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Sustainability of dual exploitation (fry and adults) of the fish *Semaprochilodus laticeps* (Characiformes: Prochilodontidae) in Colombia

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ABSTRACT

Introduction: *Semaprochilodus laticeps* is a freshwater fish species native to the Orinoco Basin that is exploited in Colombia at two different stages of its life cycle: fry (for the ornamental trade) and adults (for the consumer market). This double exploitation of juveniles and adults raises concerns about the population stability of the species.
Objective: To evaluate the sustainability of the exploitation of the species in these two life stages.
Methods: 1 277 specimens of *S. laticeps* were sampled between June and December 2017. Population parameters were estimated from length-frequency data using ELEFAN 1 routine of the FISAT II package. Length at first maturity (Lm) and length at maximum yield (Lopt) were determined using the Froese and Binohlan equations. Virtual population analysis was performed based on Jones length cohort analysis.
Results: Population parameters were as follows: K = 0.75, L∞ = 53.1 cm LE, Z = 2.92 yr-1, M = 1.24 yr-1 and F = 1.68. Lm was estimated to be 29.6 cm SL and Lopt at 33.4 cm SL. Of note, 96.3 % of the fish caught in the consumer fishery exceeded Lm and 80 % exceeded Lopt. The results of the virtual population analysis suggested that a very low proportion (0.85 %) of the population was caught as fry, possibly due to natural mortality.
Conclusions: Based on the results, as no indicators of overexploitation were identified, it is recommended to continue with the dual use of *S. laticeps*. It is recommended to maintain the existing conservation measures, such as the closed season during the reproductive period, to ensure sustainable fishery exploitation. The results obtained can serve as a reference to analyze the situation of other species currently fished for both the ornamental (fry) and food (adult) markets.

Key words: fisheries management; food fish; freshwater fish; ornamental fish trade; sustainable fishing exploitation.

RESUMEN

Sustainability of dual exploitation (fry and adults) of the fish *Semaprochilodus laticeps* (Characiformes: Prochilodontidae) in Colombia

Introducción: *Semaprochilodus laticeps* es una especie de pez de agua dulce originaria de la cuenca del Orinoco, explotada en Colombia en dos etapas distintas de su ciclo de vida: alevín (para el comercio ornamental) y adulto (para el mercado de consumo). Esta doble explotación de alevines y adultos genera preocupación sobre la estabilidad poblacional de la especie.

Objetivo: Evaluar la sostenibilidad de la explotación de la especie en estas dos etapas de vida.
Método: Entre junio y diciembre de 2017 se muestrearon 1 277 ejemplares de *S. laticeps.* Los parámetros poblacionales se estimaron utilizando datos de frecuencia de tallas con la rutina ELEFAN 1 del paquete FISAT II. La longitud de primera madurez (Lm) y la de máximo rendimiento (Lopt) se determinaron mediante ecuaciones de Froese y Binohlan. El análisis de la población virtual se realizó basándose en el análisis de cohorte de longitud de Jones.
Resultados: Los parámetros poblacionales fueron los siguientes: K = 0.75, L∞ = 53.1 cm LE, Z = 2.92 año-1, M = 1.24 año-1 y F = 1.68. Lm se estimó en 29.6 cm SL y Lopt en 33.4 cm SL. En particular, el 96.3 % del pescado capturado en la pesquería de consumo superó Lm y el 80 % superó Lopt. El análisis de la población virtual sugirió que una fracción muy baja (0.85 %) de la población fue capturada como alevines, posiblemente atribuible a la mortalidad natural.
Conclusiones: Con base en los hallazgos, al no identificarse indicadores de sobreexplotación, se recomienda continuar con el doble uso de *S. laticeps*. Se recomienda mantener las medidas de protección existentes, así como una veda durante el período reproductivo, para garantizar una explotación pesquera sostenible. Los resultados obtenidos pueden servir como referencia para analizar la situación de otras especies actualmente capturadas para el mercado tanto ornamental como de consumo.

Palabras clave: gestión pesquera; peces de consumo; peces de agua dulce; comercio de peces ornamentales; explotación pesquera sostenible.

