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Scientific Article

Fisheries biology of *Plagioscion squamosissimus* (Heckel, 1840) in a neotropical reservoir in southeastern Brazil

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ABSTRACT

Plagioscion squamosissimus (silver croaker), a non-native species from the Amazon Basin, is one of the main resources supporting artisanal fisheries in the Três Irmãos Reservoir, São Paulo state, Brazil. This study evaluated its fishery biology and population characteristics between 2015 and 2018, aiming to provide information to support species management. Data were obtained through fishery monitoring of 93 artisanal fishers and quarterly scientific sampling conducted in the lotic, transitional, and lentic zones of the reservoir. Catch composition, fishing effort, environmental variables, length-weight relationship, length at first maturity (L_{50}), and gillnet selectivity were analyzed. Spatial and temporal variability in catch per unit effort (CPUE) was assessed using principal component analysis and repeated-measures analysis of variance. The average annual landing of silver croaker was 53.5 tons, with a mean CPUE of 11.7 kg fisher^{-1} day^{-1}. CPUE was associated with temperature, with the highest yields occurring in March, indicating a preference for lentic habitats. The species exhibited isometric growth (b = 3), continuous reproduction with a peak in spring, and a L_{50} of 15.9 cm total length. The results highlight the importance of silver croaker to local fisheries and suggest gillnet mesh sizes ≥ 8 cm to enhance commercial yields, whereas smaller meshes may be used in population control strategies.

Keywords: Fishery resource; Professional fisherman; Non-native species; Catch per unit effort; Três Irmãos Reservoir.

Biologia pesqueira de *Plagioscion squamosissimus* (Heckel, 1840) em um reservatório neotropical no sudeste do Brasil

RESUMO

Plagioscion squamosissimus (corvina), espécie não nativa, originária da Bacia Amazônica, constitui um dos principais recursos explorados pela pesca artesanal no Reservatório de Três Irmãos, São Paulo, Brasil. Este estudo avaliou sua biologia pesqueira e as características populacionais entre 2015 e 2018, visando subsidiar o manejo dessa espécie. Os dados foram obtidos por meio do monitoramento pesqueiro de 93 pescadores e de campanhas trimestrais de pesca científica realizadas nas zonas lótica, de transição e lêntica do reservatório. Foram analisados a composição das capturas, o esforço de pesca, variáveis ambientais, relação peso–comprimento, comprimento de primeira maturação (L_{50}) e seletividade das redes de emalhe. A variabilidade espacial e temporal da captura por unidade de esforço (CPUE) foi avaliada por análise de componentes principais e análise de variância de medidas repetidas. O desembarque médio anual de corvina foi de 53,5 toneladas, com CPUE médio de 11,7 kg pescador^{-1} dia^{-1}. A CPUE apresentou associação com temperatura, maiores rendimentos em março, indicando preferência por ambientes lênticos. A espécie apresentou crescimento isométrico (b = 3), reprodução contínua com pico na primavera e L_{50} de 15,9 cm de comprimento total. O trabalho evidencia a importância da corvina para a pesca local, recomendando malhas ≥ 8 cm para maior rendimento comercial e malhas menores em estratégias de controle populacional.

Palavras-chave: Recurso pesqueiro; Pescador profissional; Espécie não nativa; Captura por unidade de esforço; Reservatório de Três Irmãos.

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INTRODUCTION

Inland fisheries play a fundamental role in fish production in many regions worldwide, accounting for over 12% of global fish landings (FAO, 2024; Funge-Smith & Bennett, 2019). In Brazil, this activity is widespread and difficult to regulate, as it is often carried out in remote areas. Unlike marine fisheries, inland fisheries lack fixed landing sites (Vermulm Jr. et al., 2001) and are characterized by the frequent movement of fishers in search of more productive fishing grounds (Castro Campanha et al., 2018). As a result, monitoring and biological assessments of fishery resources are often scarce, underreported, or nonexistent (Agostinho et al., 2008; Bartley et al., 2015; Castro et al., 2008a; Castillo & Baígun, 2020; Mendonça et al., 2018; Welcomme et al., 2010).

The Upper Paraná River Basin is one of the most densely populated and intensively exploited regions in Brazil, supporting major urban centers and extensive use of terrestrial and aquatic resources (Agostinho et al., 2007a). Despite harboring one of the best-studied fish assemblages in the neotropics, it is also among the regions most affected by anthropogenic pressures (Dagosta et al., 2024). Its major rivers—Paraná, Grande, Paranaíba, Tietê, Paranapanema, and Iguaçu—have been extensively dammed for hydropower generation, resulting in the construction of more than 150 large reservoirs in southeastern Brazil (Barletta et al., 2016).

The impoundment of these rivers fragmented lotic habitats and converted them into lentic systems, disrupting the life cycles of many native species, particularly long-distance migratory fishes. Declines in native fish populations were subsequently accompanied by the introduction of non-native species adapted to reservoir environments, intended to compensate for losses of economically important native species such as spotted sorubim (*Pseudoplatystoma corruscans*), golden dorado (*Salminus brasiliensis*), and pacu-guaçu *Piaractus mesopotamicus* (David et al., 2016; Novaes & Carvalho, 2013). However, the introduction of non-native species has been prohibited in Brazil since 1998 because of its adverse effects on native fish communities (Agostinho et al., 2007b).

Species introduction is considered the second main cause of biodiversity loss, along with habitat degradation, both widely presents in the Upper Paraná River Basin (Agostinho et al., 2007b; Clavero & García-Berthou, 2005; Pelicice et al., 2018; Vitule et al., 2012). Inland professional fisheries in São Paulo state are mostly directed to reservoirs in large rivers, targeting non-native, sedentary species such as tilapias (*Oreochromis niloticus* and *Coptodon rendalli*), silver croaker (*Plagioscion squamosissimus*), and exotic cichlids as sven's eartheater (*Geophagus sveni*), peacock bass (*Cichla piquiti* and *Cichla kelberi*), among others (Agostinho et al., 2007a; Barbieri et al., 2000; David et al., 2016). Silver croaker is the main target species for both professional and recreational fisheries, leading in terms of both catch numbers and biomass in the Três Irmãos Reservoir (Castro Campanha et al., 2019; Maruyama et al., 2009) and in other reservoirs in the Tietê River Basin.

