fraction of one year (relative to the recruitment age, t=0) when the oscillation wave starts. The ELEFAN_GA boot setting in the script for both sampling locations was *popSize* = 100, *maxiter* = 50, *run* = 10, *pmutation* = 0.2, and bootstrap *runs/nresamp* = 1,000. The moving average (MA) was evaluated at interval 5. The growth performance index (Φ') defined by Pauly, Munro (1984) was also calculated as follows.

$$\Phi' = {}_{log}K + 2{}_{log}L_\infty$$

Where K and L_∞ are soVBGF parameters.

The age at first sexual maturity (A_{50}) was calculated from the VBGF (Bonilla-Castillo et *al*., 2022) as follows.

$$A_{50} = \{-\ln[1-(L_{m50}.L_\infty - 1)]k-1\} + t_0$$

Where L_{m50} is the fish size when reaching sexual maturity, and L_∞ and K are VBGF parameters.

The longevity ($_{tmax}$) was estimated using two models. The one of Taylor (1958) using the equation $t_{max}^1 = t_0 + 2.996/K$, where "$t_0$" and K are VBGF parameters, and the two of Froese, Binohlan (2000) with the equation $\log_{10} t_{max}^2 = 0.5496+0.957 \log_{10} (A_{50})$, where A_{50} is the age at first sexual maturity.

4.2.6 Mortality and exploitation rate

Total mortality rate (Z) was calculated by the length-linearized curve method (Pauly, 1984), while natural mortality (M) was estimated from various empirical equations or indirect methods based on longevity, life history parameters, and ecology. The National Oceanic and Atmospheric Administration (NOAA) application (https://connect.fisheries.noaa.gov/natural-mortality-tool/) developed by Jason Cope (The barefoot ecologist's toolbox) was used. Twelve natural mortality estimators were considered (Then_nls, Then_lm, Hamel_Amax, Then_VBGF, Hamel_k, Jensen_k1, Gislason, Charnov, Pauly_lt, Roff, Jensen_Amat, and Ri_Ef_Amat) according to Hamel (2014), Kenchington (2014), Rikhter, Efanov (1976) and Then *et al*. (2015). An uncertainty level of 10% and a type of log-normal error distribution were added to the estimated values. The fishing mortality rate (F) was estimated based on the relationship F = Z-M (Pauly, 1980). The level of exploitation (E) was calculated utilizing E = F/Z.

4.2.7 Fishery assessment

The relative yield per recruit (YPR) and relative biomass per recruit (BPR) were estimated with the Thompson and Bell models (Sparre, Venema, 1998). The model was used to predict the effects of changes in fishing effort on future yields. It is possible to illustrate current fishing mortality (F_{cur}), fishing mortality at 50% of exploited virgin biomass ($F_{0.5}$), and fishing mortality at maximum sustainable yield (F_{msy}) using this method.

4.2.8 Spawning Potential Ratio

The Length-Based Spawning Potential Ratio (LB-SPR) method was developed by Hordyk *et al*. (2015a) and allows estimating the spawning potential ratio (SPR) from catch size composition. The biological parameters used were those estimated in this study: L_∞, the coefficient of variation (CV) of L_∞ assuming it to be 10% as recommended by Prince *et al*. (2015), M/K, and Length at maturity ($L_{m50\,\%\,-\,95\%}$) (Tab. 4-6). The composition of the catch sizes was categorized according to the hydrological regime (low, rising, high, and falling waters). The number of records in lengths per hydrological season was higher than 1,000 data. The model estimates the selectivity size ($L_{s50\text{-}95}$) and the F/M exploitation rate from the input data used to estimate SPR (Hordyk *et al.*, 2015b). The SPR index varies between 0 and 1, with one (1) representing an unexploited stock and zero (0) the overexploited stock. The status of a stock can be classified into three groups: Underexploited (SPR> 0.4), moderately exploited (0.2<SPR<0.4), and overexploited (SPR<0.2).

4.3 Results

A total of 7,960 and 4,793 individuals of *M. albiscopum* from Leticia (upper Solimões River) and Puerto Leguízamo (upper Putumayo River) were analyzed. The smallest capture length in the Solimões River was 9.5 and 10 cm in the Putumayo River (Figs. 4-9A-B).

During the study period, the relationship between standard length (S_L) - total weight (W_t) was $W_t = 0.0530\ S_L^{2.88}$ ($R^2 = 0.938$, $P<0.001$) for females, $W_t = 0.0453\ S_L^{2.95}$ ($R^2 = 0.867$, $P<0.001$) for males, and $W_t = 0.0557\ S_L^{2.86}$ ($R^2 = 0.926$, $P<0.001$) for the combination of both sexes in the upper Solimões River. This value was $W_t = 0.0464\ S_L^{2.97}$ ($R^2 = 0.961$, $P<0.001$), $W_t = 0.0576\ S_L^{2.88}$ ($R^2 = 0.966$, $P<0.001$), and $W_t = 0.0489\ S_L^{2.94}$ ($R^2 = 0.957$, $P<0.001$) for females, males and for both sexes combined, respectively, in the upper Putumayo Rive (Tab. 4-5).