INTRODUCTION

The sapuara, or sapoara (*Semaprochilodus laticeps*), is a member of the Prochilodontidae family and inhabits both lentic and lotic bodies in the Orinoco basin. Adult specimens of this species are caught for sustenance by riparian communities (Ajiaco-Martínez et al., 2012; De La Hoz-M et al., 2015; Novoa, 2002; Novoa & Ramos, 1982; Ramirez-Gil & Ajiaco-Martínez, 2001). Additionally, for over two decades, their fry have been collected and traded as ornamental fish (Ajiaco-Martínez et al., 2012; Duarte et al., 2016; Ortega-Lara et al., 2015).

As of now, data on catches, whether for food or ornamental fish, is fragmented. Captures for food use have been reported in ports of the Colombian Orinoco River Basin, with annual landings ranging from 7.8 to 34.2 tons between 2006 and 2017 (Autoridad Nacional de Acuicultura y pesca-AUNAP, 2017; Pineda-Arguello et al., 2011). As an ornamental fish, the annual commercialization in Puerto Carreño has varied from 22 015 specimens during the period 1998-1999 to 395 593 in 2017 (Ramírez-Gil et al., 2001; this study). Puerto Carreño is the port with the highest volumes of traded species for both consumption and ornamental purposes.

Colombian regulations have prohibit the capture of specimens smaller than the minimum size, which has been set at 35 cm standard length (SL) for sapuara since 1981 (Instituto Nacional de los Recursos Naturales Renovables y del Ambiente, 1981). Resolution 0190 of 1995 (Instituto Nacional de Pesca y Acuicultura, 1995) permits the use of *S. laticeps* as an ornamental species, including fry that do not comply with the minimum legal size. Also, the AUNAP in 2015 listed *S. laticeps* as an ornamental species in Colombia in Resolution 1924 (Autoridad Nacional de Acuicultura y Pesca-AUNAP, 2015). This allowance is motived by the economic benefits it offers to local communities in Vichada, a department with a multidimensional poverty index of 75.6 % (Departamento Administrativo Nacional de Estadística-DANE, 2021), the highest in Colombia. However, the decision-makers lack definitive arguments to assess whether the extracting fry (ornamental fishing) and adults (consumer fishing) is sustainable for the species population.

Despite being identified as one of the 20 dual-purpose species by Ajiaco-Martínez et al. 2012, there is limited and sporadic information available. There is a lack of tools available to assess the impact of exploitation on different life stages (fry and adult) as well as to evaluate the adequacy of current management measures for species protection are also lacking.

This study aims to evaluate both types of fisheries for *S. laticeps* to quantify the impact of fishing activity, improve understanding of the species, and equip regulatory institutions with decision-making tools for sustainable management. The central inquiry is whether the exploitation of sapuara for both ornamental fish (fry) and food fish (adult) markets is sustainable This study utilizes data from the Puerto Carreño fisheries as a reference point, with the aim to producing replicable results that can be applied to the study of *S. laticeps* in various regions within the Orinoco Basin. The main goal is to enhance the preservation efforts for the species and also promote socio-economic stability in the communities of the area.

MATERIALS AND METHODS

Study area: Puerto Carreño is located at 6°11'20" N & 67°29'9" W, at an elevation of 51 m.a.s.l. It is bordered by the Meta, Bita, and Orinoco rivers. Fishing operations for ornamental fish are carried out in the flood zone of the Meta River, and for consumption fishing in the three rivers. The region experiences four distinct hydrological phases: low waters prevail from January to March, the waters rise from April to June, high waters occur from July to August, and falling waters from September to December. Sampling occurred during three of these periods. The species is available for ornamental fishing only during rising and high waters, and for consumption fishing during rising waters at high.

Data collection: Between June and October 2017, digital calipers with a precision of 0.1 mm were used to measure the standard length (SL) of *S. laticeps* specimens, while digital scales with a precision of 0.1 g were used for weight measurements.

The specimens were obtained through artisanal fishing. Ornamental specimens were measured at fish collection facilities visited daily, with random selection and measurement of the maximum number possible each day. Individuals destined for consumption were measured daily at fish purchasing sites, with data compiled on all landed specimens of the species landed at each location.

