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Population biology of dominant fish species of the Santa Bárbara river, a tributary of the Nova Avanhandava reservoir (low Tietê river, São Paulo State, Brazil)

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ABSTRACT. The aim of this study is to characterize some population biology parameters of *P. squamosissimus*, *A. altiparanae* and *S. maculatus*, the dominant fish species of the Santa Bárbara river, a tributary of the Nova Avanhandava reservoir, low Tietê river. Fish samplings were performed monthly between September/2002 and August/2003, using gill nets with different mesh sizes. Females of all species have larger standard lengths than males (Mann-Whitney, $p < 0.0001$), and are more frequent in superior size classes (Kolmogorov-Smirnov, $p < 0.0001$). All populations presented isometric growth, but differences between males and females were observed. Only *P. squamosissimus* presented a gender ratio different from 1:1, with a higher proportion of males (1:2, χ^2, $p < 0.05$). The onset of gonadal maturation occurs at 15 cm in *P. squamosissimus*, 9 cm in *S. maculatus* and at 8.9 cm in *A. altiparanae*. In all species populations, the adults predominate over juveniles. The allometric condition factor (K) of *P. squamosissimus* and *S. maculatus* presented higher values in the periods from March-May and June-August, and *A. altiparanae* in the period from March-May (Kruskal-Wallis, $p < 0.05$). These results indicate that the populations successfully exploit the lentic environment, and present life cycle tactics adapted to their particular means of environment occupation.

Key words: reservoir, Tietê river, population biology, *Plagioscion squamosissimus*, *Astyanax altiparanae*, *Serrasalmus maculatus*.

RESUMO. Biologia populacional das espécies dominantes do rio Santa Bárbara, tributário do reservatório de Nova Avanhandava (baixo rio Tietê, Estado de São Paulo, Brasil). O objetivo deste estudo é caracterizar alguns parâmetros da biologia populacional de *P. squamosissimus*, *A. altiparanae* e *S. maculatus*, espécies dominantes do rio Santa Bárbara, tributário do reservatório de Nova Avanhandava, baixo rio Tietê. As coletas foram realizadas mensalmente entre setembro/2002 e agosto/2003, utilizando-se redes de esperas de malhagens variadas. As fêmeas de todas as espécies possuem maior comprimento-padrão que os machos (Mann-Whitney, $p < 0,0001$), e são mais frequentes nas classes de tamanho superiores em relação aos machos (Kolmogorov-Smirnov, $p < 0,0001$). Todas as populações apresentaram tipo de crescimento próximo do isométrico, porém diferenças entre machos e fêmeas foram observadas. Apenas *P. squamosissimus* apresentou razão sexual diferente de 1:1, com maior proporção de machos (1:2, χ^2, $p < 0,05$). A primeira maturação gonadal ocorre aos 15 cm em *P. squamosissimus*, 9 cm em *S. maculatus* e aos 8.9 cm em *A. altiparanae*. Em todas espécies, os adultos predominaram sobre os jovens. O fator de condição alométrico (K) de *P. squamosissimus* e *S. maculatus* apresentou maiores valores nos períodos de março-maio e junho-agosto, e *A. altiparanae* em março-maio (Kruskal-Wallis, $p < 0,05$). Estes resultados indicam que as populações estão explorando plenamente o ambiente lêntico, apresentando táticas de ciclo de vida ajustadas ao seu modo de ocupação do ambiente.

Palavras-chave: reservatório, rio Tietê, biologia populacional, *Plagioscion squamosissimus*, *Astyanax altiparanae*, *Serrasalmus maculatus*.

Introduction

The understanding of the factors that regulate a biological community depends on knowledge regarding the structure of the populations that compose it. Such studies provide important information for the management and administration of fishery stocks (BENEDITO-CECÍLIO; AGOSTINHO, 1997).

Vidotto and Carvalho (2007) reported that the fish community of the stretch of Santa Bárbara river under influence of the Nova Avanhandava reservoir is composed of 40 fish species, with a high dominance of a small number of species, where seven species represent 95% of the number of fish and 90% of the biomass. Among these dominant species are *Plagioscion squamosissimus* (Heckel, 1840) ("corvine"), *Astyanax altiparanae* (Garutti and Britski, 2000) ("lambari-do-rabo-amarelo") and *Serrasalmus maculatus* (Kner, 1858) ("piranha").