Table 4-5. Mean length of catch and range of standard length (S_L), weight range (W_t), length-weight relationship ("a" and "b"), 95% confidence interval (CI), r^2 determination coefficient of females (F), males (M) and all individuals (sex and unsexed, T) combined of *Mylossoma albiscopum* specimens analyzed from Puerto Leguízamo (upper Putumayo River) and Leticia (upper Solimões River). N = number of fish analyzed.

River	Sex	N	Lmean (cm)	S_L (cm) range	Wt (g) range	a ($_{CI95\%}$)	b ($_{CI95\%}$)	R^2
Upper Solimões	F	1031	15.6	10-21.2	38.0-400.0	0.0530(0.0449-0.0626)	2.88(2.82-2.94)	0.938
	M	466	14.5	9.5-21.0	43.0-440.0	0.0453(0.0344-0.0598)	2.95(2.84-3.05)	0.867
	T	6458	15.2	9.5-25.0	38.0-440.0	0.0557(0.0483-0.0643	2.86(2.80-2.91)	0.926
Upper Putumayo	F	1281	16.8	10.4-25.7	49.2-661.3	0.0465(0.0384-0.0564)	2.97 (2.90-3.04)	0.961
	M	773	15.1	10.9-25.0	53.8-558.6	0.0576(0.0492-0.0675)	2.88(2.82-2.94)	0.966
	T	3936	16.8	10.0-26.4	49.2-661.3	0.0489(0.0436-0.0549)	2.94 (2.89-2.98)	0.957

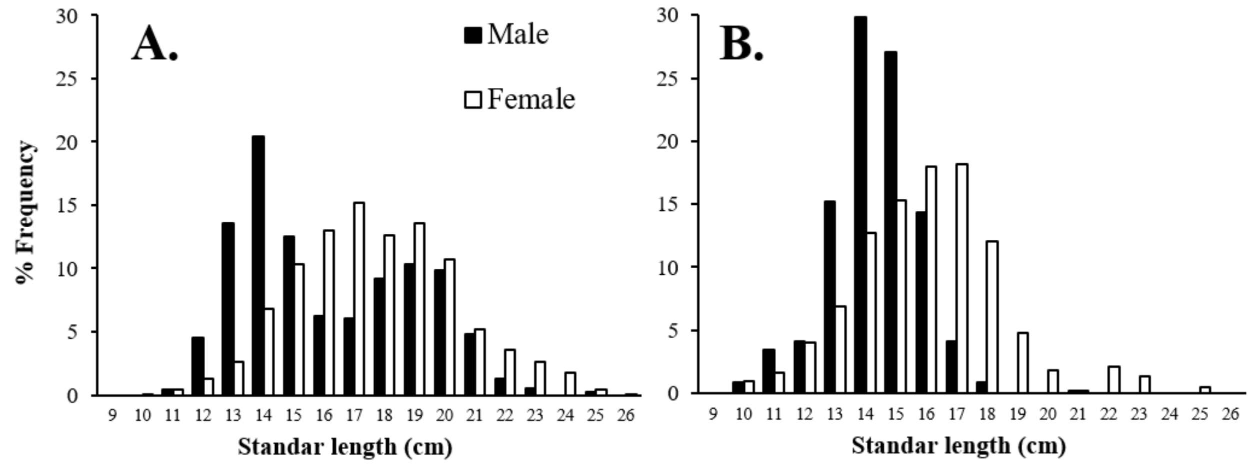

Figure 4-9. Size frequency distribution of *Mylossoma albiscopum* females and males caught over the study period in the Putumayo River (**A**) and upper Solimoes River (**B**).

4.3.1 Reproduction

In the upper area of the Putumayo River, the gonad somatic index (GSI) indicates that the reproductive season of the species occurs between February and April, with a maximum peak in March, during the rising waters season (Fig. 4-10A). This same pattern was observed over the years. On the other hand, the reproductive season for the upper Solimões River begins in October and ends in February, with a maximum peak in January, also during the rising waters period (Fig. 4-10B).

According to the data analyzed, the estimated L_{m50} and L_{m95} for the upper Solimões River were 14.6 and 16.2 cm-S_L. For the upper Putumayo, it was estimated at 14.9 and 16.1 cm-S_L, respectively. According to the histological analyzes in fish from Putumayo, 14.5 cm-S_L in females have been found during the vitellogenesis process, coinciding with the L_m data calculated in this study.

