

Population aspects of *Bryconamericus stramineus* in streams of the upper Paraná River basin, Brazil

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Abstract: In order to describe some aspects of the population ecology of *Bryconamericus stramineus* in the Guirai River basin, upper Paraná River basin, samples were taken bimonthly from October 2006 to August 2007 at seven sites in the basin. A total of 960 individuals, including 532 females, 316 males, and 112 of undetermined sex, were collected. A significant variation in the sex ratio was observed ($\chi^2 = 32.82$; $p < 0.001$). Females were larger (59.7 mm) than males (58.9 mm); however, males showed a larger angular growth coefficient (b) than females. It was estimated that 50% of females were sexually mature at 36.4 mm. The highest rate of ovary development was observed in October, while in June 2007 no mature females were found. Mean fecundity was estimated at 313 eggs, and the relative fecundity was 184.6 eggs/g. The asymptotic was estimated at 62.8 mm and the growth rate at 0.76. The growth performance index was calculated at 3.47, the longevity at 3.94 years and the mortality (M) at 1.18 years. The recruitment pattern of the species showed peaks concentrated in periods of low rainfall.

Keywords: length-weight relationship, mortality, reproductive strategy, sex ratio.

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Resumo: Com o objetivo de descrever alguns aspectos populacionais e reprodutivos de *Bryconamericus stramineus* em riachos da bacia do rio Guirai, Alto Rio Paraná, realizamos amostragens bimestrais de Outubro/2006 a Agosto/2007 em sete riachos da bacia. Foram coletados 960 indivíduos, sendo 532 fêmeas, 316 machos e 112 de sexo indeterminado. Constatamos variação significativa na proporção sexual ($\chi^2 = 32,82$; $p < 0,001$). As fêmeas foram maiores (59,7 mm) que os machos (58,9 mm); no entanto, os machos apresentaram maior coeficiente angular de crescimento (b). Estimamos que 50% das fêmeas estão sexualmente maduras com 36,4 mm de comprimento padrão. As maiores frequências de fêmeas com ovários desenvolvidos foram observadas em Outubro, sendo que o único mês em que não foram encontradas fêmeas maduras foi Junho. A fecundidade média foi estimada em 313 ovócitos e a fecundidade relativa foi de 184,6 ovócitos/g. O comprimento assintótico foi estimado em 62,8 mm e a taxa de crescimento em 0,76. O índice de performance de crescimento foi calculado em 3,47, a longevidade em 3,94 anos e a mortalidade em 1,18. O padrão de recrutamento da espécie estudada apresentou picos concentrados no período de menor pluviosidade.

Palavras-chave: estratégia reprodutiva, mortalidade, proporção sexual, relação peso-comprimento.

Introduction

The Paraná River is the main watercourse in the River Plate basin, which is the second-largest hydrological basin in South America. The floodplain of the upper Paraná River between the Porto Primavera and Itaipu dams is the last undammed stretch in Brazilian territory, and supports a high species diversity (Agostinho et al. 2000). Langeani et al. (2007) cited the occurrence of 310 fish species in the upper Paraná basin, a number that will undoubtedly increase as a result of an improvement in the sampling effort and the large number of new species whose description remain undone.

In spite of the growing number of studies on the ichthyofauna in the floodplain portion of the upper Paraná basin, few studies have been carried out in streams. Exceptions are the studies of Agostinho & Penczack (1995), Abes & Agostinho (2001), Pavanelli & Caramaschi (2003), Suárez (2008) and Suárez & Lima-Júnior (2009). The biology and ecology of stream-dwelling species remain poorly studied, possibly as a result of inadequate taxonomic knowledge, however, the high isolation level and variability in environmental conditions can lead to development of great history life strategies in stream fish, them reinforcing the need of study these fish species to define possible responses to environmental degradations.

Among the various families of fishes found in the upper Parana River, Characidae is the most diverse among the Characiformes, in which the genre *Bryconamericus* included on the “*Insertae Sedes*” (Mazzoni & Silva 2006). Studies about population ecology of small fishes in the floodplain portion of the upper Paraná River are few, except for those by Benedito-Cecilio et al. (1997), who analyzed the length/weight relationship for fish species from Itaipu Reservoir; Lizama & Ambrósio (1999, 2002), discussing population aspects of nine species in the floodplain area of the upper Paraná basin; Lizama & Ambrósio (2003), analyzing the mortality and recruitment pattern of *Moenkhausia intermedia*; Piana et al. (2006), quantifying the importance of environmental factors in density variation of *Serrapinnus notomelas*; and Lourenço et al. (2008), analyzing the length/weight relationship, recruitment and mortality of *S. notomelas* and *B. stramineus* in streams of the lower Ivinhema River basin and Benítez & Suárez (2009) analyzing population parameters for *S. notomelas* in middle Ivinhema River Basin. Brandão-Gonçalves et al. (2009) analyzing the feeding ecology of *B. stramineus* in streams of the Guirará River Basin. However, reproductive aspects are not studied by Lourenço et al. (2008) and for Brandão-Gonçalves et al. (2009) the only study about population ecology of small stream fishes in Ivinhema river basin.