Statistical analyses: The gathered data were organized in an Excel spreadsheet. The length-weight relationship was determined using the methodology of Sparre and Venema (1997), following the function: $W = aL^b$, where W is weight, L is standard length, and "a" and "b" are the equation parameters. The confidence limits of "b" were calculated according to Pauly (1984). The individual growth rate was derived from Von Bertalanffy's general growth, Equation 1:

$$L = L\_\infty \; [1-(e^{-k(t-t_0)})] \qquad (1)$$

Where L is the length, $L_¥$ is the maximum length, K is the curvature parameter, t is the age in years and t_0 is the moment in which the specimen was a size 0.

The FISAT II routine was employed, applying the Power-Wetherall graph to estimate L_∞ and Z/K parameters. The identification of the smallest length or cut length for recruitment was determined using the Pseudocapture curve.

The preliminary estimation of the metabolic rate of growth was conducted following the model of Gulland and Holt (Sparre & Venema, 1997) using the ELEFAN 1 routine.

The growth performance index (ϕ) was estimated according to Pauly and Munro (1984), Equation 2:

$$\emptyset' = Log\,(K) + 2\,Log\,(L_\infty) \qquad (2)$$

The t_0 was estimated using the empirical relationship of Pauly (1983), Equation 3:

$$Log\,(-t_0) = -0.3922 - 0.2752\,Log\,L_\infty - 1.038\,Log\,K \quad (3)$$

The instantaneous mortality rate (Z) was estimated using Equation 4, the linearized catch curve converted to lengths (Sparre & Venema, 1997):

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$$Ln \frac{C(L_1,L_2)}{\Delta t(L_1,L_2)} = c - Z * t(\frac{L_1+L_2}{2}) \quad (4)$$

Where C ($L1$, $L2$) is the catch in the number of specimens in a given size interval, Δt is the time it takes for the fish to grow from $L1$ to $L2$, calculated from the growth parameters and lengths, C is the intercept, and Z is the slope Δt.

The determination of natural mortality (M) was made according to Equation 5, the empirical equation of Pauly (Cadima, 2003; Pauly, 1984; Sparre & Venema, 1997):

$$M = 0.8 * e^{-0.0152-0.279 Ln L\_\infty + 0.6543 Ln K + 0.463 Ln T} \quad (5)$$

In this equation, L_∞, K, and T represent the parameters estimated by the growth equation and the average temperature of the ecosystem in the estimation period (27 °C). It was adjusted to 80 % following the recommendation of Pauly (1984) for L_∞ and K.

Fishing mortality (F) was estimated from total mortality and natural mortality, following the Equation 6:

$$F = Z\text{-}M \quad (6)$$

With total and fishing mortality and the growth parameters known, a virtual population analysis was performed based on the Jones length cohort analysis. For each size group, the following were estimated:

The natural mortality factor H, expressed by Equation 7:

$$H(L_1, L_2) = [\frac{L_\infty - L_1}{L_\infty - L_2}]^{-M/2K} \quad (7)$$

The number of fish caught was estimated with Equation 8:

$$C(L_1, L_2) = \Delta t^{C - Z * \left(\frac{t_1 + \Delta t}{2}\right)} \quad (8)$$

Where: $\Delta t = \frac{1}{K * Ln(\frac{L_\infty - L_1}{L_\infty - L_2})}$ C is the constant of the linearized capture curve equation (Sparre & Venema, 1997) $t_1 = t_0 - 1/K * Ln(1 - L_1/L_\infty)$

The number of surviving fish was calculated using Equation 9:

$$N(L_1)=[N(L_2) * H(L_1, L_2) + C(L_1, L_2)] * H(L_1, L_2) \quad (9)$$

To estimate the exploitation rate, Equation 10 was used:

$$\frac{F}{Z} = \frac{C(L_1,L_2)}{[N(L_1) - N(L_2)]} \quad (10)$$

The length at first maturity (L_m) and the length at maximum yield (L_{opt}) were estimated according to the equations of Froese and Binohlan (2003) (Equation 11 and Equation 12):

$$Log(L_m) = 0.8979 * Log(L_\infty) - 0.0782 \quad (11)$$

$$Log(L_{opt}) = 1.0421 * Log(L_\infty) - 0.2742 \quad (12)$$

Longevity (t_{max}) was calculated with the Equation 13 proposed by Froese and Binohlan (2003).