The introduction of *P. squamosissimus* in the upper Paraná river basin occurred between the 1960s and 1970s (MACHADO, 1977). This species provides an important supply to artisanal fisheries in many reservoirs of the low and middle Tietê river (ESPÍNDOLA et al., 2005), and the Paranapanema river basin, such as the Chavantes, Salto Grande, Capivara and Taquaruçu reservoirs (HOFFMANN et al., 2005; BRITTO; CARVALHO, 2006).

The lambari-do-rabo-amarelo (*Astyanax altiparanae*) and the piranha (*Serrasalmus maculatus*) have a wide distribution in many Brazilian rivers and reservoirs (AGOSTINHO et al., 1995), presenting great trophic plasticity and a high reproductive potential (BENNEMANN et al., 2000; ORSI et al., 2004) – important features that support the colonization and adjustment to the lentic conditions of artificial reservoirs. In addition, *A. altiparanae* and *P. squamosissimus* are some of the most captured species in the region for cage fish farming (RAMOS et al., 2008), an activity that has increased over recent years in the Santa Bárbara river.

The aim of this study is to characterize the parameters of the population biology of *P. squamosissimus*, *A. altiparanae* and *S. maculatus* – the dominant fish species of the Santa Bárbara river – such as size classes, length-weight relationship, size at onset of gonadal maturation, gender ratio and proportion of adults and juveniles. The purpose of this investigation is to define some of the life cycle tactics of these species that may be relevant to the management of fisheries resources of this reservoir.

Material and methods

The Nova Avanhandava reservoir (S 21°07' W 50°17') is the fifth of the Tietê river cascade of reservoirs. The reservoir is at an elevation of 358 m, has a surface area of 210 km^2, total water volume of 2.720 x 10^6 m^3, mean discharge rate of 688 m^3 s^{-1}, maximum depth of 30 m and water permanence time of 46 days (TORLONI et al., 1993; RODGHER et al., 2002). According to the energy company AES Tietê, variation in the altimetric level of the dam was almost insignificant in the period studied (357.9 to 358.3 m). The fish samplings were carried out monthly between September/2002 and August/2003 at the mouth of the Santa Bárbara river (S 21º05'25" W 50º07'18"). This is the most important tributary of the reservoir, flowing in its right margin and receiving strong influence of the lentic system (Figure 1). Fish were caught using gill nets with mesh sizes from 3 to 14 cm (not opposite knot lengths), comprising 1200 m^2 of nets per month. Gill nets were placed late in the afternoon and removed the following morning (14-hour exposure).