Bryconamericus stramineus (Eigenmann, 1908), popularly known as “piquirá” is one of the commonest in streams of the upper Paraná River. *Bryconamericus stramineus* is an active swimmer and its activity period is mainly in daytime (Smith 2003) predominantly insectivore in studied streams (Brandão-Gonçalves et al., 2009). Its occurrence is positively influenced by water velocity (Suárez et al. 2007). Despite its wide distribution, basic aspects of its ecology are not well known; the few available data on its biology are recent and originate from Ibicuí River in the State of Rio Grande do Sul (Lampert et al. 2007), a region with different climate regime of Upper Paraná River basin.

The present study aimed to provide information about some population aspects of *B. stramineus* in the Guirará River basin, searching to complete information with published data (Brandão-Gonçalves et al. 2009) and define basic aspects population ecology of this species (feeding, reproduction and growth) in order to answer the following questions: 1) Which equation best describes the weight/length relationship for males and females of *B. stramineus*? 2) Are there differences in the sex ratio along the year? 3) Does the mean adjusted weight of individuals vary from month to month? 4)

In which season does reproductive activity of *B. stramineus* increase in the streams sampled? 5) What is the mean standard length at which females reach first maturation? 6) Is there any relationship between fecundity and the size of females? 7) Are seasonal differences in recruitment patterns for studied population? 8) What are the growth and mortality parameters for *B. stramineus* in sampled streams?

Material and Methods

1. Study site

The Guirará River basin (22° 45' S, 54° 30' W and 22° 15' S, 53° 30' W), occupies an area of approximately 2,248 km² and includes seven municipal districts. The mouth of the Guirará River is located at an altitude of 370 m a.s.l., and the river flows for approximately 100 km until it enters the Ivinhema River, at 238 m of altitude. In its lower portion, it forms the boundary of the Parque Estadual das Várzeas do rio Ivinhema.

2. Field and laboratory methods

The fish samples were taken bimonthly from October 2006 to August 2007 at seven sites in the Guirará River basin (Figure 1). The streams were selected for their location in the basin and ease of access.

The samples were taken during daylight, with a rectangular sieve measuring 1.2 × 0.8 m (2 mm mesh size) and standardized effort (20 throws) at each site, with approximately 100-m long hauls. The equipment was slide to sweep the substrate toward the banks of the stream. This technique was used because of the difficulties of using the electric fishing in these streams, such as low electrical conductivity and high turbidity, and also due to difficult access. The permission for fish retrieval was granted by IBAMA (#13458-1).

Specimens were fixed in 10% formalin and preserved in 70% ethanol for subsequent identification. Voucher specimens were deposited at the Coleção de Peixes do Nupelia (NUP/UEM # 9322).

In the laboratory, some biometric data were measured: sex, total length (Lt), standard length (Ls), total weight (Wt), ovary weight (Wo), and the ovary maturation stage was determined for females. The maturation stages of ovaries were defined as: A, immature (filiform, translucent and very small ovaries, placed close to the dorsal wall), B, maturing (ovaries with opaque and small or medium oocytes), C, mature (ovaries almost completely occupying the coelomic cavity, swollen with large oocytes that are opaque or translucent), and D, spent (ovaries with different degrees of laxity, with distended membranes and hemorrhagic aspect). At the “spent” stage there were also included that ovaries which might be at the process of tissue recovery after spawning, because, due to the small egg size and difficult determination of gonadal stages, it was not possible to distinguish recovering phases from post-spawning ones.

After the biometric data were taken, 37 mature females (stage C), belonging to different size classes (two per each 2 mm, within the size range in which mature females were found) randomly chosen had their ovaries extracted and immersed in Gilson so that there was the film corrosion and it was possible to determine their fecundity by counting the total number of eggs in the ovaries.

3. Data analyses

The length-weight relationships for each sex were estimated by non-linear regression. The estimated values of the angular growth coefficient (b) between sexes were compared through the graphical comparison of their confidence intervals.

The sex ratio was calculated for each two months sample, aiming to assess possible variations in this population descriptor.