$$t_{max} = 3/K \quad (13)$$

The age of first maturation T_m was estimated from the Equation 14:

$$Log(T_{max}) = 0.5496 + 0.957 * Log ^{\text{™}} \quad (14)$$

The relationship between total length and fecundity proposed by Novoa and Ramos (1982) was used to estimate the total fecundity of the Sapuara population, Equation 15.

$$F = 0.00407 Lt^{4.884} \quad (15)$$

RESULTS

A total of 1 277 specimens, with lengths ranging from 1 to 50 cm, were recorded.

Specimens intended for ornamental purposes were captured within the 1 to 10 cm size range, with greater occurrence at 1-4 cm (70 %). Conversely, those measuring between 25 and 40 cm were caught for consumption, and a higher frequency was observed in the 34 to 37 cm (36 %) and 37 to 40 cm (33 %) ranges (Table 1).

The Equation 16 represents the length - weight relationship as:

$$W = 0.029L^{2.993} \quad (16)$$

The slope (b) is 2.993 ($\alpha > 0.05$), indicating isometric growth ($R^2 = 0.974$).

Monthly modal frequencies analysis of *S. laticeps* shows two modal frequencies from June to September, and only one modal group recorded in October. The modal frequency linked to ornamental fishing is only present in July.

The estimated cut length (L') was 3.91 cm, with an asymptotic length ($L\infty$) at 53.13 cm SL. Total mortality (Z) was 2.9195 year^{-1} with a confidence level of 2.27 and 3.57. Metabolic growth rate (K) was 0.75, and relative mortality (Z/K) was 4.912.

The growth curve of *S. laticeps* conforms to the Equation 17:

$$L = 53.13\ (1-e^{\ (-0.75\ (t-0.18)}) \quad (17)$$

The growth performance index Ø' was estimated to be 3.33.

The natural mortality (M) rate at an average temperature of 27 °C is 1.24 year^{-1}, with a fishing mortality (F) rate of 1.68 year^{-1}, and the exploitation rate (E) of 0.58.

Table 2 presents the virtual population data, including the number of catchable individuals, natural mortality factor, the quantity of surviving fish, and the exploitation rate. The cohort becomes extinct in the size range between 49 to 52.

In the virtual population analysis (Table 3), the catch for ornamental purposes sampled 12.2 % of the potential catch in the size range 1 to 4, and less than 5 % in the other two size groups relating to the ornamental fishery, in

Table 1
Distribution of the population of *Semaprochilodus laticeps* sampled, by length intervals in Puerto Carreño, Vichada.

Standard length (cm)	Months					Total
	6	7	8	9	10	
1-4	**0**	**630**	**0**	**0**	**0**	**630***
4-7	**0**	**194**	**0**	**0**	**0**	**194***
7-10	**0**	**69**	**0**	**0**	**0**	**69***
10-13	0	1	0	0	0	1*
13-16	0	0	0	0	0	0
16-19	0	0	0	0	0	0
19-22	0	0	0	0	0	0
22-25	0	0	0	0	0	0
25-28	3	1	1	0	5	10**
28-31	0	5	5	0	5	15**
31-34	1	22	27	1	7	58**
34-37	4	44	85	8	2	143**
37-40	9	30	70	13	3	125**
40-43	5	9	8	0	0	22**
43-46	2	1	2	2	0	7**
46-49	1	0	0	0	1	2**
49-52	0	0	0	1	0	1**
TOTAL	25	1 006	198	25	2. 3	1 277

In bold individuals used for ornamental use. *Ornamental fisheries. ** Food fisheries.

Table 2
Jones cohort analysis for *Semaprochilodus laticeps*.

