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Temporal distribution of ichthyoplankton in the Forquilha river, upper Uruguay river – Brazil: Relationship with environmental factors

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ABSTRACT. This study aimed to evaluate the temporal distribution of fish eggs and larvae in the Forquilha river (upper Uruguay river/Brazil) and its relationship with environmental variables. Ichthyoplankton and abiotic factors were sampled from September 2006 to August 2007. At the laboratory, samples were sorted and larvae were identified to the lowest possible taxonomic level. For data analysis we applied One-way Anova, Tukey's test, Pearson correlation and PCA. In this study 200 eggs and 308 larvae were collected, showing differences in the temporal distribution and influence of abiotic factors. Larvae were identified in all stages of development, being distributed in three order and eight families. These results point that the lower portion of the Forquilha river is an important drift and nursery area for fish larvae of the upper Uruguay river. The breeding season for most species was greatly marked, between October and January, coinciding with the increase in temperature and decrease of the water flow. The response of reproductive intensity varies according to the environmental variables.

Keywords: eggs and larvae, fish, reproduction, abiotic variables.

Distribuição temporal do ictioplâncton no rio Forquilha, alto rio Uruguai – Brasil: Relação com os fatores ambientais

RESUMO. Este trabalho teve por objetivo avaliar a distribuição temporal de ovos e larvas de peixes no Rio Forquilha (alto rio Uruguai/Brasil) e sua relação com as variáveis ambientais. As coletas de ictioplâncton e as aferições das variáveis ambientais ocorreram mensalmente no período de setembro de 2006 a agosto de 2007. Em laboratório, as amostras coletadas foram triadas e as larvas identificadas ao menor nível taxonômico possível. Para analisar os dados foram aplicadas a Análise de Variância Unifatorial, o teste de Tukey, PCA e a correlação de Pearson. Foram coletados 200 ovos e 308 larvas, que apresentaram diferença na distribuição temporal e influência das variáveis abióticas. Foram identificadas larvas em todos os estágios de desenvolvimento, estando distribuídas em três ordens e oito famílias. Os resultados apontam que a região inferior do rio Forquilha é um importante local de deriva e de berçário para as larvas dos peixes do alto rio Uruguai. O período reprodutivo para a maior parte das espécies foi bem marcado, ocorrendo entre os meses de outubro e janeiro, e coincidindo com o aumento da temperatura e redução da vazão da água. A resposta da intensidade reprodutiva varia de acordo com as variáveis ambientais.

Palavras-chave: ovos e larvas, peixes, reprodução, variáveis abióticas.

Introduction

For a good understanding of the reproductive behavior of fish and its relationship with the environment, it is essential to know about their spawning areas and periods, as well as about the influence of environmental mechanisms on this process (BIALETZKI et al., 2005; SANTIN et al., 2009). Studies on the ecology of fish eggs and larvae have great importance for determining both these areas and the behavior of fish (BIALETZKI et al., 2005; REYNALTE-TATAJE et al., 2012).

Abiotic factors have great effect on the early stages of fish life cycle (SANTIN et al., 2009) and can accelerate or delay fish reproductive process, and affect the hatching of eggs, larval development, species growth and survival (BAUMGARTNER et al., 2008). Reproduction of freshwater fish, independent on the strategy used, is highly cyclical, where the periodicity patterns are related to environmental conditions to which animals are exposed (SANTIN et al., 2009; REYNALTE-TATAJE et al., 2012).

Many environmental variables can influence the reproductive success (VAZZOLER et al., 1997). For temperate environments, changes in the reproductive period are closely related to photoperiod, water temperature (GUERRERO et al., 2009) and food availability (TONDATO et al., 2010). In the tropical region, the increase in water level, rainfall and electrical conductivity are considered decisive factors for reproductive periodicity of fishes (SUZUKI et al., 2009). As an example, Hermes-Silva et al. (2009) conducted a study in the upper Uruguay river and concluded that species that migrate for reproduction have the onset of gonadal maturation with increased temperature, but they only begin migration after the first rain of the season.