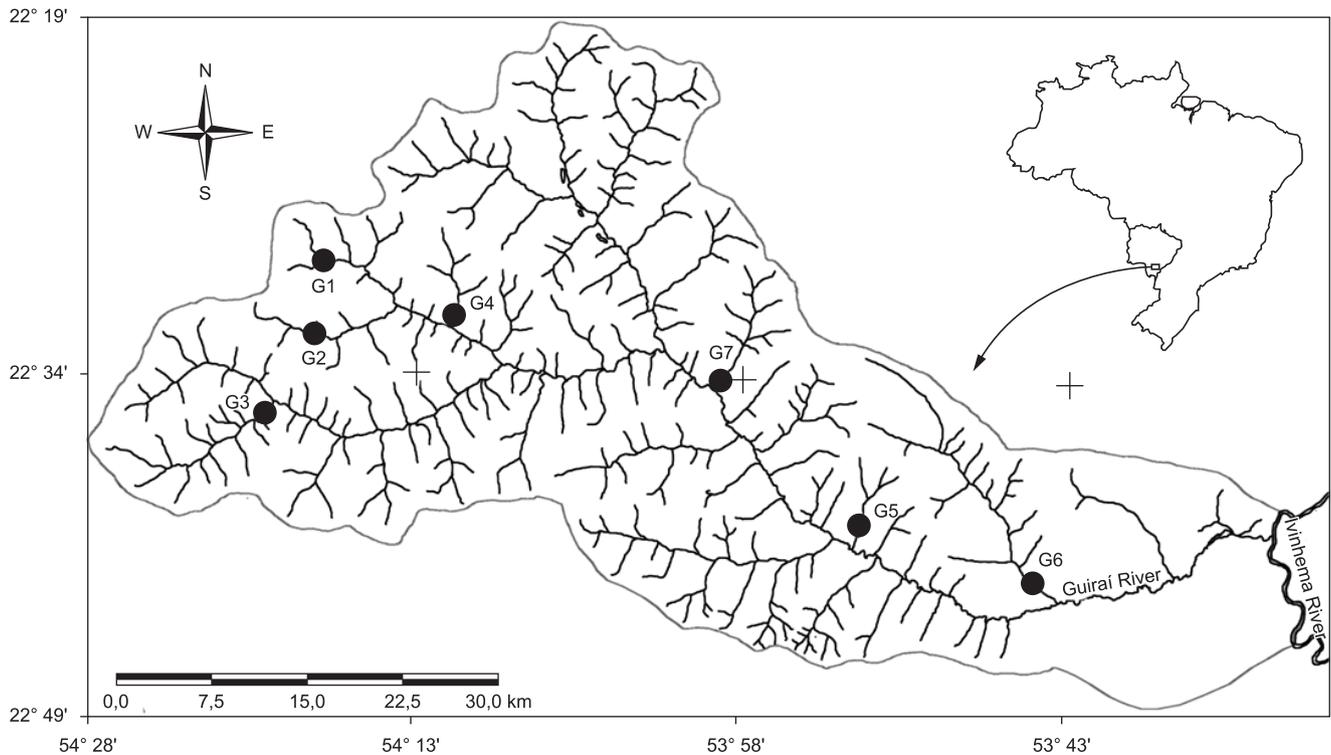


Figure 1. Location of the sampling sites where *B. stramineus* was recorded in the Guirai basin, upper Paraná River basin, from October 2006 to August 2007.

The difference in the sex ratio was assessed by the chi-square (χ^2) test, with Yates correction.

Correlations between fecundity and standard length were tested through Spearman correlation rank, in order to quantify the variation in the fecundity according to the size of females.

The probability of female maturation was obtained using logistical regression. The presence of eggs was used to determine if the individuals were spawning. Standard length was used as the explanatory variable, according to Roa et al. (1999).

In order to analyze the seasonal weight variation of individuals, a covariance analysis was carried out for the weight (response variable) as a function of sampling month (explanatory variable) and standard length (co-variable) for each sex. The data for total weight and standard length were previously converted to \log_{10} in order to satisfy the presumption of linearity (Cetra 2005).

The asymptotic length was estimated from the largest individual caught using the equation of Pauly (1983): $L_{\infty} = L_{\max}/0.95$. The estimated growth rate (k) was obtained using the method ELEFAN (Electronic Lengths-Frequency Analysis) (Pauly & David 1981), included in the software FISAT II. This procedure, as well as the subsequent uses the frequency by length class over time, identifying changes in modal length and from there estimating age groups and the growth rate and mortality.

