

Caudal fin-nipping by *Serrasalmus maculatus* (Characiformes: Serrasalminidae) in a small water reservoir: seasonal variation and prey selection

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ABSTRACT. We evaluated how seasonality affects the frequency and intensity of fin-nipping, as well as the fish prey preferences of *Serrasalmus maculatus* Kner, 1858. The study took place in a small reservoir of the Ribeirão Claro River basin, state of São Paulo, southeastern Brazil. Fish were sampled monthly from July 2003 to June 2004, using gillnets. Sampling consisted of leaving 50 m of gillnets in the water for approximately 24 hours each month. No seasonal variation in the frequency and intensity of fin-nipping was observed. Among six prey species, piranhas displayed less damage in their fins, possibly due to intraspecific recognition. Under natural conditions, the caudal fins of *Cyphocharax modestus* (Fernández-Yépez, 1948) were the most intensively mutilated, which suggests multiple attacks on the same individual. The size of individuals in this species was positively correlated with the mutilated area of the fin, whereas no such correlation was observed for *Astyanax altiparanae* Garutti & Britski, 2000 and *Acestrorhynchus lacustris* (Lütken, 1875). The high number of mutilated fish under natural conditions strongly suggests that the relationship between *S. maculatus* and its prey is more akin to parasitism than to predation. If mutilated fins negatively affect the ability of prey to swim, the spread of *S. maculatus* might result in an unnatural impact on prey fish assemblages and population structure after damming.

KEY WORDS. Community dynamics; human activities; mutilation; prey-predator interaction; Ribeirão Claro River.

The upward demand for energy sources, due to human population increases and industrial development, has motivated the construction of hydroelectric plants. When a river is dammed, fish communities are highly impacted, since damming decreases the local abundance of lotic species (ex. migratory fishes), while promoting the growth of lentic species' populations (AGOSTINHO et al. 2007, AGOSTINHO et al. 2008).

In the state of São Paulo, Brazil, *Serrasalmus maculatus* Kner, 1858, popularly known as 'pirambebas', has become increasingly widespread over the last decades, in association with the construction of dams in several river basins (RODRIGUES et al. 1978). Indeed, NORTHCOTE et al. (1987) noted that this species is highly adapted to lentic conditions, a fact that has many ecological consequences for dammed rivers. Like most *Serrasalmus* piranhas, *S. maculatus* individuals feed on the body parts of other fish (flesh, scales and fins), at least during part of their life cycle (NORTHCOTE et al. 1987, SAZIMA & POMBAL-JR 1988, CARVALHO et al. 2007).

This peculiar behavior raises ecological questions. For instance, what is the nature of the interaction between pira-

nhas and their prey? If piranha' bites result in prey death, the interaction could be classified as predatory. However, if mutilation is not that drastic and does not necessarily cause death, it may be considered parasitic (GOULDING 1980). Caudal fin-nipping may affect the swimming abilities of the prey, and that might increase the foraging costs (SAZIMA & POMBAL-JR 1988) and/or decrease the prey's ability to escape from predators. Also, it may have a negative impact on prey reproduction (e.g., courtship displays and migratory events) (FU et al. 2013). On the other hand, fin mutilation may be very convenient for the piranha, since it is a renewable resource (mutilated fins usually regenerate) (NORTHCOTE et al. 1987). In addition, fin-nipping differs from the typical predator-prey interactions in that it is not limited by the predator-prey size ratio (BARTHEM & GOULDING 1997, LOWE-McCONNELL 1999).