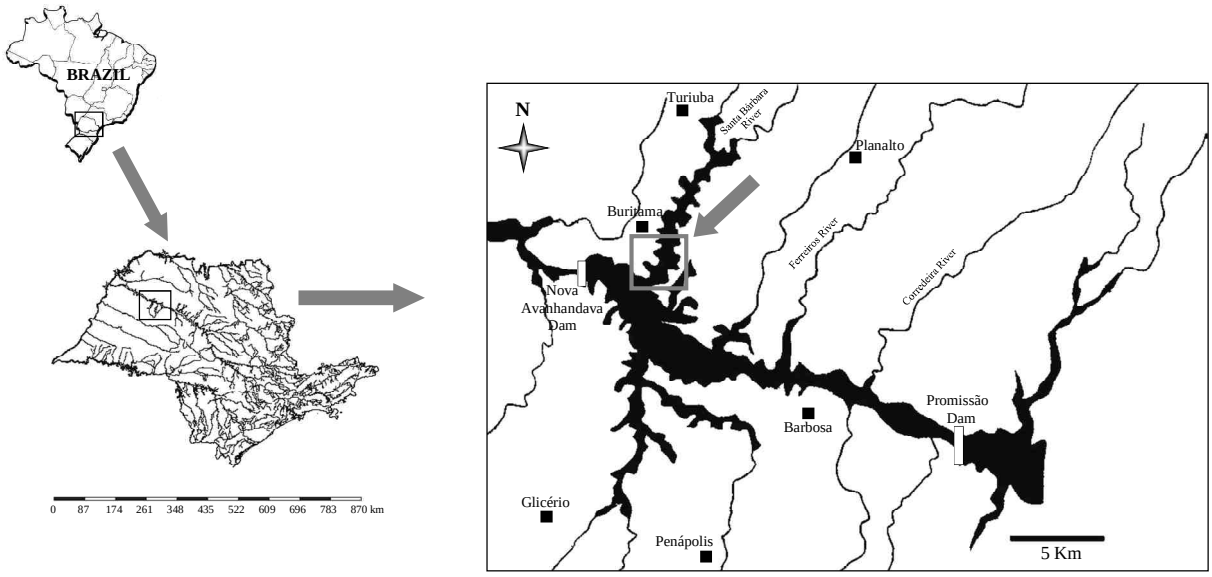

Figure 1. The study site; position of Nova Avanhandava reservoir and Santa Bárbara river in São Paulo State. In the grey box, the stretch of Santa Bárbara river where fish were collected. Modified from CESP (1998).

During sampling, 644 specimens of *Plagioscion squamosissimus*, 599 of *Astyanax altiparanae* and 398 of *Serrasalmus maculatus* were collected; each fish was weighed with a centigram approximation and measured (total and standard length), preserved in 10% formalin and conserved in 70º GL alcohol. A sub-sampling of these specimens was also performed for detailed analysis (gender identification and macroscopic assessment of gonadal maturation), totaling 118 males and 66 females of *P. squamosissimus*, 66 males and 88 females of *A. altiparanae* and 52 males and 61 females of *S. maculatus*. Voucher specimens were deposited in the Museu de Zoologia da Universidade Estadual de Londrina (MZUEL n. 4,729 to MZUEL 4,760).

The distribution of size classes (Ls) was estimated, according to the Sturges expression (STURGES, 1926) W = K/R, where W is the size class amplitude; K is the number of classes [1 + (3,222. log N)], where N is the number of collected specimens) and R is the total amplitude of the data (Ls max - Ls min). The size classes were analyzed for species and gender (males and females) of each species. Differences in relative frequency of each size class between males and females were evaluated by the Kolmogorov-Smirnov non-parametric test ($p < 0.05$). Differences in the mean length between males and females were also calculated using the non-parametric Mann-Whitney test (U Test; $p < 0.05$).

The length-weight relationship was calculated according to the expression $Wt = a\ Ls^b$, where *Wt* = total weight, *Ls* = standard length, *a* = intercept, and *b* = regression coefficient (LE CREN, 1951; SANTOS, 1978). The values of *a* and *b* were obtained after mass and length were log-transformed and subsequent line adjustments using the minimum squares method. The intercept (*a*) represents the condition factor of the population and (*b*) represents the allometric growth rate of the species, tending to assume values between 2.0 and 4.0 (SANTOS, 1978), where b = 3.0 indicates isometric growth – that is, the proportional increase in length and weight.

The allometric condition factor (K) was calculated for periods of three months, regardless of gender, with the expression $K = Wt/Ls^b$, where *b* values were obtained from the length-weight relationship of the raw data of each species, in agreement with Lima-Junior et al. (2002). These values were analyzed with the Kruskal-Wallis non-parametric test ($p < 0.05$).

The chi-square method was applied to evaluate the gender ratio (χ^2, $p < 0.05$). Size at onset of gonadal maturation was determined from the size of the smaller individual in reproduction (gonads in advanced maturation stage), according to Suzuki and Agostinho (1997) and Orsi et al. (2002). These data were also used to calculate the relative frequency of juveniles and adults. All analyses were performed using Biostat 5.0 (AYRES et al., 2007).

Results and discussion

The females had higher values of mean standard length for all species analyzed (Mann-Whitney, $p < 0.0001$, Table 1). Females that were larger than males have also been observed for *P. squamosissimus* in other Tietê reservoirs, such as Bariri (RODRIGUES et al., 1988; MARCIANO et al., 2005). and Barra Bonita (CASTRO, 1994), and also in the population of *A. altiparanae* in the Tibagi river (ORSI, 2001). This attribute is a typical characteristic of many Characiformes from the Neotropical region, such as *A. altiparanae* and *S. maculatus*, and may be related to reproduction dynamics – for example, due to the larger size of the gonads that occupy the visceral cavity of females (VAZZOLER; AMADIO, 1990).

Table 1. Minimum, maximum, mean and median values of standard length (Ls) of males and females of dominant species of the Santa Bárbara river.