The growth performance index (ϕ) was obtained for the equation proposed by Pauly & Munro (1984): $\phi = \log k + 2\log L_{\infty}$. The longevity was estimated according to the equation proposed by Taylor (1958): $t_{\max} = t_0 + 2,996/k$.

Total mortality (Z), which is here defined as natural mortality (M), was obtained according to the empirical formula of Pauly (1980) which uses the information of the growth parameters (L_{∞} e k) and mean temperature ($^{\circ}\text{C}$) of the environment: $\ln M = -0,0066 - 0,279 \ln L_{\infty} + 0,6543 \ln k + 0,463 \ln T$. The mean water temperature, obtained in field in all samples was calculated at 23.8 $^{\circ}\text{C}$. The

recruitment pattern was obtained using the distribution of frequency of standard length and of the growth parameters (L e k) estimated for each species using the routine included on the software FISAT II.

Results

A total of 960 individuals of *Bryconamericus stramineus* were analyzed, including 316 males, 532 females, and 112 for which the sex could not be determined. The highest number of individuals was collected in October 2006, followed by February and August 2007 (Table 1).

During the entire sampling period, females were more frequent, with significant variations in the sex ratio during the year (Table 1). The proportion of females was higher ($\chi^2 = 32.82$; $p < 0.001$) especially in October and December.

The maximum standard length of males was 58.9 mm (median = 37.2 mm; sd = 8.066), with females reaching 59.7mm (median = 38.0 mm; sd = 8.314). The maximum total weight of males was 3.18 g (median = 0.67 g; sd = 0.525), and females reached 3.22 g (median = 0.74 g; sd = 0.568) (Figure 3).

The model produced for the variation of total weight as a function of standard length for males ($\text{Weight} = 0.0000749 * \text{SL}^{3.165}$) explained 97.8% of the data variation, and for females ($\text{Weight} = 0.0000424 * \text{SL}^{3.313}$) explained 97.7% (Table 2 and Figure 3). Both sexes showed an angular growth coefficient (b) higher than 3; males showed a confidence interval of b between 3.25 to 3.37, and females varied from 3.12 to 3.21, showing a positive allometric growth (Figure 2). Considering the confidence interval for the angular growth coefficient, females showed a higher rate of weight increase as a function of length than did males.

The co-variance analysis showed that the seasonal variation over the year interacting with standard length had a significant influence on the total weight of both sexes. The calculated mean adjusted weight

Table 1. Abundance of individuals, sex ratio (females:males) and χ^2 of sex ratio of *B. stramineus* by sampled month in the Guirai River basin, upper Paraná River basin. ns = non significant; ** = significantly at $\alpha = 0.01$; significantly at $\alpha = 0.001$.

Month	Number of individuals	Sex ratio	χ^2
October	277	2.14	16.33 ***
December	135	2.22	8.35 **
February	231	1.42	2.85 ns
April	96	1.10	0.10 ns
June	161	1.46	2.41 ns
August	60	1.90	2.79 ns

Table 2. Results of co-variance analysis of the weight of males and females of *B. stramineus* as a function of the seasonal variation and Standard Length (LS) for the streams studied in the Guirai River basin, upper Paraná River basin, between October 2006 and August 2007. *** = Significant at $\alpha < 0.001$.

Sexes	N	R ²	F-months	F-Standard length
Males	316	0.986	9.079***	17525.1***
Females	532	0.988	14.43***	30552.3***