Serrasalmus maculatus is the only member of *Serrasalmus* that is native in the Upper Paraná River Basin. Several studies about its biology (e.g., feeding, reproduction, growth, behavior, population structure, and stock and recruitment) have been carried out (SAZIMA & MACHADO 1990, LAMAS & GODINHO

1996, AGOSTINHO 2003, AGOSTINHO et al. 2003, CARVALHO et al. 2007), including some studies concerning the mutilation habits of this species (NORTHCOTE et al. 1987, SAZIMA & POMBAL-JR 1988, AGOSTINHO et al. 1997, AGOSTINHO & MARQUES 2001). However, some questions regarding prey selection and the intensity of prey mutilation need to be answered to clarify the influence of *S. maculatus* on local fish species, food web networks and community dynamics. Answering these questions could for example help us to predict the effects of the invasion of the Upper Paraná River System by *Serrasalmus marginatus* Valenciennes, 1837 after the suppression of a natural barrier ("Sete Quedas" falls) through the construction of the Itaipu Hydroelectric Power Plant. According to AGOSTINHO et al. (2007), this nonnative species mutilates other fish species and is more aggressive than *S. maculatus*.

In this paper, we conduct a one-year study in a small reservoir to test whether the intensity and frequency of caudal fin-nipping by the piranha *S. maculatus* vary among seasons and fish species and if the frequency of intraspecific fin-nipping is higher than its interspecific frequency.

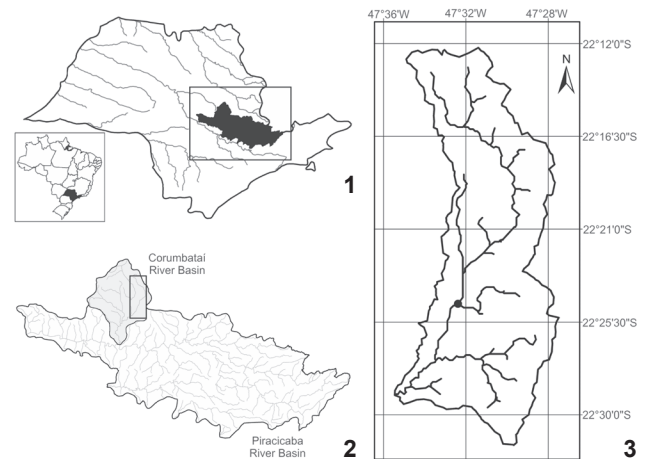
MATERIAL AND METHODS

This study was conducted in a reservoir administrated by the Water and Sewage Autonomous Department of Rio Claro (DAAE – Departamento Autônomo de Água e Esgoto), state of São Paulo. The reservoir is located relatively near the urban area of Rio Claro (22°24'43"S, 47°32'27"W) (Figs. 1-3). It was constructed in 1949, and it currently supplies about 50% of the water consumed by the city's population. It is a semi-lentic system (A. Camargo pers. comm.), reaching a maximum depth of about 2 m. Following Köppen's classification, the climate of the area is Cwa, i.e. subtropical with dry winter and rainy summer season (SMA 2005). Air temperatures ranged from 20° to 27.7°C in January, and from 14.9° to 17.1°C in July

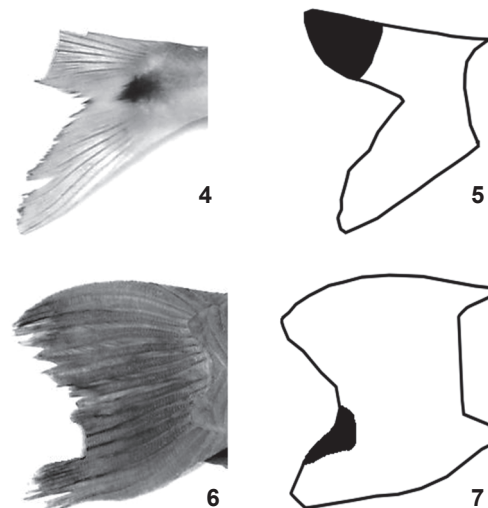
Fish were sampled monthly from July 2003 to June 2004. The biological data were grouped into four seasons: winter (July-September), spring (October-December), summer (January-March) and autumn (April-June). Collections were done using five gillnets (mesh distances between adjacent knots: 1.5, 2.0, 2.5, 3.0 and 3.5 cm), each measuring 10 m, totaling 50 m in extension. Gillnets were submersed for 24 hours, starting at noon, and checked every three hours to remove entangled fish.