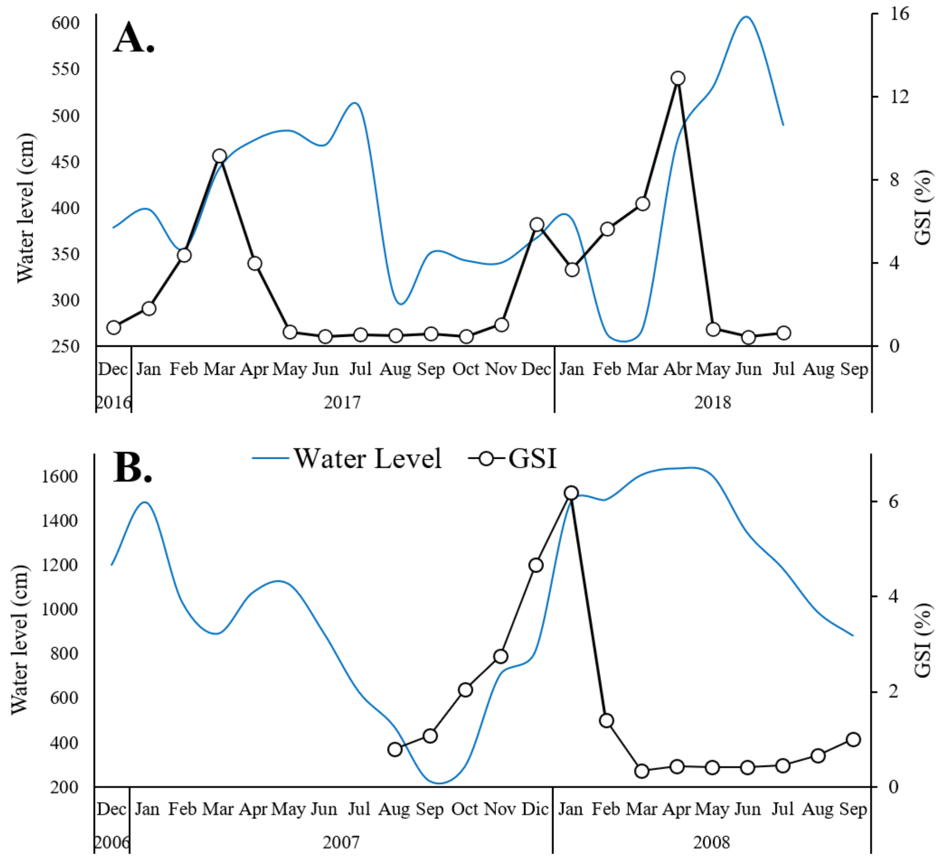

Figure 4-10. Mean monthly Gonad Somatic Index (GSI) values (**circles**) of *Mylossoma albiscopum* females between 2013 and 2017 in relation with the water level (**dotted line**) in the upper Putumayo River (**A**) and 2006 and 2008 in the Solimões River (**B**).

4.3.2 Growth parameters

The estimated parameters of the ELEFAN_GA_boot routine using the VBGF seasonality for the upper Solimões River are L_∞ = 28.33 cm, K = 0.37 yr^{-1}, and t_{anchor} = 0.06. The intensity of the growth oscillation (C) was 0.87, and the point during the summer period (t*s*) was estimated at 0.62 (August). In the case of Putumayo, the estimated parameters are L_∞ = 28.63 cm, K = 0.39 yr^{-1}, and t_{anchor} = 0.22. The intensity of the growth oscillation (C) was 0.73, and the point during the summer period (t*s*) was estimated at 0.46 (June) (Fig. 4-11A-B). Although the VBGF parameters are very similar between both rivers, the Growth Performance Index (Φ') indicates that the fish from the Putumayo River have a better growth efficiency than those from the upper Solimões River (Tab. 4-6).

The estimated longevity (t_{max}) for *M. albiscopum* varied between 5.23-7.25 in the upper Solimões River and 5.09-7.64 in the Putumayo River, depending on the model. When age is estimated with the calculated VBGF parameters, the largest individuals captured in the study for Solimões (25 cm) and Putumayo (26.4 cm) are estimated at 5.3 and 6.1 years, respectively.

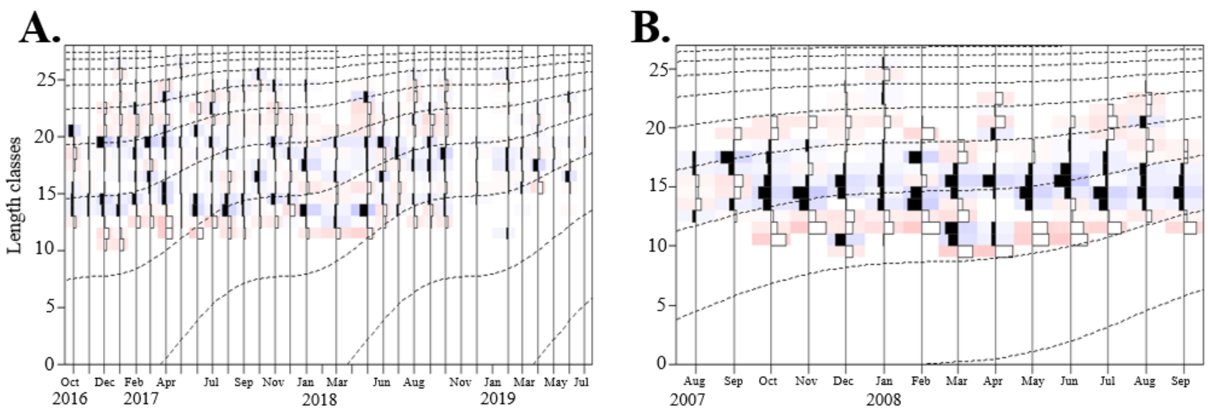

Figure 4-11. Restructured montly length frequency distributions and the corresponding seasonalized von Bertalanffy growth function for *Mylossoma albiscopum* (sexed and unsexed individuals combined) in (**A**) the upper Putumayo River and (**B**) the upper Solimões River.

Table 4-6. Population parameters of *Mylossoma albiscopum* in the upper Solimões River and upper Putumayo River estimated using the von Bertalanffy oscillating seasonal growth function (soVBGF) ELEFAN_GA method with the TropFishR genetic algorithm function. Upper and lower 95% confidence intervals. Longevity t_{max}^1 and t_{max}^2 calculated from Taylor (1958) and Froese, Binohlan (2000).