		Ls min	Ls max	Mean	Median	Mann-Whitney Test (U)
Plagioscion squamosissimus	Males	9.4	35.0	18.97	18.55	< 0.0001
	Females	14.4	47.5	21.97	20.70	
Astyanax altiparanae	Males	6.0	12.0	8.65	8.50	< 0.0001
	Females	6.7	14.2	10.43	10.50	
Serrasalmus maculatus	Males	4.5	22.0	11.74	11.30	< 0.0001
	Females	6.3	24.0	15.84	15.00	

The distribution by size classes of total populations revealed that *P. squamosissimus* has a modal frequency at 15 to 20 cm, *A. altiparanae* at 8.1 to 9 cm and *S. maculatus* does not present a defined modal distribution; however, individuals were more frequent in the size classes from 6 to 12 cm (Figure 2). Additionally, females were predominant in higher size classes (Kolmogorov-Smirnov, $p < 0.0001$). Males of *P. squamosissimus* were more frequent in the size class from 15 to 20 cm, while females occurred more frequently in the size class from 20 to 25 cm. Males of *A. altiparanae* were more frequent at 7.1 to 8 cm, and females at 11.1 to 12 cm. Males of S. *maculatus* occurred more frequently at 8.1 to 10 cm and 12.1 to 14 cm, and females at 12 to 24 cm.

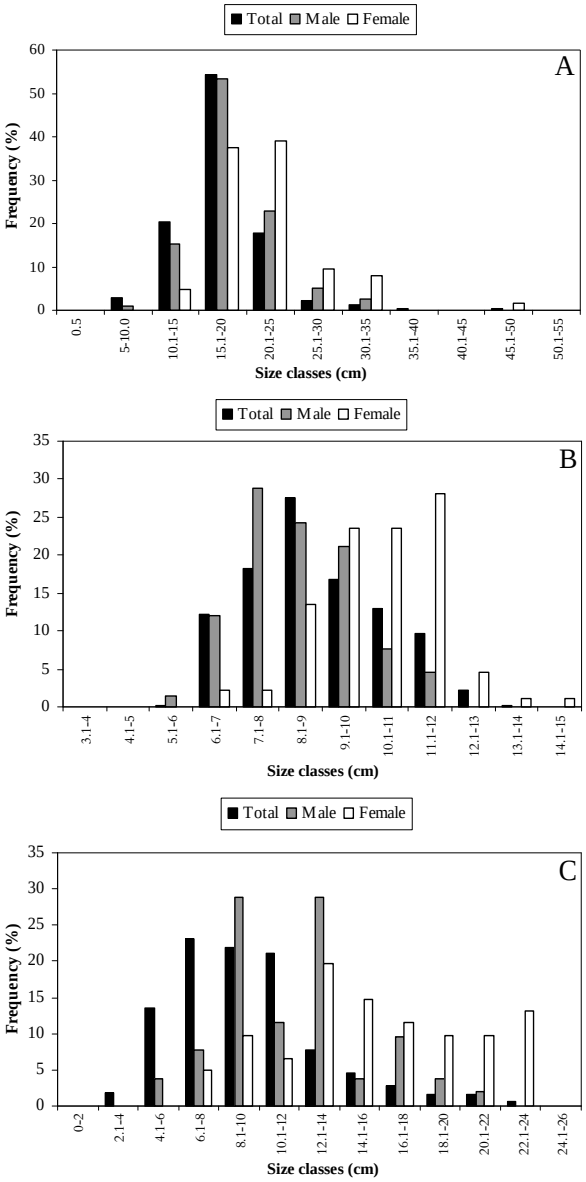

Figure 2. Frequency (%) by size classes of standard length of dominant fish species of the Santa Bárbara river. A: *P. squamosissimus*; B: *A. altiparanae*; C: *S. maculatus*.

Vazzoler (1996) reported that the dominance of females in higher size classes occurs because they present a greater growing rate than males. This pattern was also observed for the *A. altiparanae* population from the Tibagi river (ORSI, 2001) and in the *P. squamosissimus* population in the Barra Bonita reservoir (CASTRO, 1994). Orsi et al. (2004) affirmed that the presence of many size classes could reveal the coexistence of age groups in space and time, indicating that the lentic environment is suitable for the development of all stages of the life cycle (eggs, larvae, juveniles and adults).