After collection, fish specimens were identified to species and measured (standard length, body weight and caudal fin area). To obtain the caudal fin area of each specimen, a line was drawn around the caudal fin margins using a standardized paper. A second copy was obtained by using a paper free of secretions, and then cut out according to the contours of the caudal fin. The mass of each cut was obtained using an analytical balance, and these data were converted into surface area that represented the caudal fin area, based on 0.0096 g/cm² of standardized paper. When caudal fins were nipped, the total

area was estimated based on a visually established outline of the intact caudal fin (Figs. 4-7). This procedure was always conducted by the same person. The area lost by mutilation was calculated by subtracting the mutilated caudal fin area from the estimated intact caudal fin area.



Figures 1-3. Location of studied area: (1) Piracicaba River Basin in State of São Paulo; (2) Ribeirão Claro stream (□) in Corumbataí River Basin; (3) Ribeirão Claro Basin with indication of studied area (●), 22°24'33''S, 47°32'25''W.



Figures 4-7. Schematic representation of the procedure to obtain caudal fin area lost by mutilation (area is detached in black). (4-5) example based on an individual of *Acestorhynchus lacustris*, standard length: 14.1 cm: (4) original caudal fin, (5) contour of estimated intact caudal fin; (6-7) example based on an individual of *Hoplosternum littorale*, standard length: 14.8 cm: (6) original caudal fin, (7) contour of estimated intact caudal fin.

Fish samples were arranged in three groups: Group 1 – fish with signs of regeneration in the caudal fin, which may have been mutilated before being caught in the gillnets; Group 2 – fish without signs of fin regeneration, which have probably been mutilated while in nets or more recently; Group 3 – fish with intact caudal fins. The regeneration signs were identified as a colorless region located marginally in the mutilated portion.

We used contingent χ^2 tables to test if the frequencies of mutilated individuals (Groups 1 and 2) were independent from species and seasons. To account for the small number of individuals captured in some species, the p values were calculated with a Monte Carlo simulation (HOPE 1968). An analysis of variance (ANOVA) was used to test if there were differences in the average intensity of fin-nipping (area of caudal fin lost by predation) among seasons, considering all species together.

Differences between species in the intensity of fin-nipping were also tested. In this case, we used only fish samples with regenerating fins (Group 1) to ensure that we were evaluating natural predation rather than mutilation by nets. An analysis of covariance (ANCOVA) was used to account for the effect of fish size (standard length – cm) on the mutilated area of the caudal fin. The fin-nipped area and the standard length were log transformed to ensure the assumptions of linearity, normality and homogeneity of variance.

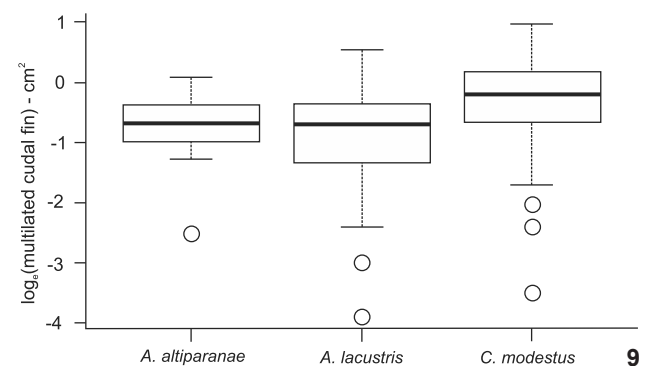
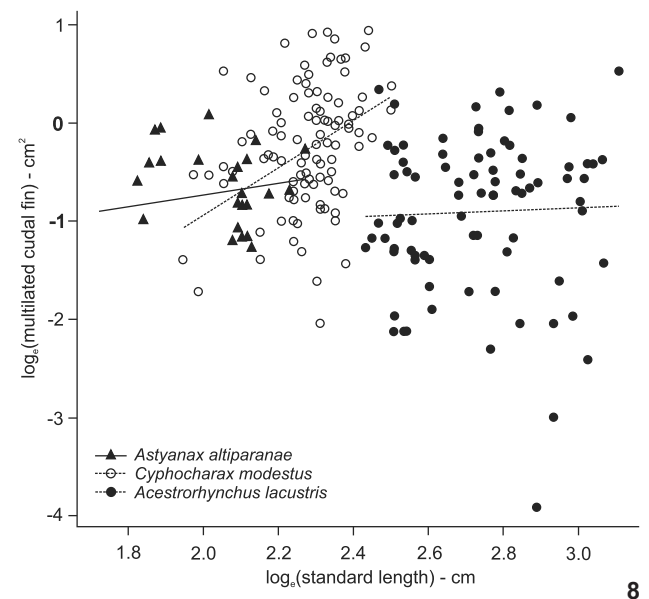
RESULTS