SITE	PARAMETER	MODA	LOWER	UPPER
Upper Solimões	L_∞	28.33	26.72	30.21
	K	0.37	0.32	0.58
	t_{anchor}	0.06	0.01	0.1
	C	0.87	0.43	0.98
	t_s	0.62	0.06	0.98
	Φ’	2.47	2.44	2.70
	Longevity (t_{max}^1)	7.25		
	Longevity (t_{max}^2)	5.23		

Upper Putumayo	L_∞	28.63	27.09	30.11
	K	0.39	0.31	0.47
	t_{anchor}	0.22	0.15	0.31
	C	0.73	0.41	0.99
	t_s	0.46	0.18	0.85
	Φ’	2.52	2.39	2.67
	Longevity (t_{max}^1)	7.64		
	Longevity (t_{max}^2)	5.09		

4.3.3 Mortality parameters and exploitation rates

The weighted values of the natural mortality (M) estimated for *M. albiscopum* in the upper Putumayo and Solimões rivers were very similar (0.88 and 0.86, respectively). Regarding the age of first capture (t_{50}), Solimões recorded younger fish in the landings in relation to Putumayo. The fishing exploitation rate (E) was higher in the Solimões River (0.67) than in the Putumayo River (0.54). However, both localities register E>0.5 (Tab. 4-7).

Table 4-7. Mortality, exploitation rate and age of first capture of *Mylossoma albiscopum* in the upper Solimões and Putumayo rivers.

PARAMETER	PUTUMAYO	SOLIMÕES
Total mortality (Z) yr^{-1}	1.91	2.61
Natural mortality (M) yr^{-1}	0.88	0.86
Fishing mortality (F) yr^{-1}	1.03	1.76
Exploitation rate (E)	0.54	0.67
Age at first capture (t_{50})	1.79	1.43

4.3.4 Thompson & Bell model

Contrary to t_{50} and t_{max}, F_{cur} was lower in the Putumayo River (1.03) than in the Solimões River (1.76), as observed in the analysis of relative yield per recruit (YPR) and biomass per recruit (BPR) (Fig. 4-12). Comparing $F_{0.5}$ and its corresponding F_{cur} in each river, F_{cur} was higher than $F_{0.5}$ in the Solimões River, while the Putumayo River registered a lower F_{cur} value than $F_{0.5}$. In another parameter, E_{cur} exceeded the exploitation rate at 50% of biomass ($E_{0.5}$) in Solimões. Finally, the E_{cur} value for the Putumayo River was lower than $E_{0.5}$ (see Tab. 4-8).

Table 4-8. Biological reference points, yield per recruit (YPR) and biomass per recruit (BPR) estimated for *Mylossoma albiscopum* in the upper Solimões and Putumayo rivers.

PARAMETER	PUTUMAYO	SOLIMÕES
Current fishing mortality rate (F_{cur})	1.03	1.76
Fishing mortality rate at 50% biomass ($F_{0.5}$)	1.22	0.94
Fishing mortality rate at Maximum Sustainable Yield (F_{MSY})	5.97	4.17
Current explotation rate (E_{cur})	0.54	0.67
Explotation rate at 50% biomass ($E_{0.5}$)	0.58	0.52