L_1	L_2	C (L_1, L_2)	t (L_1)	Dt	H (L_1, L_2)	N (L_1)	F / Z	F	Z
1	4	5 168	0.03	0.08	1.05	43 489	0.58	1.68	2.92
4	7	4 330	0.10	0.08	1.05	34 509	0.58	1.68	2.92
7	10	3 587	0.19	0.09	1.06	26 985	0.58	1.68	2.92
10	13	2 932	0.28	0.10	1.06	20 753	0.58	1.68	2.92
13	16	2 361	0.37	0.10	1.07	15 659	0.58	1.68	2.92
16	19	1 868	0.48	0.11	1.07	11 557	0.58	1.68	2.92
19	22	1 447	0.59	0.12	1.08	8 312	0.58	1.68	2.92
22	25	1 094	0.71	0.14	1.09	5 798	0.58	1.68	2.92
25	28	803	0.85	0.15	1.10	3 897	0.58	1.68	2.92
28	31	567	1.00	0.17	1.11	2 503	0.58	1.68	2.92
31	34	382	1.17	0.19	1.13	1 518	0.58	1.68	2.92
34	37	242	1.36	0.23	1.15	854	0.58	1.68	2.92
37	40	140	1.59	0.27	1.19	434	0.58	1.68	2.92
40	43	71	1.86	0.35	1.24	191	0.58	1.68	2.92
43	46	29	2.21	0.47	1.34	67	0.57	1.67	2.91
46	49	8	2.68	0.73	1.57	15	0.57	1.62	2.86
49	52	1	3.41	1.73		1.1	0.50	1.24	2.48

C (L1, L2): Capture possible; H (L1, L2): Natural mortality factor; N (L1): Number of surviving fish; F/Z: Exploitation rate.

Table 3
Virtual population of *Semaprochilodus laticeps* in Puerto Carreño, Vichada.

L_i	L_{i+1}	Number of individuals				% OSC / C (L_1, L_2)	% OSC / N (L_1)
		C (L_1, L_2)	Ornamental sampled catch (OSC)	Difference	N (L_1)		
1	4	5 168	630	4 538	43 489	12.2	1.4
4	7	4 330	194	4 136	34 509	4.5	0.6
7	10	3 587	69	3 518	26 985	1.9	0.3
10	13	2 932			20 753		
13	16	2 361			15 659		
16	19	1 868			11 557		
19	22	1 447			8 312		
22	25	1 094			5 798		
25	28	803			3 897		
28	31	567			2 503		
31	34	382			1 518		
34	37	242			854		
37	40	140			434		
40	43	71			191		
43	46	29			67		
46	49	8			15		
49	52	1			1		

Table 4
Fecundity estimates of the virtual population of *Semaprochilodus laticeps* in Puerto Carreño, Vichada

Ls	Lt	Number of individuals		Fecundity Media	Fecundity
		Population	Females		
31	36	1 518	759	162 396	123 263 380
34	40	854	427	271 679	116 041 130
37	43	434	217	386 771	83 984 214
40	46	191	95	537 655	51 273 138
43	50	67	33	807 912	26 869 780
46	53	15	8	1 073 885	8 138 721
49	57	1	1	1 532 100	766 050
Total Fecundity					410 336 413

comparison to the potential catch (C (L1, L2)). When comparing the caught ornamental fish to the estimated population (N(L1)) within the size range, it is evident that the observed catch accounts for only 1.4 % of the estimated population for fish ranging from 1 to 4 cm in size. In the other two size groups, it accounted for less than 1 %. For this population, the number of specimens caught for the ornamental market comprises only 6.8 % of the total possible catches and 0.85 % of the estimated population.

The fecundity of the spawning age classes in this total virtual population reaches 410 336 413 eggs (Table 4). When comparing this value with the actual commercialization in the study year of 395 593 specimens, the latter represents 0.096 % of the total spawned.

The estimated length at first maturity (L_m) was 29.6 cm SL with confidence limits ranging from 22.1 to 39.6 cm SL. Likewise, the estimated length at maximum yield (L_{opt}) was 33.4 cm SL with confidence limits between 24.3 and 46.0 cm SL. It was observed that 96.3 % of monitored specimens caught in the consumer fishery (Table 1) had sizes greater than L_m, while 80 % had sizes greater than L_{opt}. The study estimated that 52.7 % of specimens measured between 30.1 and 36.7 cm SL ((± 10 % L_{opt}), while 51 % were mega-spawners with a size greater than 36.7 cm SL). The longevity value was calculated to be 4 years, and the age of first maturity was estimated at 1.13 years.