The silver croaker, *P. squamosissimus* (Heckel, 1840), is native to the Amazon Basin, in which it inhabits rivers, channels, and lakes. It is a carnivorous (piscivorous) species, feeding mainly on fish, although juveniles feed on aquatic insects (Hahn et al., 1997; Ota et al., 2018; Stefani & Rocha, 2009). It exhibits a multiple batch spawning strategy, with a reproductive season that extends from spring to summer, peaking in October (Carnelós & Benedito-Cecílio, 2002). This species was first introduced into the Pardo River in 1966, subsequently spreading to other rivers in the Upper Paraná Basin (Agostinho, 2007a; Braga, 1997). Given that *P. squamosissimus* is an introduced carnivorous (piscivorous) species, a deeper understanding of the structure and dynamics of its population is essential, also considering its importance for food security and the economic viability of local, artisanal fisheries. Additionally, it is important to discuss whether management efforts should aim to control or eradicate this species, given its abundance, piscivorous feeding habits, and non-native status.

In this context, the present study aimed to characterize the fisheries biology of *P. squamosissimus* in a neotropical reservoir in southeastern Brazil, using the Três Irmãos Reservoir as a case study. It sought to analyze the importance of silver croaker to local fisheries by estimating catches with the primary fishing gear (gillnets) and by assessing key morphometric and biological characteristics of the population, providing insights for sustainable fisheries management.

MATERIAL AND METHODS

Study area

The Três Irmãos Hydroelectric Power Plant is in the lower Tietê River, São Paulo state, Brazil. It began operation in 1991, with an installed capacity of 1,292 MW and an average flow of 733 $m^3 \cdot s^{-1}$. The reservoir covers a flooded area of 817 km^2 with a total volume of 13.8×10^6 m^3 (CESP, 2015). It is the last reservoir in the cascade system of the Tietê River, receiving water from 11 main tributaries, including the Pereira Barreto Canal, which provides a significant water flow connection and a navigable link to the Ilha Solteira Reservoir, in the Paraná River (Castro et al., 2008a). The climate of the region is classified as Aw (tropical with dry winters), with a dry season from April to September and a rainy season from October to March, with an average annual rainfall of 143 mm (INMET, 2021). In 2015, the reservoir reached its lowest recorded water level at 319.6 m, with a flow of 193.7 $m^3 \cdot s^{-1}$. With increased rainfall in 2016, the reservoir recovered, reaching 327.9 m in water level and 875 $m^3 \cdot s^{-1}$ in flow (ANA, 2020).

The sampling design consisted of two complementary approaches: monthly monitoring of professional artisanal fishing (commercial fishery) and quarterly scientific fishing surveys (experimental fishery).

Artisanal fishery

For artisanal fishery monitoring, eight fishing communities were selected from the 23 identified around the reservoir. These were grouped into three categories (Fig. 1), based on hydrological conditions:

- Group 1: lotic (riverine) environments: Buritama Fishermen's Village, Pio Prado Bridge, and Ribeirão Azul;
- Group 2: transitional environments: Lambari Bridge and Ribeirão das Cruzes;
- Group 3: lentic (lake-like) environments: Sud Mennucci, Kilometer 11, and Pereira Barreto.

Data collection was based on the participation of professional artisanal fishermen. Standardized landing forms were provided, requiring information on the date, number of fishing days, number of fishers per boat, fishing gear used, and total daily catch by species and/or group of species. Fishers filled out these forms, which were collected monthly during field visits for data verification and clarification. Monitoring was carried out from March 2015 to October 2017. The fishermen population was estimated using the snowball sampling method (Bailey, 1982), in which fishermen report the presence of other fishermen in the region. Fishery productivity ($kg \cdot ha^{-1} \cdot year^{-1}$) was calculated by dividing the annual average catch (kg) by the reservoir area in hectares (Agostinho et al., 2007a; Castro et al., 2008b; Novaes & Carvalho, 2011). The relationship between fishing effort (fishermen-days) and total catch (kg) was first tested using Pearson's linear correlation. The significance of this relationship is a prerequisite for