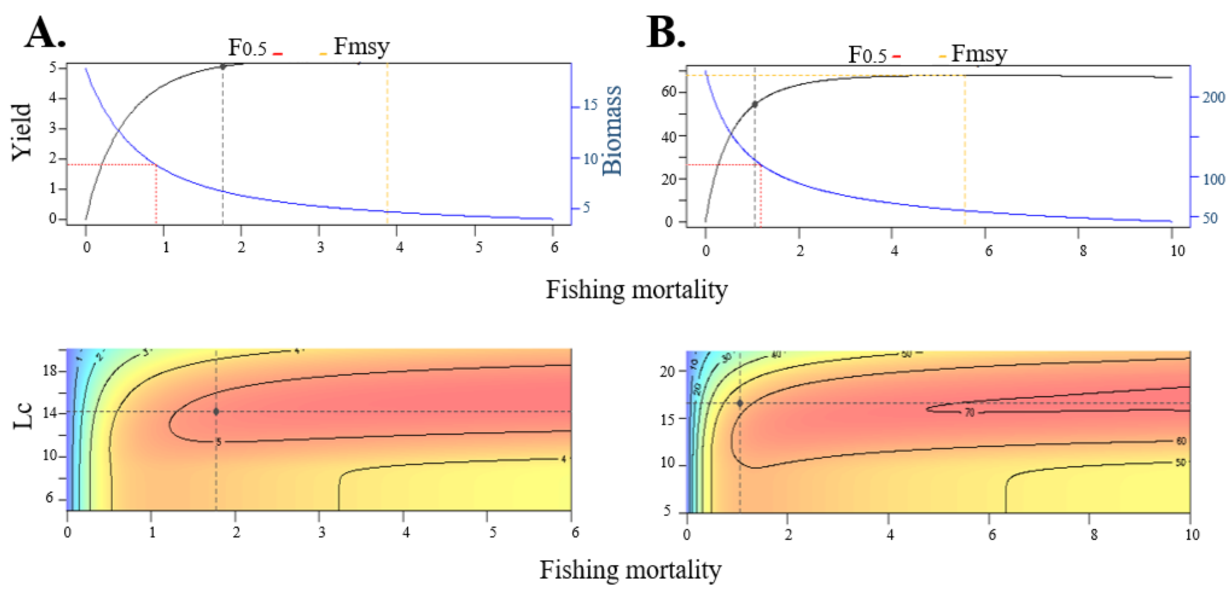

Figure 4-12. Yield per recruit (YPR) and biomass per recruit (BPR) from the Thompson & Bell model and isopleth diagram of *Mylossoma albiscopum* in the upper Solimões (**A**) and Putumayo (**B**) rivers. The **black dot** represents yield and biomass under current fishing pressure. The **yellow** and **red line** corresponds to the fishing mortality rate at maximum sustainable yield (F_{MSY}) and fishing mortality at 50% of the virgin stock biomass ($F_{0.5}$).

4.3.5 Spawning potential ratio

Figure 6 illustrates S_{L50}, S_{L95}, F/M ratio, and SPR for each hydrological period in both rivers. SPR values based on frequency lengths in the upper Solimões river ranged between 0.19 and 0.23, with a maximum value in the rising water season of 0.23 (0.21-0.24) and a minimum value during high waters of 0.19 (0.17-0.21). In contrast, for the Putumayo River, the values were between 0.35-0.58, with maximum values in the high water season of 0.58 (0.51-0.66) and a minimum value of 0.35 (0.3-0.4) during low water (Fig. 4-13).

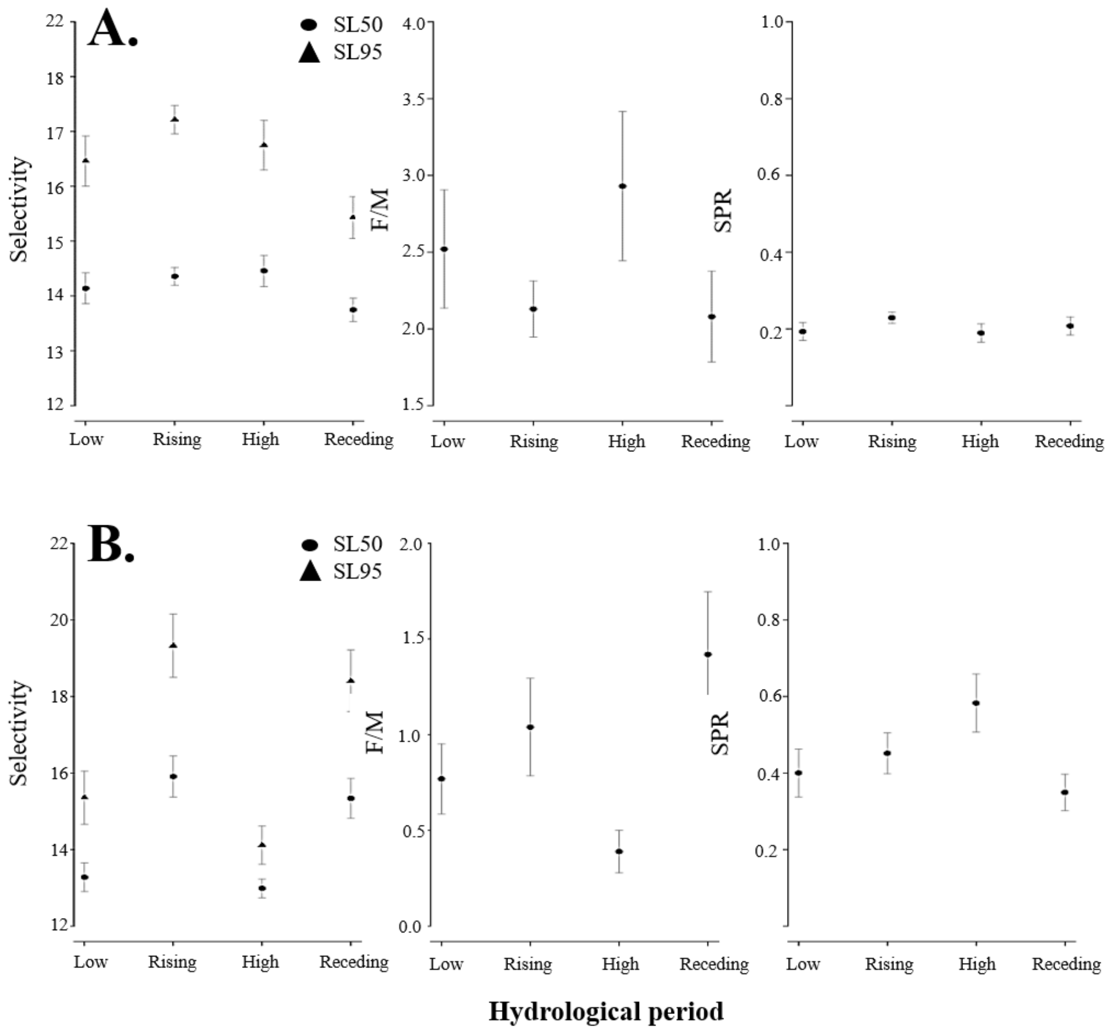

Figure 4-13. LB-SPR output for the life history parameters for *Mylossoma albiscopum*. Selectivity, relative fishing mortality rate (F/M) and spawning potential proportion (SPR) in the upper Solimões (**A**) and Putumayo (**B**) rivers during the four hydrological periods. Confidence intervals (95%) are shown in vertical bars.