DISCUSSION

This study introduces the first virtual population analysis of *S. laticeps* in the Colombian Orinoco River Basin, focusing specifically on the Puerto Carreño sector. The results reveal that the species has potential for both dual exploitations, its fry stage for ornamental purposes and adult stage for consumption.

The observed characteristics of the *S. laticeps* population evaluated, align with a species exhibiting rapid growth, high natural mortality, and low life expectancy, consistent with the traits reported by Pérez-Lozano and Barbarino (2013) for *Prochilodus mariae*, a species in the same family, in the Apure River within the Venezuelan Orinoco River Basin. According to the categorization scale established by Winemiller and Taphorn (1989), *S. laticeps* is identified as an r^2 strategist due to its generation duration exceeding 12 months, a single breeding season per year, high fertility, and absence of parental care.

The growth performance index calculated for *S. laticeps* (3.3) exceeds the estimates for *Semaprochilodus taeniurus* and *Semaprochilodus insignis*, as derived from the L_∞ and K data of Guerreiro et al. (2018). This difference may be attributed to the fact that Guerreiro and colleagues based their estimation on specimens with sizes larger than 14 cm. In contrast, our study includes fishes with sizes ranging from 1 cm *LS*. The inclusion of fry in our analysis may contribute to an overall higher estimate of the growth index. The Tmax found (4 years) falls within the range estimated from the K values for the afore mentioned species Froese (2004).

Parameters such as *K*, *Tmax*, *Tm*, and estimated fecundity position *S. laticeps* as a highly and moderately productive, resilient species according to scale proposed by Musick (1999). This aligns with van Treeck et al. (2020) assertion that species with characteristics such a small size, short life expectancy, rapid growth, early maturation and high mortality rates, like *S. laticeps* are less susceptible to anthropogenic disturbances.

Consistent with Froese (2004), the current exploitation of *S. laticeps* in the Puerto Carreño region does not indicate evidence of overfishing, with 96.3 % of specimens reproducing before capture and 80 % surpassing Lopt. A healthy age structure is affirmed by the indicator of 41 % mega-spawners, surpassing Froese (2004) proposed range of 30 to 40 %. This is critical, as mega-spawners, comprising the largest and oldest specimens, contribute to higher egg quantity and quality, producing more resilient larvae (Fenberg & Roy, 2008; Perry et al., 2010).

Virtual population analysis results indicate a minimal fraction (0.85 %) of *S. laticeps* is captured for the ornamental fish market, posing negligible impact compared to the estimated population and total fecundity of the spawning age class. This supports the conclusion that ornamental exploitation does not compromise natural population renewal, but rather takes advantage of the species during its highest mortality stage, in line with the assertion of Caddy (2015) that early life stages experience the highest natural mortality.

In contrast to conventional size-based regulatory frameworks in Colombian fisheries, influenced by Ulltang (1975) and Gulland (1985), which have been criticized for promoting the selective harvesting of larger specimens and adversely affecting populations (Allendorf & Hard, 2009; Diekert, 2012; Enberg et al., 2012; Fenberg & Roy, 2008; Heino et al., 2013; Venturelli et al., 2012; Zhou et al., 2010) our comprehensive analysis strongly advocates for the elimination of minimum size constraints for *S. laticeps*. This imperative is driven by the need to enhance resource utilization efficiency for fishermen and stakeholders in both consumer and ornamental markets. Nevertheless, we propose the implementation of protective measures, including temporal closures during the reproductive period and the prohibition of gill nets in locations associated with the parental population (such as lagoons connected to rivers), to ensure the sustainable harvesting of this species.

The results obtained in the Puerto Carreño sector can serve as a reference to analyze the situation of the rest of the species currently captured for the ornamental (fry) and edible (adult) fish markets.

Ethical statement: the authors declare that they all agree with this publication and made significant contributions; that there is no conflict of interest of any kind; and that we followed all pertinent ethical and legal procedures and requirements. All financial sources are fully and clearly stated in the acknowledgments section. A signed document has been filed in the journal archives.

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