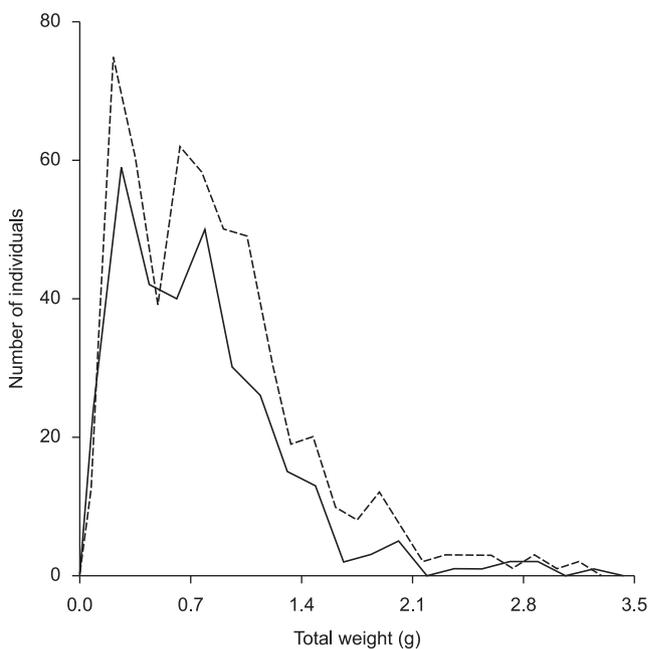
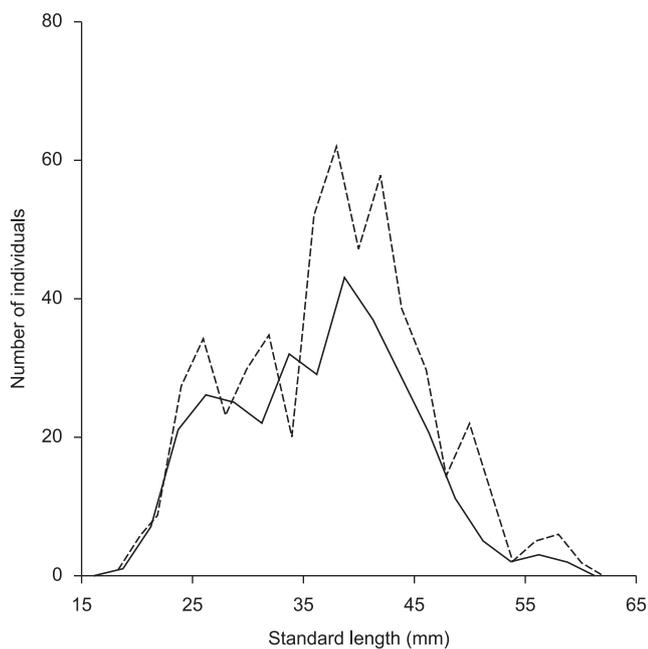


Figure 2. Density plot of Standard Length (mm) and Total weight (g) for males (solid line) and females (dotted line) of *B. stramineus* in streams in the Guirai River, upper Paraná River basin from October/2006 to August/2007.

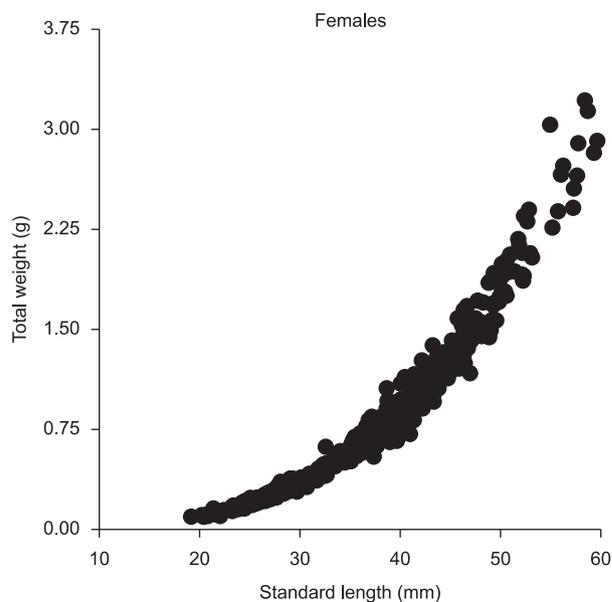
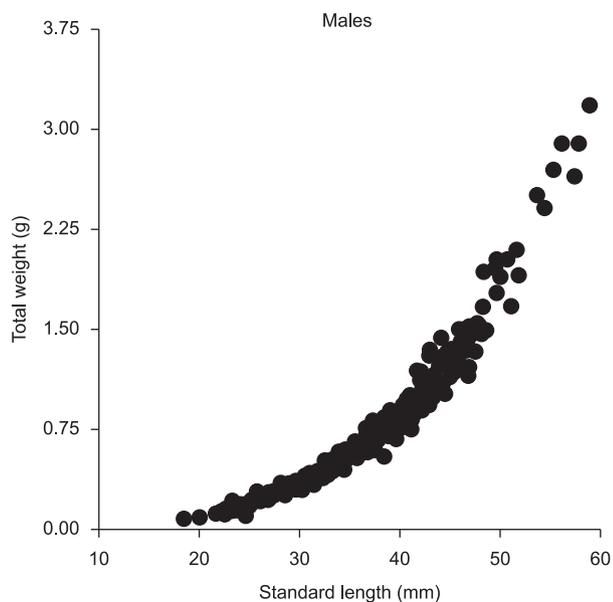


Figure 3. Length-weight relationships for males and females of *B. stramineus* in streams of the Guirai River, upper Paraná River basin from October/2006 to August/2007.

for females was greater than that for males. In December, both sexes showed lower values (Figure 4).

The logistical regression of the proportion of mature females as a function of standard length yielded an estimate for the mean length at which 50% of females are sexually mature of 35.1 mm (Figure 5).