Species presented nearly isometric growth, with a *b* value of 2.9229 in *P. squamosissimus*, *b* = 2.9989 in *A. altiparanae,* and *b* = 2.9965 in *S. maculatus* (Table 2). These data reveal that the three species populations preserved isometric growth, however, the differences between genders indicate distinct intra-population strategies. Males of *P. squamosissimus* and *A. altiparanae* presented negative allometry (2.881 and 2.8897, respectively), while females of this species had positive allometry (3.0265 and 3.113, respectively). However, *Astyanax altiparanae* from the Tibagi river (ORSI et al., 2002) and *P. squamosissimus* from the Bariri reservoir (RODRIGUES et al., 1988) presented similar growth rates for both genders. Conversely, females of *S. maculatus* presented negative allometry (2.8692) and males had positive allometry (3.2247), the same observed for *S. spilopleura* (= *S. maculatus*) by Fujihara (1997) in the Jurumirim reservoir (upper Paranapanema river).

Table 2. Number of analyzed specimens (n), condition factor (a), growth rate (b) and determination coefficient (R^2) from the length-weight relationship of the dominant species of the Santa Bárbara river.

Species		n	a	b	R^2
Plagioscion squamosissimus	Total	644	0.0249	2.9229	0.9662
	Male	118	0.0273	2.881	0.9704
	Female	66	0.018	3.0265	0.9772
Astyanax altiparanae	Total	599	0.0314	2.9989	0.9033
	Male	66	0.0371	2.8897	0.9531
	Female	88	0.025	3.113	0.9606
Serrasalmus maculatus	Total	398	0.0367	2.9965	0.9722
	Male	52	0.0217	3.2247	0.991
	Female	61	0.058	2.8692	0.9704

Differences in the growth rate between males and females may be related to body proportions; as such, they may present sexual dimorphism due to their reproductive, behavioral and trophic strategies, and the pattern of spending energy in body maintenance (ORSI; SHIBATTA, 1999). For example, *P. squamosissimus* presented positive allometry in the Tibagi river (ORSI et al., 2002) and in the Barra Bonita reservoir (CASTRO, 1994), while in the Bariri reservoir the same species presented negative allometry (RODRIGUES et al., 1988). This finding may indicate an adjustment in the tactics of colonization of the environments. Barbieri et al. (1985) related that distinct populations of a given species could show different growth rates, responding in distinct ways to availability of food and spatial resources, or to the competition for an ecological niche.

The 1:1 gender ratio was observed in *S. maculatus* (χ^2, $p < 0.05$, Table 3) in agreement with *S. spilopleura* (= *S. maculatus*) from the Bariri reservoir (MOTA et al., 1982), but differently to that

observed in the Jurumirim reservoir (FUJIHARA, 1997), where this species presented a higher proportion of females. *A. altiparanae* also exhibited a 1:1 gender ratio, differing from the 1:3 ratio of the Congonhas II population in the Tibagi river (ORSI et al., 2004). According to Vazzoler (1996) and Rodrigues et al. (1988), the gender ratio of fish can change along their life cycle, due to successive biological events, such as growth and mortality rates, which operate differently for males and females and may facilitate the catching of individuals of one gender. Orsi et al. (2004) affirmed that females, when they reach a larger size, explore the habitat efficiently and are less affected by predation risks.

Table 3. Chi-square values (χ^2), applied to gender ratio data, and size at onset of gonadal maturation of dominant species of the Santa Bárbara river.

	χ^2	Gender ratio	Size of first gonadal maturation
Plagioscion squamosissimus	16.02*	1:2	15.0 cm
Astyanax altiparanae	3.39	1:1	8.9 cm
Serrasalmus maculatus	0.72	1:1	9.0 cm

*Statistic significance.

The population of *P. squamosissimus* presented more males than females (1:2 gender ratio), as also observed by Marciano et al. (2005), in the Bariri reservoir. In contrast, Castro (1994) observed the opposite in the Barra Bonita reservoir. According to Odum (1988), the larger number of females can be an indicator of fast population growth. Barbieri (1992) affirmed that a gender ratio that is different from 1:1 can be caused by gear selectivity, or even by natural population stratification.