4.4 Discussion

4.4.1 Reproduction

Although *M. albiscopum* is a vital species in artisanal fishing in the Orinoco and Amazon basins (Bonilla-Castillo *et al*., 2021; García-Dávila *et al*., 2018; Isaac, de Almeida, 2011; Lasso *et al*., 2011), few published works report reproductive biology aspects. In the upper Amazon basin, studies in the Ucayali River confirm the presence of mature individuals between October and March, with a reproductive peak in December during the rising water season (Zavaleta- Flores *et al*., 2022). García Vásquez (2016) reported mature females during that same season in the lower Marañón basin (near Iquitos). Likewise, Zacardi *et al*. (2018) found high densities of *Mylossoma* larvae during the beginning of the flood (January and February) in the Marrecas Islands archipelago in the lower Amazon River (near Santarém). This same behavior was observed in the upper Orinoco basin in the Cafre River in Colombia, where Useche *et al*. (1993) point out that the reproductive season of the species is highly related to water seasonality. In the middle Orinoco and also in rivers of the Apure sub-basin, *Mylossoma* begins its reproduction in May with the start of the rainy season and the rise of the waters (Lasso Alcalá, Sánchez-Duarte, 2011). Apparently, the reproductive strategy of *M. albiscopum* is to carry out spawning during the beginning of the rains and the rise in the level of the rivers, favoring the formation of habitats and floodplains that provide shelter and food to the larvae (Goulding *et al*., 2019; Isaac *et al*., 2016). This same behavior is observed in other Characiformes such as *P. nigricans* in the Putumayo River (Bonilla-Castillo *et al*., 2018) and *P. altamazonica* in the upper Amazon (García-Vásquez *et al*., 2010). However, it is crucial to understand how the flooding patterns of the Amazon rivers vary (Junk *et al*., 2012), as demonstrated in this study where the hydrological regimes of the Solimões and Putumayo rivers are different, and in turn, the identification of the reproductive seasons of the species.

4.4.2 Growth and mortality parameters

The distribution of the catch sizes between sexes was different, with the females being the largest individuals, as recorded for *M. albiscopum* by García Vásquez (2016) in the locality of Iquitos (low Marañón River) and Zavaleta- Flores *et al*. (2022) in the Ucayali River. The maximum length recorded in this study (25 and 26.4 cm in Leticia and Puerto Leguízamo, respectively) did not change significantly from that observed by Galvis *et al*. (2007) 15 years ago in the Colombian Amazon, or like the work of Correa *et al*. (2015) in the Pantanal-State of Mato Grosso (21 cm) and the lower Caquetá river (27 cm) or even the one of Santos *et al.*, (2006) in Manaus-Brazil. However, the values were lower than those recorded by Ramírez-Gil *et al*. (2001) in the lower Orinoco region of Colombia (31 cm). The growth rate estimated in this study was very similar between both locations, as reported in the Ucayali River (Zavaleta- Flores *et al*., 2022). However, the asymptotic lengths estimated in this study were 5.5 cm lower than those recorded by Zavaleta-Flores *et al*. (2022). Nonetheless, this parameter can vary according to the calculation method used (Schwamborn *et al*., 2019). This study registered a von Bertalanffy growth model with seasonality (soVBGF) by considering the hydrological regime of rivers as a variable that affects the physiology and growth of Amazonian fish, particularly of species associated with flooded forests (Gomiero *et al*., 2007). The growth of *M. albiscopum* follows a seasonal oscillatory pattern with a rapid growth rate in June and August, corresponding to the high and low water regimes in the Putumayo and Solimões, respectively. This result coincides with the periods where the best condition factor are registered for the species, according to the hydrological cycle in the Amazon (Tribuzy-Neto *et al*., 2017). In addition, Osei *et al*. (2021) observe that research on population parameters considering standard VBGF in species that register seasonal patterns probably generates high values in the biological reference points leading to poor management decisions.

The Φ' estimated in this study for *M. albiscopum* in the upper Putumayo basin (2.52) was higher than that obtained in the upper Solimões (2.47), as well as that calculated for the Ucayali River with the data from Zavaleta- Flores *et al*. (2022). Apart from the genetic characteristics that determine the growth potential of the species, the high growth rate exhibited by *Mylossoma* in the upper reaches of the Amazon and Putumayo basins can be attributed to food type and availability. The contribution offered by the floodplain as a source of food and shelter has been documented (Claro-Jr *et al*., 2004). Nevertheless, threats such as climatic variations, the intervention of the water rounds, overfishing (spawning biomass), construction of hydroelectric plants (interruption of migratory routes), excess sediment load due to deforestation, and the introduction of exotic species place the balance of the populations in the tropics at risk (Doria *et al*., 2021; Duponchelle *et al*., 2021)