Through analysis of the variation in the gonadal maturation stages, it was estimated that around 50% of females were mature in October, with a gradual reduction in their frequency until June, when no mature female was found (Figure 6). This suggests that gonadal maturation takes place mainly between October and February, with subsequent spawning mainly from April to August.

The mean fecundity was estimated at 313 eggs/female and the absolute fecundity ranged from 187 to 844 eggs on females measuring from 31.6 to 59.7 mm. The mean of the relative fecundity was 184.6 eggs/g, and, although we have found a statistically strong correlation between the fecundity and the standard length of females (Spearman $r = 0.736$; $p < 0.001$), our chart showed widely

scattered points, which makes the interpretation of this correlation less significant (Figure 7).

The asymptotic length (L_{∞}) of *B. stramineus* was estimated at 62.8 mm and the growth rate (K) at 0.76. The growth performance index (ϕ) was calculated at 3.47, the longevity at 3.94 years and the natural mortality (M) at 1.18. The recruitment pattern of the species showed peaks concentrated in periods of low rainfall (Figure 8).

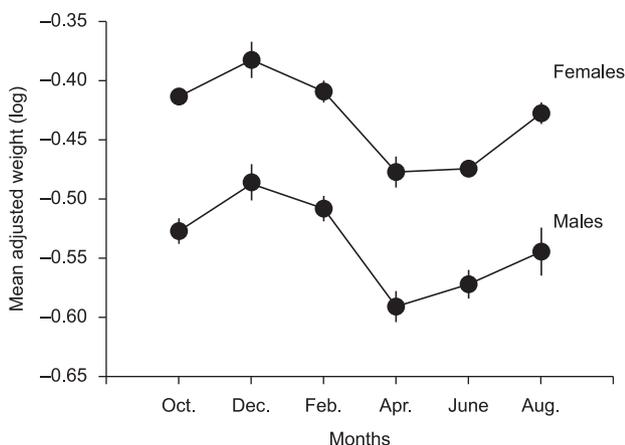


Figure 4. Mean adjusted weight and confidence interval for males and females of *B. stramineus* during the sampling months in the Guiraí River, upper Paraná River basin from October/2006 to August/2007.

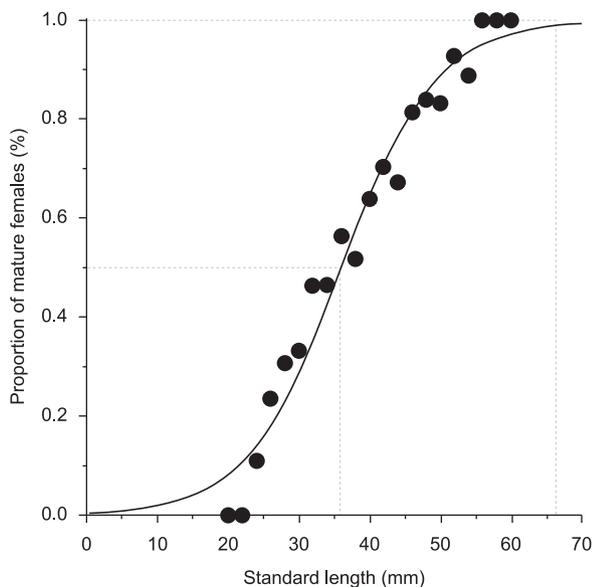


Figure 5. Proportion of mature females as a function of Standard Length of *B. stramineus* in streams of the Guiraí River, upper Paraná River basin.

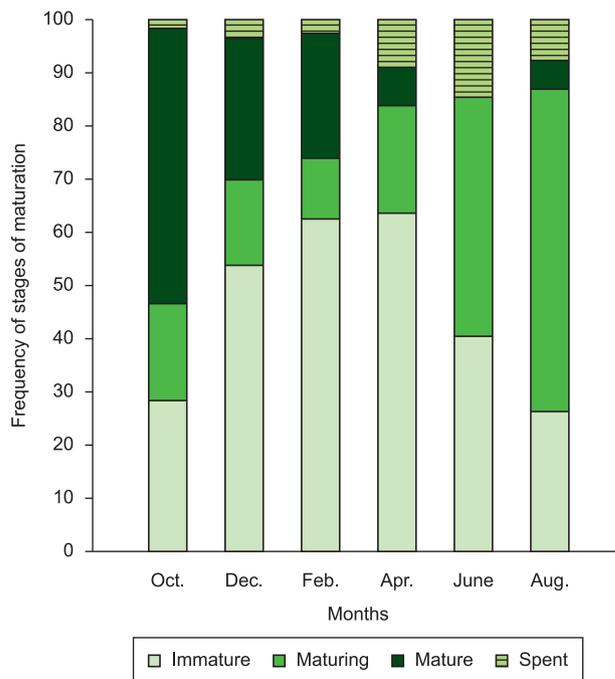


Figure 6. Frequency of the four maturation stages in females of *B. stramineus* in streams of the Guiraí River, Upper Paraná River basin, from October/2006 to August/2007.