Individuals of seven fish species were caught, totaling 734 specimens (Table 1). Caudal fin-nipping was observed in 627 specimens, while signs of regeneration in the caudal fins were reported in only 206 individuals of three species (Table 1). The frequency of fin-nipping varied significantly among species ($\chi^2 = 156$, $df = 6$, $p < 0.001$) and was lower in *S. maculatus*. Only 25% of the piranhas had signs of mutilation, whereas the mutilation frequency obtained for other species was higher: 76.4% in *Acestrorhynchus lacustris* (Lütken, 1875), 80.0% in *Hoplias* gr. *malabaricus* (Bloch, 1794), 87.39% in *Astyanax altiparanae* Garutti & Britski, 2000, 96.2% in *Cyphocharax modestus* (Fernández-Yépez, 1948) and 100% in *Hoplosternum littorale* (Hancock, 1828) and *Schizodon nasutus* Kner, 1858.

The number of captured fish varied between the seasons. A greater number of individuals was caught in the spring (219), while the other seasons yielded similar numbers (Autumn = 179, Winter = 175, and Summer = 164). Nonetheless, there was no significant variation among seasons in the frequency of fin-nipping ($\chi^2 = 2.29$, $df = 3$, $p = 0.515$) and in the intensity of the mutilation caused by it ($F_{3,624} = 1.38$, $p = 0.249$).

Clear signs of fin regeneration were only found in *A. altiparanae*, *A. lacustris* and *C. modestus*. The frequency of mutilation did not differ among these species ($\chi^2 = 4.41$, $df = 2$, $p = 0.110$). The influence of the standard fish length on the area of mutilated caudal fin was significant only for *C. modestus* (ANCOVA: $F_{interaction} = 4.11$, $p = 0.017$) (Figs. 8-9). The average

area of caudal fin-nipping was also greater in *C. modestus* (Fig. 8). After excluding this species from ANCOVA model, we verified no difference between *A. altiparanae* and *A. lacustris* in relation to the mean area of mutilated caudal fin (ANCOVA: $F_{species} = 0.61$, $p = 0.302$) and no significant influence of fish size (ANCOVA: $F_{SL} = 0.27$, $p = 0.604$) (Figs. 8-9).



Figures 8-9. Mutilated caudal fin area for each species with regenerating caudal fins (Group 1 – see Methods). (8) Mutilated caudal fin area related to standard length of prey for each species. (9) Median (line), 1st and 3rd (rectangle), confidence interval (bars) and outliers (circles) of mutilated caudal fin area for each species. All values were log transformed.

DISCUSSION

As reported in other studies (NORTHCOTE et al. 1987, AGOSTINHO et al. 1997, AGOSTINHO & MARQUES 2001, ANDRADE & BRAGA 2005), the great number of fish with caudal fin-nipping may be

Table 1. List of species and number of individuals with intact or mutilated caudal fins, with discrimination of individuals with regenerating caudal fins (percentual number of individuals with intact or mutilated caudal fin, detaching regenerating of non-regeneration individuals, by species).