4.4.3 Resource status

The application of the Thompson & Bell model and its yield per recruit (YPR) and biomass per recruit (BPR) methods determined that *M. albiscopum* from the upper Solimões River is in a state of overfishing. However, the results indicate that the fishing mortality (F_{cur}) was lower than the fishing mortality at F_{MSY}. This result was confirmed by the exploitation rate (E = 0.67), which was lower than E_{MSY}. However, the effect of a high natural mortality rate (M) is that the fish reach very soon the age at which natural mortality exceeds biomass gain due to growth, making it challenging to estimate MSY (Sparre, Venema, 1998) correctly. In such a case, keeping the curve per recruit (B/R) at 50% as a precautionary measure (Coll *et al*., 2013) with an $F_{0.5}$ of 0.94 is suggested. In practical terms, the recommendation is to prohibit using gill nets smaller than 3 inches in mesh size to achieve this fishing mortality rate in the tri-border zone of Brazil, Colombia, and Peru, given that a large part of the individuals captured in this analysis did not reach sexual maturity age.

The opposite situation was recorded in the Putumayo River, where the exploitation rate (E_{cur}) was lower than E_{MSY}. Apparently, the configuration of the gillnets and the effort units in this sector allowed reaching a F_{cur} value lower than $F_{0.5}$ (target reference point).

4.4.4 Spawning Potential Ratio

The LB-SPR model is built under the equilibrium condition assumption, i.e., natural mortality (M), fishing mortality (F), and recruitment are considered constant. However, these parameters are far from reality for populations in the tropics (Hordyk *et al*., 2015a). However, when comparing these results with those obtained from the Thompson & Bell method, the state of overfishing of the resource in the upper Solimões River with a high fishing rate (F/M>1) during all hydrological periods and critical values is in the SPR (0.1-0.23).

On the other hand, in the Putumayo River, the resource evaluation using both methods indicates moderate exploitation of underexploited SPR (0.35-0.58). These results apparently indicate sustainable fishing. It is important to mention that the resource evaluation using the LB-SPR method did not meet the logistic capture selectivity condition because the fishing methods in the study areas used gillnets with dome-shaped capture selectivity. However, studies have shown to be effective under this limitation (Hommik *et al*., 2020). Despite breaking the rule of this model, i.e., not having a logistic type catch distribution, the results obtained, maintain the expected trend and recognize the absence of large individuals in catches, particularly in the Solimões River, where there are very few (Fig. 4-9). Perhaps the values may be overestimated, but they show that the conditions of the species in the upper Solimões River are less favorable than in the upper Putumayo

River basin. It is interesting to observe how 20% of the SPR of the population in the Solimões River stabilized under different fishing levels and hydrological periods. Nevertheless, the spawning biomass is barely enough to replace the existing adults but not enough for the population to grow. Improving %SPR by allowing more individuals to reach their maturity age before being captured is necessary. Their life traits and reproduction strategies are favorable for the recovery of the population, as confirmed by Zavaleta- Flores *et al*. (2022).

The relative fishing mortality (F/M) values for both rivers varied according to the hydrological periods due to different levels of effort carried out depending on the water level. During the high water season, the fish disperse in the flooded forest, and in low water, they concentrate in lagoons and streams, being more likely to be caught with less effort. When the relative effort level (F/M) is >1, it leads to a reduction in SPR, relative yield, and spawning stock biomass (SSB) (Hordyk *et al*., 2014), as observed in the upper Solimões River.

The frequency distribution of the catch sizes shows that 40.1 and 26.5% of the fish caught in the Solimões and Putumayo rivers were below $L_{m50\%}$. This finding suggests that *M. albiscopum* in the Amazon is captured after recruitment, and the proportion of "mega spawners" (>18 cm S_L) is low in capture composition, contrary to what happens in the upper Putumayo.

The SPR indicators are interpreted concerning reference points and knowledge of the fishery (Hommik *et al*., 2020). The threshold SPR value of 0.2 indicated by Goodyear (1993) is considered the upper limit point where a population maintains acceptable productivity, and an SPR value of 0.40 is recognized as a substitute for MSY (Hordyk *et al*., 2016).

This study concludes that *M. albiscopum* is a species that has a resilience capacity in the face of fishing pressure due to its rapid growth and reaching its sexual maturity size in a short time. However, for its optimal use, it is crucial to protect and conserve floodplain forests, the connectivity of aquatic ecosystems, understand the function of flood pulses in the biology of the species, and implement capture techniques that do not endanger the spawning biomass and overfishing by growth.

5 Conclusiones y Recomendaciones

5.1 Conclusiones

Calophysus macropterus

- Las distribuciones de frecuencia de tallas de captura por sexo, tanto para el bajo río Marañón - Ucayali y Amazonas cerca de Iquitos como en el alto Putumayo fueron diferenciadas, siendo, las hembras quienes registraron las mayores longitudes.
- Los individuos de *Calophysus macropterus* de la cuenca alta del Amazonas, presentaron una mejor eficacia de crecimiento respecto a los organismos de la cuenca alta del río Putumayo (ǿ = 3.176 y 3.023 respectivamente).
- El inicio del periodo reproductivo de *Calophysus macropterus* en la cuenca alta del río Putumayo - sector Puerto Leguízamo, ocurre entre los meses de diciembre y marzo, durante la temporada de aguas en ascenso.
- La localidad de Iquitos (Perú) así como sus zonas aledañas, no son área de reproducción para *C. macropterus*.
- Aparentemente los sitios de reproducción de *Calophysus macropterus* en la región occidental de la cuenca Amazónica, se localizan en las zonas próximas al pie de monte amazónico como sucede con el sector de Puerto Leguízamo, el cual se distribuye entre los 150 y 230 m.s.n.m.
- La talla media de madurez sexual-TMM no difiere significativamente entre sexos o entre sistemas fluviales en la región occidental de la Amazonia.
- Las unidades de stock de *C. macropterus* en ambas cuencas hidrográficas señala un estado de sobrepesca.