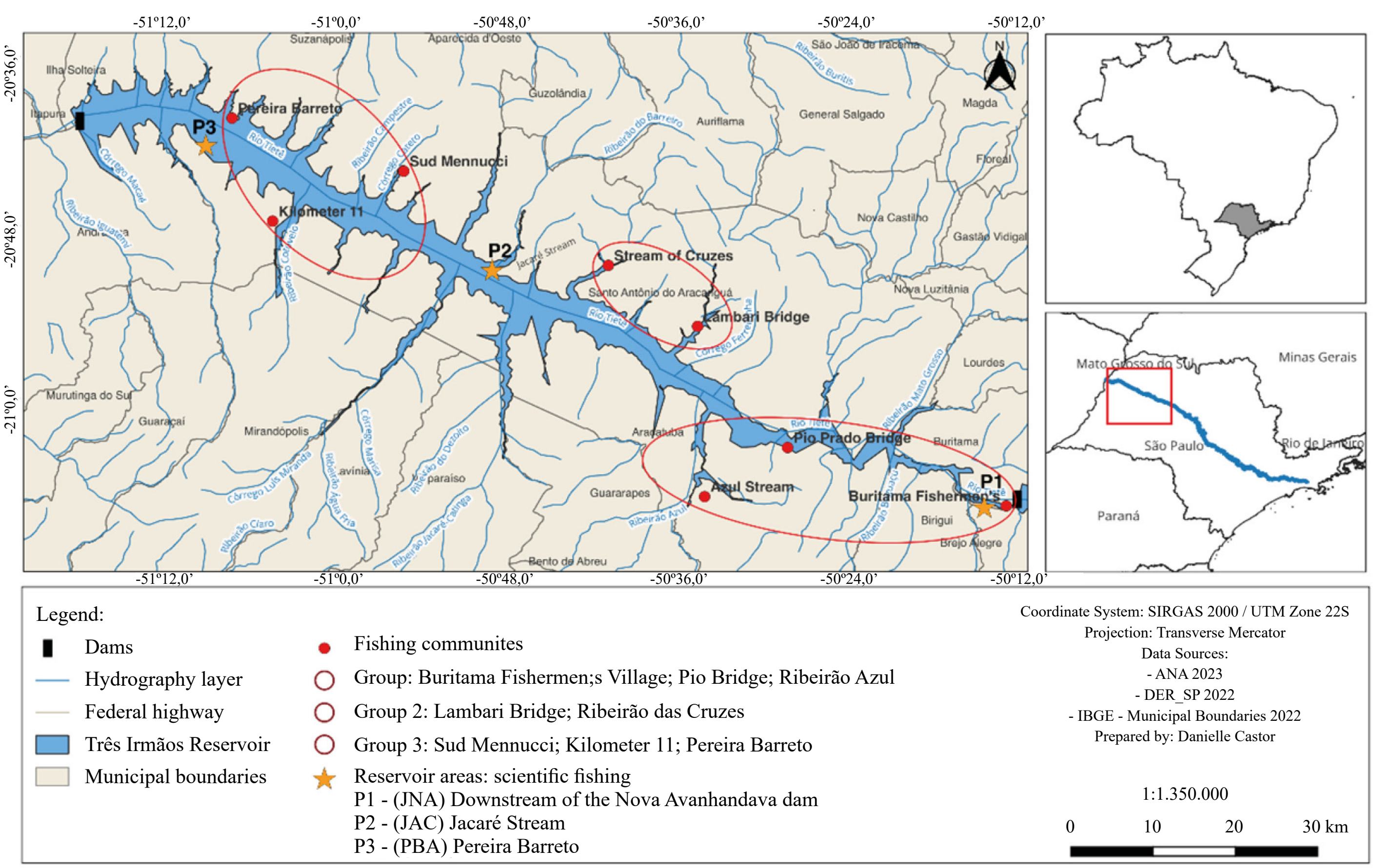


Figure 1. Map showing the location of fishing communities and scientific sampling stations in the Três Irmãos Reservoir, São Paulo, Brazil.

calculating the catch per unit effort (CPUE), which was estimated using Eq. 1:

$$CPUE = \sum C_i \Big/ \sum f_i \qquad (1)$$

where: C_i: the catch (kg) of the ith record; f_i: the corresponding fishing effort (fisher-days) (Petrere Jr. et al., 2010).

To verify whether CPUE was an appropriate index of fishing yield, two conditions were tested: linearity and significance of the relationship between fishing effort and total catch, and whether the intercept was close to 0. Linearity was evaluated with Pearson's regression after testing for normality using the Shapiro-Wilk's test. The significance of the regression was assessed by testing the null hypothesis (H_0) that the intercept (a) and slope (b) of the regression equation are equal to 0, using the t-test formula described by Kaps and Lamberson (2004). A non-significant intercept suggests the regression line passes near the origin, while a significant slope indicates a proportional relationship between effort and catch (Barros et al., 2020). Environmental variables recorded during the study included reservoir water level (m), rainfall (mm), and air temperature (°C). These, together with the CPUE for silver croaker, were analyzed to assess seasonal patterns using principal component analysis (PCA). The PCA was based on the correlation matrix due to differing units measure among environmental and CPUE used variables (Hammer et al., 2001).

We performed two-way repeated-measures analysis of variance (ANOVA) to evaluate the effects of environment (lotic, transition, and lentic zones), year, and the interaction between these factors on croaker CPUE. CPUE data were log-transformed [$\text{Log}_{10}(x + 1)$] prior to the analyses to meet the assumptions of normality and homogeneity of variances. Residual normality was assessed using the Shapiro–Wilk's test and by visual inspection of normal probability plots (Q-Q plots). Homogeneity of variances and sphericity assumptions were evaluated using Levene's and Mauchly's tests, respectively. When significant differences were detected, means were compared using Tukey's post hoc test at a significance level of 5% ($p < 0.05$) (Zar, 2010).

Experimental fishing

The experimental fishing methods complied with animal ethics standards and were approved by the Animal Use Ethics Committee of the Fisheries Institute (08/2016 CEUA-IP).

Experimental fishing was conducted quarterly at three sampling points (Fig. 1):

- P1, sited downstream of the Nova Avanhandava Dam in a lotic environment;
- P2, at Jacaré Stream, in a transitional environment;
- P3, at the main body of the reservoir in a lentic environment (Fig. 1).

The sampling effort was standardized using 13 gillnets with mesh sizes ranging from 3 to 20 cm between opposite knots and length of 20 m each. The nets were set for 24 hours, with checks every 12 hours. Gillnet catches were complemented by rod-and-reel fishing for 6 hours at each point. Fish were euthanized using eugenol, sorted by site, mesh size, and time of capture, and identified taxonomically using keys and specialized literature (Britski et al., 1999; Fricke et al., 2015; Ota et al., 2018).

For each captured *P. squamosissimus*, total length (cm), standard length (cm), and total weight (g) were recorded. These data were used to analyze key biological parameters: length-weight relationship, length at first gonadal maturation, and vulnerability to capture based on mesh size.

The length-weight relationship was modeled using the power function (Eq. 2), in accordance with more recent methodological recommendations, as this approach preserves the residual structure of the original model and avoids potential biases associated with logarithmic transformation of the data (Froese, 2006; Packard, 2014; Xiao et al., 2011).

$$Wt = a.Lt^b \qquad (2)$$

For comparison with the traditional approach, widely used in the literature, a linear regression was also fitted after logarithmic transformation of the data. The estimates of parameters *a* (condition factor) and *b* (allometric coefficient) obtained from the two methods were very similar. Therefore, we chose to retain the parameter estimates from the nonlinear model.

Log-transformed (King, 2007; Le Cren, 1951; Vazzoler, 1996), to (Eq. 3):

$$\log_{10} Wt = \log_{10} a + b.\log_{10} L_t \qquad (3)$$

Growth type (isometric or allometric) was tested with a one-tailed Student's t-test ($p < 0.025$), comparing the b coefficient to the theoretical isometric value of 3 (Kaps & Lamberson, 2004; Zar, 2010).