Taxon	Common name	Number of individuals caught (%)		
		Intact caudal fin	Mutilated caudal fin	
			Regenerating	Non-regenerating
Characiformes				
Anostomidae				
<i>Schizodon nasutus</i> Kner, 1858	Taguara, Ximborê	0	–	48 (100.0)
Characidae				
<i>Acestrorhynchus lacustris</i> (Lütken, 1875)	Peixe-cachorro	54 (23.58)	81 (35.37)	94 (41.05)
<i>Astyanax altiparanae</i> Garutti & Britski, 2000	Lambari	15 (12.61)	25 (21.01)	79 (66.38)
<i>Serrasalmus maculatus</i> Kner, 1858	Piranha	27 (75.0)	–	9 (25.0)
Curimatidae				
<i>Cyphocharax modestus</i> (Fernandéz-Yépez, 1948)	Saguiru	11(3.81)	100 (34.60)	178 (61.59)
Erythrinidae				
<i>Hoplias aff. malabaricus</i> (Bloch, 1794)	Traíra	2 (20.0)	–	8 (80.0)
Siluriformes				
Callichthyidae				
<i>Hoplosternum littorale</i> (Hancock, 1828)	Caborja	0	–	20 (100.0)

related to the method used to capture them, since fish trapped in gillnets are more susceptible to predation by piranhas. On the other hand, great numbers of fish with mutilated fins have been caught in castnets (e.g., NORTHCOLE et al. 1987, SAZIMA & POMBAL-JR 1988), suggesting that the frequency of mutilation may be naturally elevated in locations where populations of *S. maculatus* are established. In the present study, it was not possible to confirm whether fish without signs of regenerating caudal fins have been mutilated when netted or not. Nonetheless, since the same fishing method was employed throughout the study period, considerations about the seasonal variation in frequency and intensity of caudal fin-nipping are still valid.

The lack of seasonality in both frequency and intensity of caudal fin mutilation contrasts with the results reported by SAZIMA & POMBAL-JR (1988), who showed that fin-nipping was intensified during the dry season. These authors raised three hypotheses to explain this: 1) the greater recruitment of juvenile piranhas at the beginning of the dry season, 2) decreased water turbidity (which improves the perception of prey), and 3) decrease in the number of prey shelters (due to a decrease in the water level and density of aquatic vegetation).

We are unable to confirm if the area of study is a reproductive and nursery site for *S. maculatus*, and thus the occurrence of differential inputs of juvenile piranhas throughout the year is unknown. Moreover, the influence of variables related to the other two hypotheses in the intensity of piranha predation was not evaluated. Nonetheless, the absence of seasonal variation suggests that, given the opportunity, *S. maculatus* individuals will mutilate their prey in high rates

throughout the year. Additionally, the fact that the number of individuals caught varied between seasons and the frequency and intensity of caudal fin mutilation did not, suggests that piranhas and other species show similar responses to seasonal effects, mostly related to activity variation associated with water temperature or reproduction dynamics (BENEMANN et al. 1996, VAZZOLER 1996). In other words, when prey species are more active, and therefore more susceptible to being captured, piranhas are also more active and, consequently, the absolute number of mutilated individuals increases, but the frequency and intensity remains almost the same.

The high rates of attack on individuals of a given species may increase either due to greater vulnerability of prey or some preference by predators (WINEMILLER & KELSO-WINEMILLER 1993). Considering the sampling method employed in the present study, it is reasonable to assume that all individuals in gillnets were equally vulnerable to piranha attack, so that intraspecific differences in mutilation frequency was mainly related to predator's choice. The lower frequency of fin-nipping in specimens of *S. maculatus* in relation to other species was remarkable, indicating some degree of intraspecific recognition, which prevents piranhas from preying on conspecific individuals. AGOSTINHO & MARQUES (2001) evaluated the selection of prey caught in nets by *S. maculatus* and *S. marginatus* and observed that netted piranhas showed the lowest frequencies of fin-nipping. According to these authors, the body shape of piranhas might favor intraspecific recognition, as pointed by MARKEL (1972), who stated that piranhas usually avoid attacking oval-shaped fish. However, NORTHCOLE et al. (1987) contradicted this