Mylossoma albiscopum

- Los parámetros poblacionales de *Mylossoma albiscopum* no fueron tan distintos entre los sectores del alto río Solimões y Putumayo (Longitud asintótica L_∞ = 28.33, coeficiente de curvatura K = 0.37, coeficiente de crecimiento ǿ = 2.47 y L_∞ = 28.63, K = 0.39 y ǿ = 2.52 respectivamente).
- La talla media de madurez sexual-TMM no difirió entre ambos sectores hidrográfico, ubicándose en un rango de 14.6 y 14.9 cm Ls.

- La temporada reproductiva de *Mylossoma albiscopum* se lleva a cabo durante la época de aguas en ascenso, como se comprobó para ambos ríos (diciembre - febrero en el río Solimões y abril - junio en el río Putumayo).
- Los cálculos de rendimiento por recluta en el modelo Thomson & Bell, señalan el desarrollo de la pesca de manera sostenible en el río Putumayo, al encontrase por debajo de la tasa de explotación al 50% de la biomasa ($E_{0.5}$). Situación distinta al observado en el río Solimões.
- Por primera vez se utiliza el método de proporción potencial de desove basado en longitudes LB-SPR en una pesquería artesanal de la Amazonia colombiana. Los resultados obtenidos respondieron de manera adecuada, a pesar de no cumplir el supuesto de selectividad tipo logístico.
- Los modelos de evaluación de pesquerías Thompson & Bell y Length-Based Spawning Potencial Ratio (LB-SPR) lograron explicar de manera equiparable, el estado del stock de *Mylossoma albiscopum* en dos subcuencas hidrográficas de la Amazonia colombiana.

5.2 Recomendaciones

Metodológicas

- Para la estimación de los parámetros poblacionales y evaluación de los recursos pesqueros continentales en la Amazonia, se debería tomar registros del stock independientes de la pesca artesanal, debido al sesgo que genera en los tamaños de captura la selectividad de los artes de pesca.
- Se deberían implementar modelos económicos en la evaluación de los recursos pesqueros y con ello, tener argumentos financieros para la gestión de las pesquerías artesanales.
- Se recomienda hacer análisis de sensibilidad de los parámetros y estimación de la variabilidad.
- Utilizar más de un modelo estadístico para evaluar el estado de los recursos pesqueros al igual que la mortalidad natural (M).
- Se considera necesario la identificación de unidades de stock en *Mylossoma albiscopum* y *Calophysus macropterus* en las cuencas Amazonia y Orinoquía con el propósito de establecer estrategias de manejo y una gestión administrativa de los recursos, de acuerdo a las características biológicas y pesqueras (por ejemplo, tasas de reclutamiento, biomasas de la población desovaste, tasa de mortalidad por pesca, entre otros).

- Divulgar y concertar con los pescadores y el gremio pesquero de los ríos Putumayo y Solimões, la identificación de los puntos de rendimiento por recluta y económicos en "*pro*" de la conservación del recurso y la socioeconomía familiar.

Calophysus macropterus

- Se debería prohibir la pesca con la mano y el uso de animales en descomposición para la captura del simí o mota en toda la Amazonia, por los riesgos que implica a la salud pública y el alto número de capturas de individuos por debajo de la talla mínima de madurez.
- A pesar que la talla mínima de madurez, calculado en este estudio es inferior a la longitud reglamentaria en Colombia, se recomienda continuar con esta talla (32 cm) como un principio precautorio del recurso, a menos, que indicadores de pesca señalen lo contrario.
- En cuanto a las características de rasgos de vida de la especie, como velocidad de crecimiento, edad de madurez y longevidad, se considera que la población puede tolerar los niveles de pesca actual bajo la configuración que tiene el palangre de fondo o calandrio en ambas subcuencas hidrográficas.
- Es importante evaluar el estado actual de la población al día de hoy por subcuenca, dado a los efectos que ha tenido la moratoria de pesca (Acto Administrativo Nº 1710 de 23 de agosto de 2017 de la Autoridad Nacional de Acuicultura y Pesca-AUNAP) y los niveles de metilmercurio en músculo, con el propósito de continuar o suspender la veda.

Mylossoma albiscopum

- No permitir el uso de redes de monofilamente por debajo de 3 pulgadas o 7.6 centímetros en tamaño de malla tanto en el río Putumayo como en río Amazonas.
- Por tratarse de una especie que hace migraciones de tipo lateral (aguas blancas-aguas negras), es pertinente no permitir el uso de redes en la confluencia de los ríos de origen andino y amazónico, durante la temporada de reproducción.
- Promover la conservación y restauración de las rondas hídricas y los planos inundables del bosque, por su rol en el ciclo biológico y ecológico de *Mylossoma albiscopum*.
- Fomentar la piscicultura de la palometa como especie promisoria.

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