The condition factor (K), used as an indicator of fish well-being and energy reserves, was calculated using Fulton's condition factor (K_f), assuming isometric growth (b = 3), according to Eq. 4:

$$K_f = Wt/Lt^3 \qquad (4)$$

Differences in condition factor among sampling periods were assessed using the Kruskal–Wallis' test, followed by Dunn's post hoc test with Bonferroni correction when significant differences were detected ($\alpha = 0.05$).

Gonadal maturation stages were classified macroscopically using a subsample (N = 338) as described by Vazzoler (1996). The length at first maturity (L_{50}) and the length at full maturity (L_{100}) were estimated using a logistic regression curve (Brown & Rothery, 1993) fitted with nonlinear models in R software (Hammer et al., 2001). Capture frequencies were analyzed by season and zone for both gillnets and rod fishing. Vulnerability to different mesh sizes was assessed by analyzing the length and weight distributions using boxplot graphics.

RESULTS

Monitoring of professional artisanal fisheries in the Três Irmãos Reservoir

A total of 93 professional artisanal fishers (63.1% of the estimated population) participated in the fishery monitoring program, providing 493 completed landing forms between March and October (the open fishing season) from 2015 to 2017 (Table 1).

Table 1. Number of monitored fishers, estimated fisher population, and number of landing forms collected in fishing communities in the Três Irmãos Reservoir, SP, Brazil.

Reservoir zone	Fishing community	Municipality	Monitored	Estimated	Landing forms
Group 1 (lotic)	Buritama Fishermen's	Buritama	19	27	98
	Rio Prado Bridge	Araçatuba	19	**35**	94
	Ribeirão Azul	Araçatuba	5	10	42
Group 2 (transition)	Lambari Bridge	Santo Antônio Aracanguá	11	13	57
	Ribeirão das Cruzes	Santo Antônio Aracanguá	8	9	52
Group 3 (lentic)	Sud Mennucci	Sud Mennucci	19	22	88
	Kilometer 11	Pereira Barreto	8	21	19
	Pereira Barreto	Pereira Barreto	4	12	43
Total			93	149	493

During the monitoring period, 42 fish species were identified (Arimura Matsumoto et al. , 2026), with a total landed biomass of 480.2 kg. Silver croaker (*P. squamosissimus*) accounted for one-third of this total (33.5%), followed by *G. sveni* and *S. setepele* (33.1%) and tilapias (*O. niloticus* and *C. rendalli*), at 9.4%. Together, these species made up 76% of the total monitored catch, and all are non-native. Regarding CPUE, over the three years, was 31.6 kg fisher^{-1} day^{-1}. The total average annual production from the reservoir was 160.4 tons, with an overall productivity of 2 kg·ha^{-1}·year^{-1}. For silver croaker specifically, the CPUE was 11.9 kg fisher^{-1} day^{-1}, and productivity was 0.7 kg·ha^{-1}·year^{-1}. A significant Pearson's correlation (r = 0.69) between fishing effort and catch confirmed that CPUE is a reliable index of fishing productivity for this species (Fig. 2). The t-test for the slope ($t_{(22,\ 0.025)} = 4.46$, $p < 0.05$) was significantly different from 0, indicating proportionality between effort and catch. The intercept was not significantly different from 0 ($t_{(22,\ 0.025)} = 0.103$, $p > 0.05$), meaning the regression line passes close to the origin.

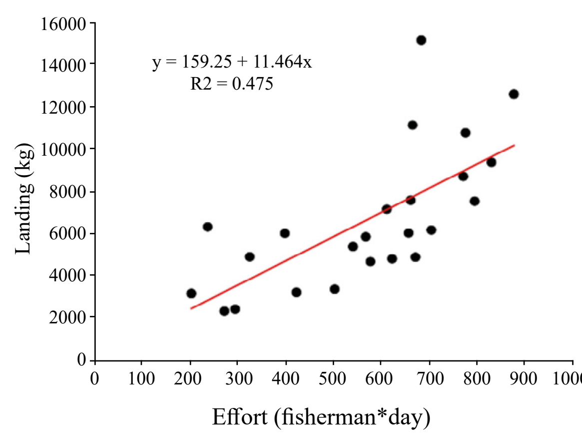


Figure 2. Simple linear regression between fishing effort (fisher-days) and catch (kg) of silver croaker in the Três Irmãos Reservoir from 2015 to 2017.

As for the PCA, the first two axes explained 70.2% of total variability (Fig. 3). Axis 1 (36.9%) reflected increases in CPUE alongside higher rainfall and temperature, and axis 2 (33.3%) differentiated 2015 from 2016 and 2017, which had higher water levels and flow rates.

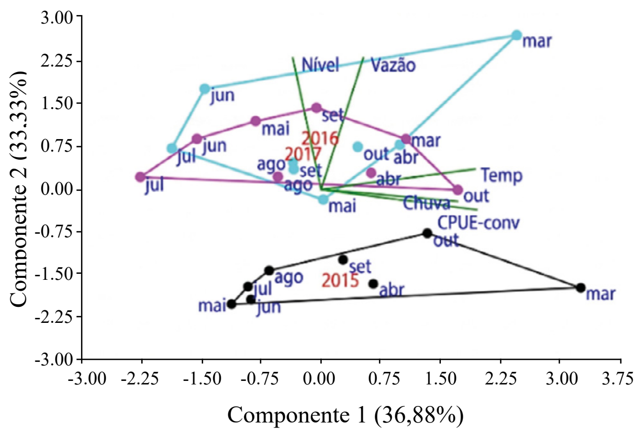
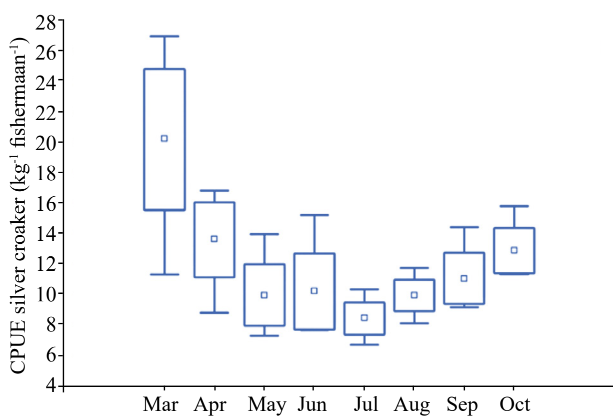


Figure 3. Principal component analysis showing the temporal variability of silver croaker catch per unit effort, and environmental variables from 2015 to 2017 in the Três Irmãos Reservoir.