hypothesis after finding several fish species with ovate bodies, mainly *C. modestus*, suffering from high rates of caudal fin-nipping. LOWE-McCONNELL (1999) reported that some piranha species produce sounds when netted, and correlated this behavior as a putative warning to other piranhas, avoiding intraspecific mutilation. Another question that may be related to this behavior refers to a vertical black band located in the sub-terminal region of caudal fin in piranhas, which contrasts with its whitish background. Piranhas are visually-oriented predators (SAZIMA & MACHADO 1990) and the highlighted black band in their caudal fin may act as a visual intraspecific recognition sign. However, it should be pointed out that, generally, tropical freshwaters are turbid most of the time. This may have driven evolutionary pathways to other effective modes of perception, and weakens the hypothesis of visual recognition. As in other ostariophysian fish, the environmental perception of piranhas in turbid systems should rely mainly on olfactory and auditory cues (Weberian apparatus) (HELPMAN et al. 2009). Furthermore, although the role of the lateral line is not fully understood, it is known that perception, specially of movements around the fish, is one of its roles (HELPMAN et al. 2009). In this regard, according to SATOU et al. (1991), the typical movements of a fish species could also be a way of communicating with other fish, and in the present case, might play a role in intraspecific recognition (HELPMAN et al. 2009).

The three species that showed signs of regenerating caudal fins (*C. modestus*, *A. lacustris* and *A. altiparanae*) had similar frequencies of fin-nipping. This result might be related to the high abundance of these species in the studied area (Silva, unpublished data). As above mentioned, the highest mutilation frequency could occur under natural condition and abundant species would naturally be the most susceptible targets of attacks.

While ecological aspects (i.e., abundance) can explain the frequency of fin-nipping, natural history traits might explain differences in the intensity of mutilation. Among the species with signs of regeneration in the caudal fins, the highest values of mutilated area were obtained for *C. modestus*. According to NICO & TAPHORN (1988) and WINEMILLER (1989), younger piranhas, including *S. maculatus* (AGOSTINHO et al. 2003), often feed upon fin rays and gradually increase their consumption of pieces of flesh as they grow. Therefore, it is more plausible that the larger fin areas lost by *C. modestus* resulted from cumulative attacks conducted by young piranhas than from single attacks performed by adult individuals. NORTHCOTE et al. (1987) also observed that *C. modestus* was the most frequent prey of *S. maculatus*, which may be the result of its association with river bottoms. High rates of cumulative attacks were also observed for *Geophagus brasiliensis* (Quoy & Gaimard 1824), which forages by revolving the substrate (SAZIMA & POMBAL-JR 1988). Moreover, fish species that forage close to the bottom usually move slowly, favoring piranha attacks. These species can probably be recognized as slow-swimmers due to their relatively high body (see GATZ 1979).

The positive relationship between the size of *C. modestus* and the area of the prey's mutilated caudal fin can be explained by the fact that larger individuals are more easily detected by piranhas, resulting in multiple attacks. Moreover, this pattern could result from successive attacks performed at periods shorter than the time required for fin regeneration, as observed by NORTHCOTE et al. (1987) and SAZIMA & POMBAL-JR (1988) in *G. brasiliensis*.

Acestrorhynchus lacustris and *A. altiparanae* were the least mutilated species, suggesting that individuals of these species are less susceptible to cumulative attacks by piranhas. Both species are nektonic and have effective swimming performance (*A. altiparanae*: CENEVIVA-BASTOS et al. 2010, *A. lacustris*: SILVA & GOITEIN 2009), which probably help them to avoid sequential attacks.

The great number of mutilated individuals under natural conditions suggest that the fin-nipping behavior probably consists in a parasitic interaction, since the individuals attacked survived the mutilation event (see GOULDING 1980). For now, we are unable to verify how much these individuals were definitely harmed in their swimming efficiency or foraging behavior. This is an interesting issue, concerning the effect of fin-nipping on resource acquisition and energy allocation on the growth or reproduction of prey species. Such studies are essential to understand prey-predator relationship, and may also help to predict the effect of misuse of natural resources. The construction of several small reservoirs, for example, may increase the strength of predation (or parasitism) by increasing the feeding efficiency of species that are pre-adapted to lentic conditions, which contributes to the widespread negative effect of river damming.

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