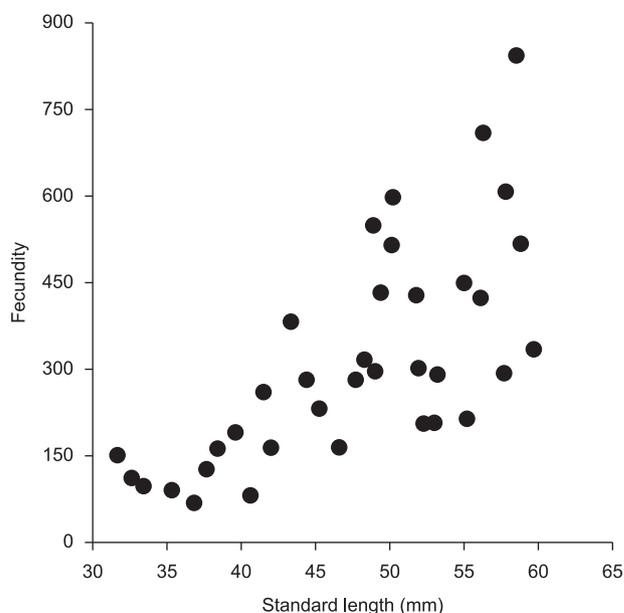


Figure 7. Scatterplot of fecundity in function of standard length of females of *B. stramineus* in streams of the Guiraí River, upper Paraná River basin, from October/2006 to August/2007.

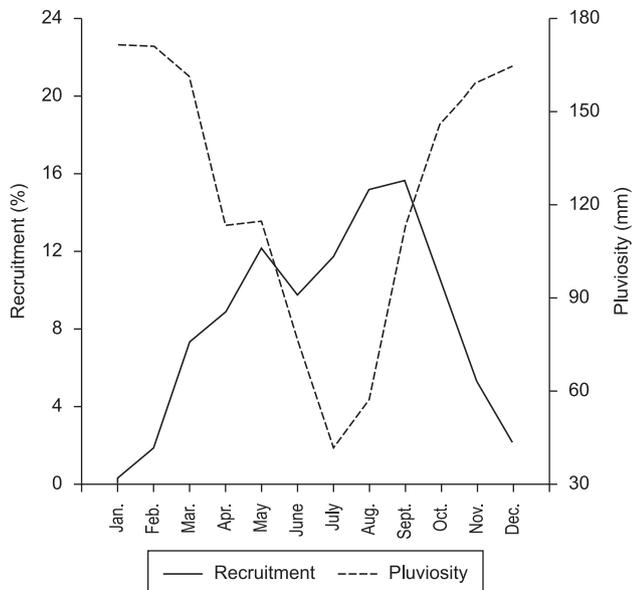


Figure 8. Temporal variation in recruitment estimated for *Bryconamericus stramineus* and pluviosity over the year in streams of the Guiraf River, upper Paraná River basin, from October/2006 to August/2007.

Discussion

The sex ratio differed from 1:1, which is commonly observed on fishes studies (Vazzoler 1996), during the entire sampling period, with a higher proportion of females. In a study about reproductive ecology of *Astyanax fasciatus*, Gurgel (2004) suggests that differences in sex ratio during the reproductive period are due to the increase in the weight of the gonads of females, which make them more susceptible to capture. However, this idea is not applicable to our study, due to the small mesh size used, and also because the active sampling minimized this possibility. The higher proportion of females may be a strategy of this species to replace losses from predation (Vazzoler 1996), what is expected for small sized species. Females predominance may occur as a result of high food availability (Fernandez et al. 2003) as a strategy to speed population growth. However, both hypothesized factors may interact, leading to the observed predominance of females in *B. stramineus*. Additionally, the sexes may show differences in spatial distribution, with females occurring in areas that were not sampled out of the breeding season; then during the breeding season, both sexes are concentrated in the areas that were sampled, resulting in the higher proportion of females found.