Monthly CPUE distribution (Fig. 4) showed the highest values in March (20.2 kg·fisher^{-1}·day^{-1}) and the lowest in July (8.5 kg·fisher^{-1}·day^{-1}), corresponding to the dry season (winter).

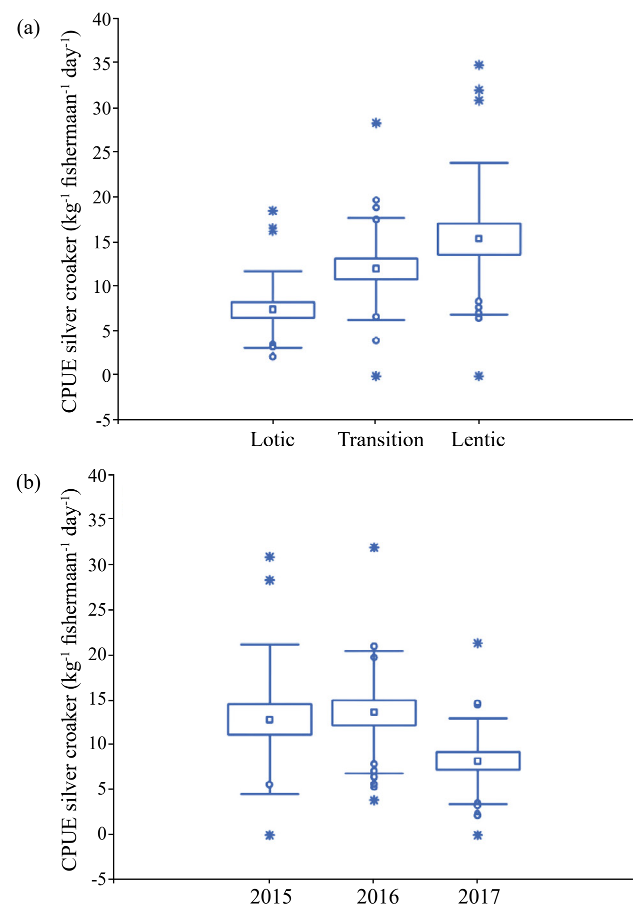


Mean; Box: Mean±SE; Whisker: Min-Max

Figure 4. Box-whisker plot showing monthly silver croaker's catch per unit effort (CPUE), including mean, standard error (SE), minimum, and maximum.

All assumptions of the two-way repeated-measures ANOVA were met. Residual normality, assessed using the Shapiro–Wilk's test ($W = 0.97$, $p = 0.80$) and visual inspection of normal probability (Q–Q) plots, showed no significant departures from normality. Homogeneity of variances was confirmed by Levene's test for 2015 ($F = 0.16$, $p = 0.68$), 2016 ($F = 1.74$, $p = 0.27$), and 2017 ($F = 1.36$, $p = 0.34$). Mauchly's test of sphericity was also non-significant ($W = 0.82$, $p = 0.68$).

The analysis revealed significant differences in CPUE among reservoir zones ($F = 5.81$, $p < 0.05$) and among years ($F = 21.62$, $p < 0.05$). The interaction between zone and year was not significant ($p > 0.05$). Tukey's post hoc test indicated that CPUE in the lotic zone was significantly lower than in the lentic and transition zones (Fig. 5a). Similarly, CPUE in 2017 was significantly lower than in 2015 and 2016 (Fig. 5b). The lowest CPUE was recorded in the lotic zone (7.40 kg·fisher^{-1}·day^{-1}), while 2017 also exhibited the lowest mean CPUE (9.4 kg·fisher^{-1}·day^{-1}).



SD: standard deviation. ◻ Mean ▭ Mean±SE ⌶ Mean±SD ○ Outliers ✱ Extremes.

Figure 5. Box-whisker plots of silver croaker's catch per unit effort (CPUE) by (a) reservoir zone and (b) year, showing means, standard errors (SE), minimum, and maximum values.

Experimental fishing

A total of 1,460 silver croaker individuals were captured using experimental fishing methods. Standard length ranged from 6.8 to 55.0 cm, with a mean of 20.4 cm (± 3.8), and total weight ranged from 10.7 g to 3,500.0 g, with a mean of 187.9 g

(± 167.5). The largest specimens were caught in summer at site P2 (transitional zone), while the smallest were caught in autumn at P3 (lentic zone) (Table 2).

The overall length-weight relationship was (Eq. 5):

$$Wt = 0.01739.SL^{3.04} \quad (5)$$

Table 2. Descriptive statistics of standard length (SL, cm) and total weight (Wt, g) for silver croaker (*P. squamosissimus*) by season and sampling zone in the Três Irmãos Reservoir (2015–2018).

Category	N	SL (cm) mean ± SD	Min–Max	Wt (g) mean ± SD	Min–Max
Overall	1,460	20.4 ± 3.8	6.8–55.5	187.9 ± 167.5	10.7–3,500.0
Spring	253	20.5 ± 4.3	10.0–44.3	190.4 ± 176.3	15.0–1,920.0
Summer	704	20.1 ± 3.7	9.0–55.5	179.0 ± 172.8	12.0–3,500.0
Autumn	333	21.1 ± 3.0	6.8–34.2	191.4 ± 88.7	10.7–78.0
Winter	170	20.0 ± 4.9	10.2–47.0	214.1 ± 234.7	30.0–2,725.0
Sampling points					
P1	300	19.9 ± 3.5	10.0–44.3	169 ± 135.8	15.5–192.0
P2	581	20.6 ± 3.9	9.0–55.5	199.8 ± 182.6	12.0–3,500.0
P3	579	20.4 ± 3.9	6.8–47.0	185.5 ± 165.8	10.7–2,725.0

The exponent b = 3.04 did not significantly differ from 3.0 (t = 1.29, one-tailed $p > 0.025$), indicating isometric growth.