The onset of gonadal maturation, determined from the size of the smaller individual in reproduction of *P. squamosissimus* was 15 cm, close to the 15.9 cm observed by Vazzoler (1996) in the upper Paraná river. However, in other rivers and reservoirs, the onset of gonadal maturation occurs in larger specimens, from 18 to 24 cm (GODINHO et al., 1997; RODRIGUES et al., 1988; LOUBENS, 2003; MARCIANO et al., 2005). For *S. maculatus* the onset of gonadal maturation occurred at 9 cm, the same observed by Vazzoler (1996) and smaller than that observed by Rodrigues et al. (1978) (16.5 cm) and Lamas and Godinho (1996) (17.8 cm). *A. altiparanae* presented the onset of gonadal maturation at 8.9 cm, larger than the 6.9 cm observed in Corumbataí river basin (GOMIERO; BRAGA, 2007) and Paraná river (VAZZOLER, 1996).

Fish display a wide range of ages at first reproduction and, within a given species, this feature may vary with growth and mortality rates that, consequently, can be influenced by environmental conditions (WOOTON, 1990). The early gonadal maturation is an efficient mechanism to expand the genetic representation of the population in the next breeding, but can expose smaller individuals to predation risk, and reduce the reproductive potential in more advanced ages (RICKLEFS, 1996; VAZZOLER, 1996). The decrease in the size of onset of gonadal maturation can be interpreted as a good reproductive tactic for colonization of a new environment (ORSI et al., 2002), particularly for introduced species, such as *P. squamosissimus*. Carnelós and Benedito-Cecílio (2002) observed that this species presented an increase in fecundity after introduction in the Itaipu reservoir, and reached gonadal maturation at a smaller length than immediately after impoundment. This evidence indicates that the reproductive strategy, besides trophic plasticity, is an important factor in the successful colonization of the new environment.

In contrast, in stable environments, such as the Nova Avanhandava reservoir, which present minimum variations in water level, species can present late gonadal maturation as a response to low mortality rates. This observation can explain the late maturation of *A. altiparanae* when compared to other localities (GOMIERO; BRAGA, 2007).

The most practical aspects of knowing the size at first gonadal maturation is for the control and support of fishery stocks and to assist the establishment of regulations to capture of species in a given environment that is subject of management, farming or stocking (BARBIERI; BARBIERI, 1988).

Adults were dominant in all species (Figure 3), with 86.7% in *P. squamosissimus,* 70.1% in *A. altiparanae* and 85.9% in *S. maculatus*. Higher proportions of adults in these species were also observed by Orsi et al. (2002). According to these authors, the prevalence of adults indicates that the population completely exploits the lentic environment and does not make great trophic or reproductive migrations. However, the rate among juveniles and adults can vary in different populations of the same species, due to environment attributes. A higher rate of juveniles of *P. squamosissimus* was observed by Braga (2001) in tributaries of the Volta Grande reservoir. Rejecting the selectivity of fishing gear, the greater proportion of adults may be a strategy to increase the individuals prepared for spawning, providing successful colonization of the environment, particularly for *A. altiparanae*, a potential prey of the two other species.

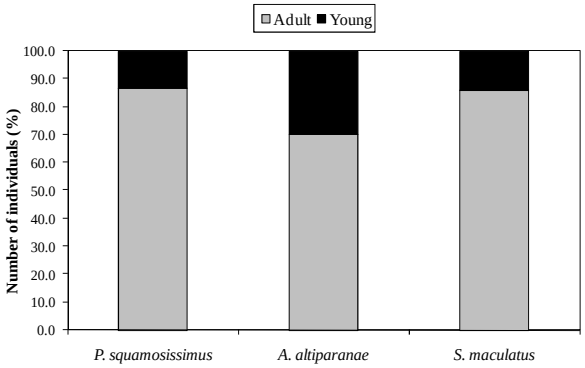

Figure 3. Proportion of adults and juveniles (%) in the dominant species of the Santa Bárbara river.

The higher allometric condition factor (K) of *P. squamosissimus* occurred during the periods of March-May and June-August. In addition, all periods presented differences in K values when compared (Kruskal-Wallis, $p < 0.05$), except for the periods of September-November and June-August when compared to March-May (Figure 4). *A. altiparanae* presented the highest K value in the March-May period, and great variation along the year, where only the September-November period, when compared to December-February, presented no differences. *S. maculatus* also presented higher K values in the March-May and June-August periods. Low variation in K value along the year was observed for this species, where only the period of March-May was different from September-November and December-February.

The allometric condition factor is a good index of the well-being of a fish, reflecting recent nutritional conditions (VAZZOLER, 1996), and can indicate the reproductive periods of the species. Differences in K value can be interpreted as variation in the body fat amount, changes in the environment related to gonadal maturation and the feeding intensity (ROSSI-WONGTSCHOWSKI, 1977; WOOTON, 1990) and the growing of the species (JONES et al., 1999).