Braga et al. (2006) suggested that mortality rate and growth can act differently on the sexes, also creating differences in the sex ratio. In this study the angular growth coefficient (b) of both sexes of *B. stramineus* was estimated at higher than 3 and males presented faster grew than females. According to Santos et al. (2002) this fact may be related to competitive advantages and reduction of vulnerability to predators, as in these streams, it was observed that females reach larger sizes and consequently a higher total weight compared to males of the same standard lengths. This tendency can be explained because females of species without parental care usually expend much more energy on reproduction than males.

According to Pauly (1980), the natural mortality is a result of three factors: "physiological" mortality caused by diseases, old age or both (ignoring predation), "selective" mortality of individuals less resistant to diseases because of advanced age, or both, making them more accessible to predators, and "chance" mortality, which

unrelated to any physiological mechanisms, and proportional only to the number of possible encounters with potential predator. This last one may be conceived of as the main component of natural mortality in small-sized fishes which tend to be low in the food chain and have a large number of predators. Due to the small size of *B. stramineus*, as well as for the two species *Astyanax* studied by Lizama & Ambrósio (2004), the high mortality rate can be assigned to "chance" mortality.

When individuals are born they invest in physical growth, and it is assumed that, being small in size, they are more vulnerable to predation, and the more rapidly they reach theoretical length, the greater are their chances of survival (Costa & Araújo 2003). Therefore, when they reach sexual maturation, part of the stored energy is channeled into reproductive events, which leads to the reduction of growth rate (Vazzoler 1996).

Usually, the data concerning fecundity do not take into account the individual's size or weight, or even if the fecundity value refers to an oocyte batch or to the whole reproductive period. This makes comparisons among species all the more difficult. Fecundity can be a variable characteristic. It can change among species and within individuals of the same species. Also, it can change among individuals of the same size within a reproductive period, between successive reproductive periods as well as with latitude (Vazzoler 1996, Lampert et al. 2004, Lampert et al. 2007). However, all these studies cited showed that fecundity was positively influenced by female size, corroborating the hypothesis of higher reproductive investment by larger individuals (Wootton 1999).

In this study, the relative fecundity of *B. stramineus* was estimated in 184.6 eggs/g (= 0.18 eggs/mg). Lampert et al. (2007) calculated a relative fecundity of 0.35 oocytes/mg for the same species in the Ibicuí river, RS. In a study about *B. iheringii* in the Vacacaí river, RS, Lampert et al. (2004) estimated a relative fecundity of 0.36 oocytes/mg. Mazzoni & Silva (2006) estimated a relative fecundity of 110 eggs/g (= 0.11 eggs/mg) for *B. microcephalus* in Atlantic Rainforest streams. According to Nikolskii (1969) different populations live under different conditions and so naturally differ in fecundity. Nikolskii (1969) also said that the differences between populations of a give species (and also of similar species with similar protection from enemies) reflect the food supply and exposure to predators. So, we can interpret the differences found in fertility in these studies as a response of species to environmental characteristics and pressures to which they are subjected.

The seasonally also influences on the population aspects of species. The influence of seasonal variations on the weight of individuals is considered a result of changes in resource availability, interacting with reproductive activity (Braga et al. 2006). In the present study, the seasonal variation noted in the mean adjusted weight of individuals was equivalent in males and females, suggesting that feeding dynamics were more important than reproduction, even though females had higher mean adjusted weight than males. A further corroboration of this hypothesis is the fact that the highest mean adjusted weight was observed in December, whereas the largest number of mature females was observed in October.

This population showed a polymodal pattern of length and weight, although three more cohesive modal groups were observed, with two smaller peaks for each one. Associated with these smaller peaks, the frequency of the stages of maturation during the months showed that the species has a relatively long breeding season, although the highest frequency of mature females was observed in October. Therefore, it is possible to infer that either this population shows a spawning split during the rainy season, or part of the population reproduces in the beginning of the rainy season while another part must accumulate energy in this period in order to reproduce later. This second possibility would lead to the existence of different age

classes in the population, clearly distinguishable by the histogram of length. However, only histological analyses and analyses of the type of spawning can allow us to define the existence of different size classes of eggs in the ovaries.

Although its breeding season is relatively long, this species showed higher reproduction peaks between October and February. In the same way, Lampert et al. (2007) found that *B. stramineus* in Rio Grande do Sul has peaks of mature females between September and December, probably being also influenced by rainy season, with higher temperatures providing better body conditions for reproduction.

Thus, the small size of *B. stramineus* has great influence on various attributes of life history of the species, as a higher proportion of females as a strategy to restore the population losses by predation, the production of the more offspring it is possible to increase the probability of survival of offspring, the rapid growth to try to evade predation, and also the mortality occurring especially by risk factors. The population and reproductive strategies adopted by this species probably account for its wide distribution and high density found in the streams of the upper Paraná River basin.

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