When comparing b values by season, a significant difference was found only in summer (b = 3.15; t = 3.86; $p < 0.05$), suggesting positive allometric growth during this period (Table 3).

Table 3. Length-weight relationships for silver croaker by season in the Três Irmãos Reservoir (2015–2018).

Season	N	a	b	r^2	Growth type
Spring	253	0.019	3.002	0.76	Isometric
Summer	704	0.013	3.145	0.91	Positive allometry
Autumn	333	0.021	2.969	0.95	Isometric
Winter	170	0.020	3.030	0.98	Isometric

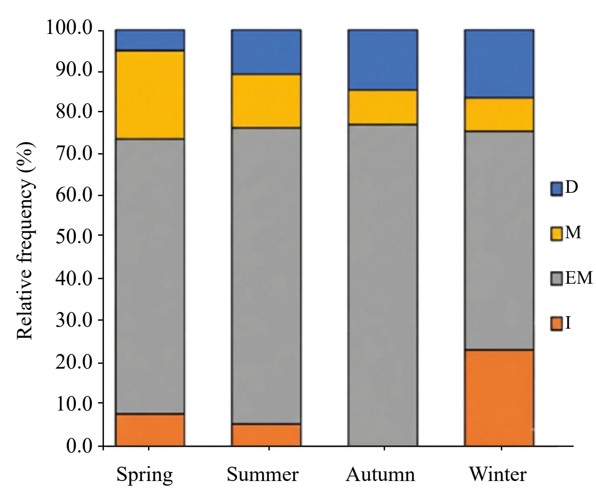
Fulton's condition factor (K_f) varied significantly among seasons. In the lotic zone (P1), K_f reached its highest values in spring and its lowest values in summer ($p < 0.001$). In the transition (P2) and lentic (P3) zones, K_f was significantly higher during winter than in the other seasons ($p < 0.001$), suggesting seasonal variation in energy reserves (Table 4).

Gonadal analysis showed that spawning occurs year-round, with a peak in spring and summer (Fig. 6).

The length at first gonadal maturation (L_{50}) was 12.5 cm standard length (SL) or approximately 16.0 cm total length (TL) for both sexes combined. For females, L_{50} was 13.2 cm SL, and for males 11.8 cm SL. Full maturity (L_{100}) was reached at 19.0 cm SL (Fig. 7).

Table 4. Seasonal variation in Fulton's condition factor (K_f) for silver croaker by sampling zone in the Três Irmãos Reservoir.

Zone	Season	K_f	Zone	Season	K_f	Zone	Season	K_f
P1	Spring	0.021	P2	Spring	0.019	P3	Spring	0.019
	Summer	0.019		Summer	0.020		Summer	0.019
	Autumn	0.020		Autumn	0.019		Autumn	0.019
	winter	0.019		winter	0.023		winter	0.023



D: spawned; M: mature; EM: maturing; I: immature.

Figure 6. Seasonal distribution of the proportion of gonadal maturation stages, by grouped sex, of silver croaker in the Três Irmãos Reservoir, between July 2015 and January 2018.

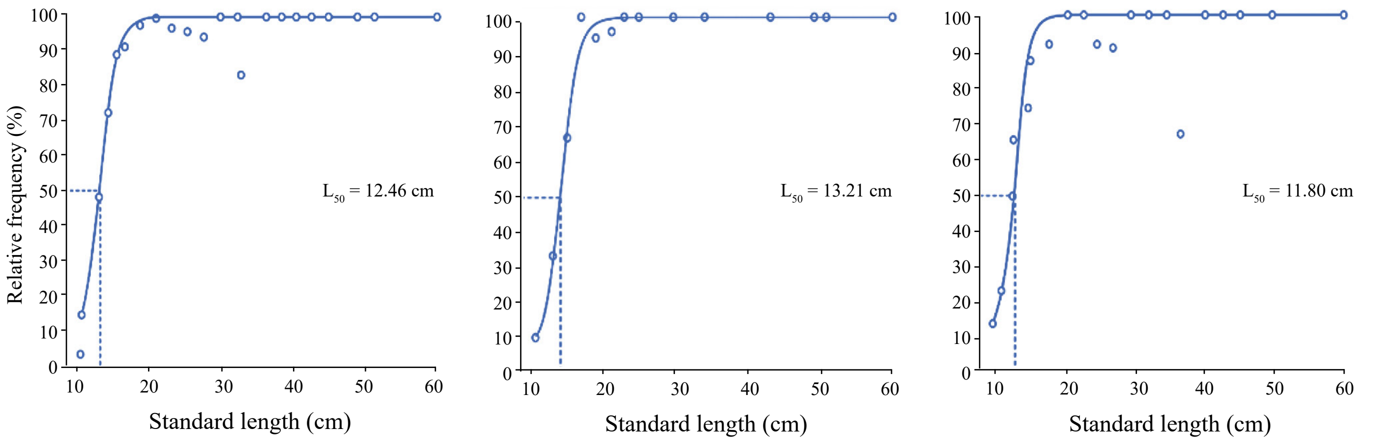


Figure 7. Estimated standard length (SL) of first gonadal maturation (L_{50}) for the (a) grouped sexes, (b) female and (c) male of silver croaker in the Três Irmãos Reservoir, SP, Brazil, between July 2015 and January 2018.

Gillnets captured more individuals during summer (50.6%), especially in the lentic zone (P3—Pereira Barreto), while rod-and-reel catches peaked in summer and were most frequent in the transitional zone (P2—Jacaré) (Fig. 8).

Analysis of gillnet mesh selectivity showed that mesh sizes between 3–6 cm caught 50% of fish in the range 17.0–22.5 cm (SL) and weight in the range 100–200 g, whereas the larger mesh (20 cm) targeted larger individuals in the range 26.0–40.0 cm (SL) and weight in the range 350–1,550 g (Fig. 9).