The smallest K values were observed in the periods of September-November and December-February in *P. squamosissimus* and *A. altiparanae*, usually the periods that overlap with the spawning season of the majority of species (Figure 4).

According to Agostinho et al. (1990), the decrease in K value can be related to the metabolic consumption that occurs in this period. In contrast, increases in K may be related to a better exploration of feeding resources during certain periods of the year, due to availability of environmental resources, associated with a higher ability of exploration of the aquatic environment (ROSSI-WONGTSCHOWSKI, 1977; GOMIERO et al., 2008).

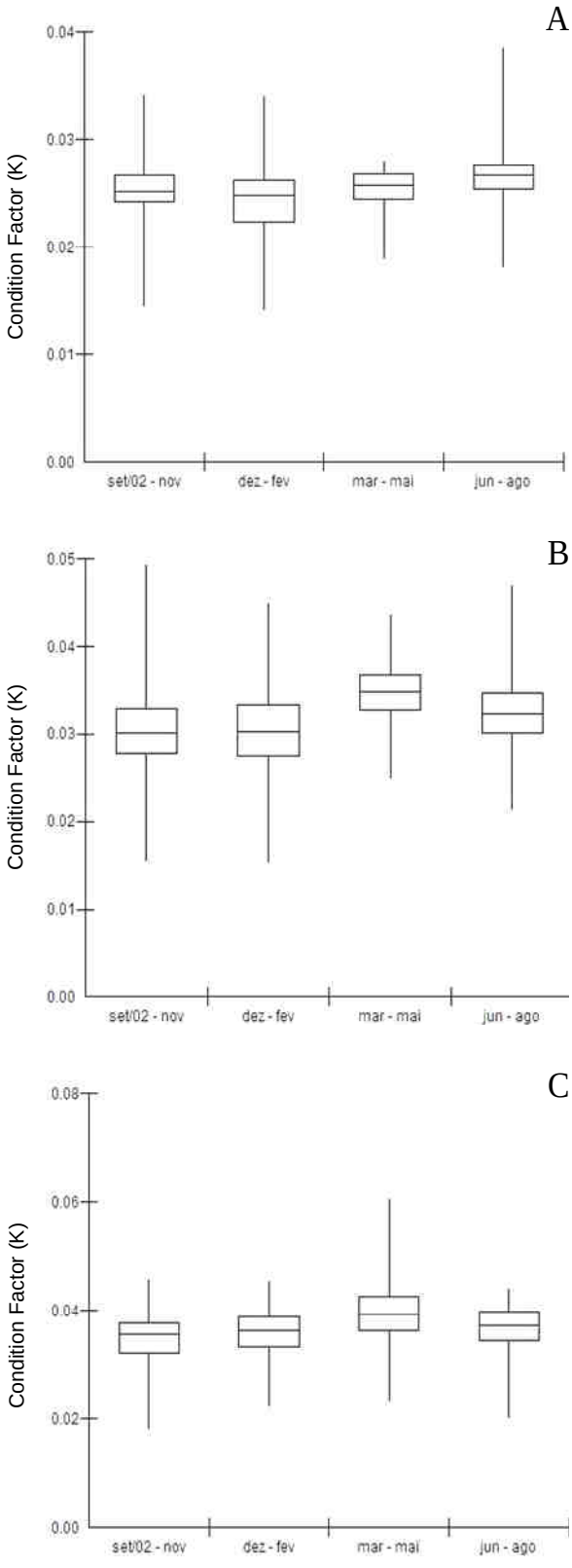

Figure 4. Variation of allometric condition factor (K) by periods of dominant species of the Santa Bárbara river. A: *P. squamosissimus*; B: *A. altiparanae*; C: *S. maculatus*. Vertical lines: maximum and minimum values; box: first and third quartile; horizontal lines: medians.

Conclusion

The results indicate that these dominant species (two native and one introduced), that represent great abundance of fish community of this reservoir, successfully exploit its lentic compartment, and display life cycle tactics adapted to their particular means of environment occupation. In addition, this set of tactics appears to be important to the coexistence of this three species, since *P. squamosissimus* and *S. maculatus* are medium to large size predator species and *A. altiparanae* is a small size foraging species.

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