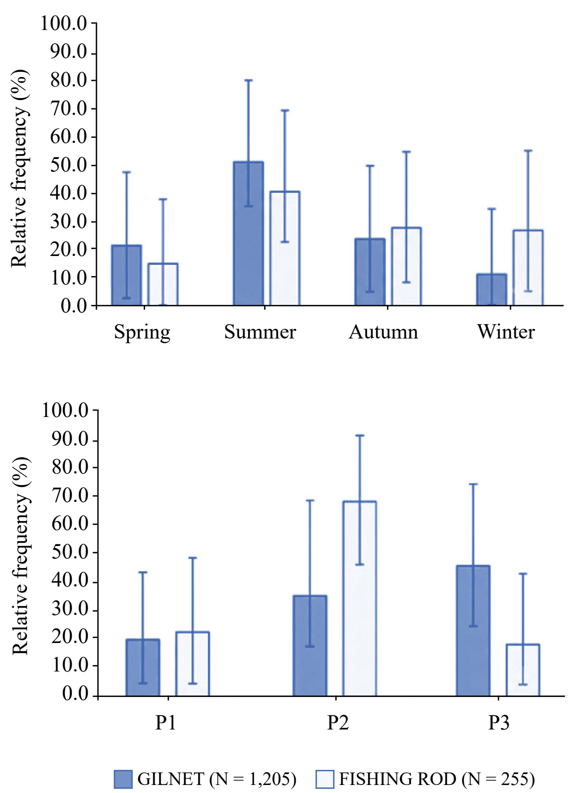
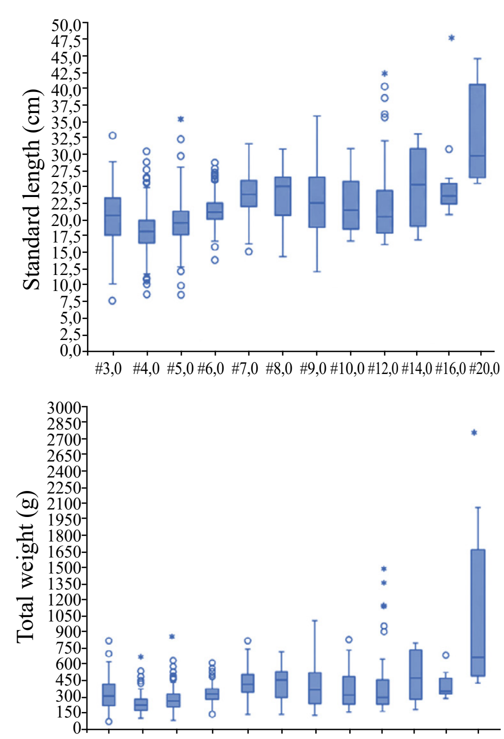


Figure 8. Mean relative frequency of the number of silver croaker individuals in experimental fishing, with gillnet and rod (reel/spinning reel), by (a) season and (b) collection points, in the Três Irmãos Reservoir, SP, Brazil. Whiskers shows standard error.



Line inside box: median; floor and top box: first quartile (Q1) and third quartile (Q3); whiskers: max and min; ○: outliers; *extremes.

Figure 9. Box-whisker plot of (a) standard length (cm) and (b) total weight (g) of silver croaker by net mesh of Três Irmãos Reservoir, SP, Brazil.

DISCUSSION

Artisanal inland fisheries are complex socio-ecological systems that involve interactions between ecological, economic, and cultural components (Arlinghaus et al., 2019; Berkes et al., 2001). Despite their social relevance for food security and income generation in rural communities (FAO, 2024), inland fisheries in Brazil remain poorly documented and largely unregulated (Bartley et al., 2015; Castillo & Baigún, 2020). The present study highlights the pivotal role of *P. squamosissimus* as the primary target species in the Três Irmãos Reservoir, reflecting a fisheries system predominantly supported by non-native species.

The observed fishery productivity for *P. squamosissimus* (0.7 $kg{\cdot}ha^{-1}{\cdot}year^{-1}$) in the Três Irmãos is low compared to other reservoirs in the Tietê River system, which ranges from 2.1 to 9.8 $kg{\cdot}ha^{-1}{\cdot}year^{-1}$ (Castro et al., 2008b; CESP, 2011; 2013; 2014; 2015). This lower productivity is expected for terminal reservoirs in cascade systems, in which cumulative sedimentation, nutrient retention, and reduced primary productivity constrain fish yields (Agostinho et al., 2007a; Petrere Jr., 1996; Winemiller et al., 2016). Nevertheless, the fishery remains socially relevant, as fishing effort is primarily family-based, involving multiple household members in both fishing and post-harvest processing. This characteristic aligns with patterns observed in small-scale fisheries globally, that livelihoods depend not only on ecological productivity but also on the social fabric and fisher communities' adaptive strategies (Allison & Ellis, 2001; FAO, 2024). The temporal analysis revealed that CPUE peaks in warmer months (March) and declines during cooler, drier weather (July). This pattern mirrors the seasonal influence of water temperature on fish activity, metabolism, and vulnerability to capture (Jeppesen et al., 2005). Furthermore, spatial differences showed significantly lower CPUE in the lotic zone, confirming the species' preference for lentic environments with deeper waters and lower flow, as previously reported for *P. squamosissimus* (Agostinho et al., 2007a; Maruyama et al., 2009).

The length-weight analysis indicated isometric growth for silver croaker in most seasons, with a temporary shift to positive allometry in summer, likely reflecting increased food availability and fat accumulation prior to the peak reproductive period (Costa et al., 2009; Hahn et al., 1997). Condition factor (K) analyses further support this, indicating better physiological condition in winter for fish in lentic and transitional zones, possibly as an adaptive energy storage strategy for subsequent reproductive activity (Fonteles-Filho, 2011; Froese, 2006). In lotic zones, lower K values in winter may result from less favorable environmental conditions such as higher flow and reduced prey availability (Bozza & Hahn, 2010; Santos et al., 2014).

Reproductive analyses show a prolonged reproductive period with a peak in spring, typical of tropical fish, with multiple batch spawning strategies (Vazzoler, 1996). The observed length at first gonadal maturation (L_{50}) of 15.9 cm TL is substantially lower than values reported in other reservoirs such as Barra Bonita (24.0 cm; Braga, 1997) and Bariri (26.8 cm; Marciano, 2005). This reduction suggests a possible compensatory response to the high fishing pressure, a well-documented phenomenon in which populations under exploitation tend to mature earlier and at smaller sizes (Jørgensen et al., 2007; King, 2007; Lorenzen, 2016). Such plasticity enhances the invasive potential of *P. squamosissimus*, contributing to its dominance in lentic systems. This is consistent with patterns seen in other non-native piscivores, in which high reproductive rates and flexible life-history traits facilitate rapid population establishment (Olden et al., 2006; Vitule et al., 2012).

Management and conservation implications

From a management perspective, a central dilemma arises: whether fisheries policies should prioritize population control or even eradication of this non-native species to promote native biodiversity, or focus on optimizing its sustainable exploitation to support local livelihoods. From a biodiversity conservation perspective, favoring the capture of juveniles (below L_{50}) could contribute to controlling the population. However, this approach faces legal constraints, as Brazilian fishing regulations prohibit the use of gillnets with mesh sizes below 8 cm (IBAMA, 2009). Furthermore, it risks collateral impacts on native species with similar size ranges. Conversely, from a food security and economic standpoint, promoting the capture of adult individuals using mesh sizes $\geq$ 8 cm supports higher market value, improves fish quality, and aligns with sustainable fishing principles (FAO, 2024). An additional management pathway is the diversification of fish utilization. Smaller individuals, often undervalued, could supply niche markets (*e.g.*, snack foods, bait for recreational fishing), contribute to aquafeed production, or support zoo and aquarium industries, as suggested by recent bioeconomic assessments (Bartley et al., 2015; Castro Campanha et al., 2019).

Broader ecological dynamics further contextualize these findings, as the dominance of non-native species such as *P. squamosissimus* reflects large-scale environmental transformations driven by damming and habitat modification in the Upper Paraná Basin (Agostinho et al., 2008; Pelicice et al., 2018). Under these conditions, efforts to restore native fish populations face significant barriers, including the irreversible conversion of riverine to lentic habitats and ongoing biological invasions (Dagosta et al., 2024; Winemiller et al., 2016). Therefore, integrated management strategies should adopt a pragmatic approach, balancing conservation goals with the fisher communities' socio-economic reality. Recent frameworks, such as the ecosystem approach to fisheries (FAO, 2024), recommend moving beyond species-centric management to incorporate ecosystem processes, stakeholder participation, and socio-economic resilience.

CONCLUSION

Despite the low fishery productivity observed in the Três Irmãos Reservoir, which is typical of terminal reservoirs in cascade systems, the professional artisanal fishery remains an essential source of food, income, and cultural identity for local communities. This fishery is predominantly based on sedentary, non-native species, especially silver croaker (*P. squamosissimus*) and sven's eartheater (*G. sveni*), which together supply a significant portion of the regional fish market. The analysis demonstrated that silver croaker fishing is more productive during the warmer months (March to October) and in lentic environments, in which the species shows better growth, condition, and reproductive performance. The dominant use of gillnets with mesh sizes from 8 to 20 cm aligns with the target sizes that maximize market acceptance and yield. Therefore, the long-term viability of this activity as a socioeconomic driver is contingent upon a balance between the sustainability of fishery resources, the mitigation of ecological impacts on native ichthyofauna, and the overhaul of current legislation. The biological indicators observed—early maturation (L_{50} = 15.9 cm TL), isometric growth, and prolonged reproductive season—reflect both the adaptability of *P. squamosissimus* to lentic environments and the pressure exerted by intensive fishing. These traits underline the species' invasive potential and its resilience in anthropogenically altered ecosystems.

Management recommendations

Given the trade-offs between biodiversity conservation and the socioeconomic importance of the fishery, we propose a dual management strategy for sustainable use, and the adoption of mesh sizes ≥ 8 cm to capture individuals above the first maturity length, improving product quality, reducing overfishing of juveniles, and enhancing economic returns. Additionally, reducing soak time (haul nets every 5 hours) to minimize bycatch of native species and improve fish freshness. For control of the non-native population, if conservation is prioritized, incentive programs for the capture and utilization of small-sized fish for alternative markets (*e.g.*, snacks, aquafeeds, bait) could be adopted, but this requires adjustments to current legislation, technological development, and further impact assessments. Both strategies should be embedded within an ecosystem-based management framework that recognizes the socio-ecological complexity of reservoir fisheries, involving fishermen, local communities, and government agencies in co-management processes. Given the irreversible ecological transformations caused by dam constructions in the Upper Paraná Basin, complete eradication of *P. squamosissimus* is both biologically and logistically unfeasible. Instead, adaptive management, coupled with monitoring and participatory governance, offers a realistic path toward balancing fishery sustainability with biodiversity conservation goals.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

Suppementary .Material is available at: https://doi.org/10.5281/zenodo.21089354

AUTHORS' CONTRIBUTIONS

Conceptualization: Matsumoto A.A., Castro P.M.G.; **Formal Analysis:** Castro P.M.G., Petesse M.L., David G.S.; **Investigation:** Matsumoto A.A., Castro P.M.G., Brazão M.L., **Resources:** Castro P.M.G.; Supervision: Castro P.M.G., David G.S.; **Validation:** Matsumoto A.A., Petesse M.L.; **Data curation:** Castro P.M.G., Maruyama L.S.; **Writing – original draft:** Matsumoto A.A., Castro P.M.G., Petesse M.L., David G.S.; **Writing – review & editing:** Petesse M.L., David G.S.; **Final approval:** Matsumoto A.A.

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DECLARATION OF THE USE OF ARTIFICIAL INTELLIGENCE TOOLS

The authors declare that no artificial intelligence tools were used in the production of this manuscript.

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