However, for some Brazilian river basins, as the Uruguay, most of these works regard juveniles and adults, thus, there are only a few works that address the temporal distribution of eggs and larvae.

Knowing the distribution of ichthyoplankton within an annual cycle in a hydrographic basin may be a valuable tool for determining the reproductive period of the species that inhabit a particular region. In Brazil, the works of Santin et al. (2009) in the Pantanal region of the Brazilian state of Mato Grosso, and the works of Bialetzki et al. (2005) and Reynalte-Tataje et al. (2011) in the upper Paraná river, are all related to the distribution of these organisms over time.

Some studies have been conducted for the upper Uruguay river; however, these studies focus on the main river channel and mouths of tributaries. There are few studies on the tributaries, and these are important water bodies, because they serve as an alternative route for migratory species (CORRÊA et al., 2011). Thus, this work aims at assessing the temporal distribution of eggs and larvae in the Forquilha river, an important tributary of the Uruguay river and the first upstream of the Machadinho dam, and its relationship with environmental variables.

Material and methods

The collection of ichthyoplankton was performed from September 2006 to August 2007 in the Forquilha river with the sampling point located at 7 km from its mouth. This point in the river is within the city of Maximiliano de Almeida (Rio Grande do Sul State, Brazil). It is a tributary of the Uruguay river that flows into the reservoir of the Machadinho Hydroelectric Power Plant (upper Uruguay river, Brazil) (Figure 1). The region at the sampling point is characterized as a lotic environment, where a waterfall is the separation between this site and a lentic environment, directly affected by the reservoir of UHE and located closest to the river mouth.

Samples were collected by means of surface trawling using 500 μm cylindrical conical nets, which were dragged by boat for 30 minutes from 9-10 pm (CORRÊA et al., 2011). This time of collection was chosen due to the greater abundance of eggs and larvae on the water surface at night (HERMES-SILVA et al., 2009). The collected material was stored in 500 mL bottles containing 4% formalin.

The abiotic variables water temperature (°C), dissolved oxygen (mg L^{-1}) and pH were measured using a multiparameter probe. Rainfall (mm) and flow (m^3 s^{-1}) data were acquired from the records provided by ANEEL (National Electric Power Agency). Both the values of water quality and ichthyoplankton sampling, however, were obtained by the field staff at same time.

In the laboratory, samples were sorted using a stereoscopic microscope and a Bogorov counting chamber. Larvae and eggs found were separated and quantified. The identification of larvae was performed to the lowest possible taxonomic level and the classification of development was made according to Nakatani et al. (2001). For the genus *Hypostomus*, in this study, it was only considered specimens with less than 50 mm. The reproductive strategies of the species found were verified, being classified as short distance migrant (SD), sedentary (S) and unknown (UNK) for the species without such information (REYNALTE-TATAJE; ZANIBONI-FILHO, 2008).

The abundance of ichthyoplankton was standardized to a volume of 10 m^3, and only the larvae identified at least to the genus level were considered for the analysis.

To assess differences in arithmetic mean of monthly abundance ($\log_{10} x + 1$; dependent variable) of eggs and larvae, a univariate analysis of variance (one-way ANOVA) was applied, having as independent factor the months of the year. When the results of ANOVAs were significant, the Tukey's test was applied to assess differences in the abundance of ichthyoplankton between the months.

In order to test the association of environmental variables (biotic and abiotic) with the abundance of total eggs, total larvae and specific taxas, Pearson correlations were run. Previously, a Principal Components Analysis (PCA) was applied with the intent of reducing the dimensionality of environmental variables. To reduce the variability of data, all variables, except pH, were previously log-transformed ($\log_{10} x + 1$) to linearize the relationships between variables. Only the axes with eigenvalues higher than those generated at random were retained for interpretation (Broken-Stick criterion) (JACKSON, 1993). Environmental variables with structure coefficients above 0.4 were considered biologically significant (HAIR et al., 1984).

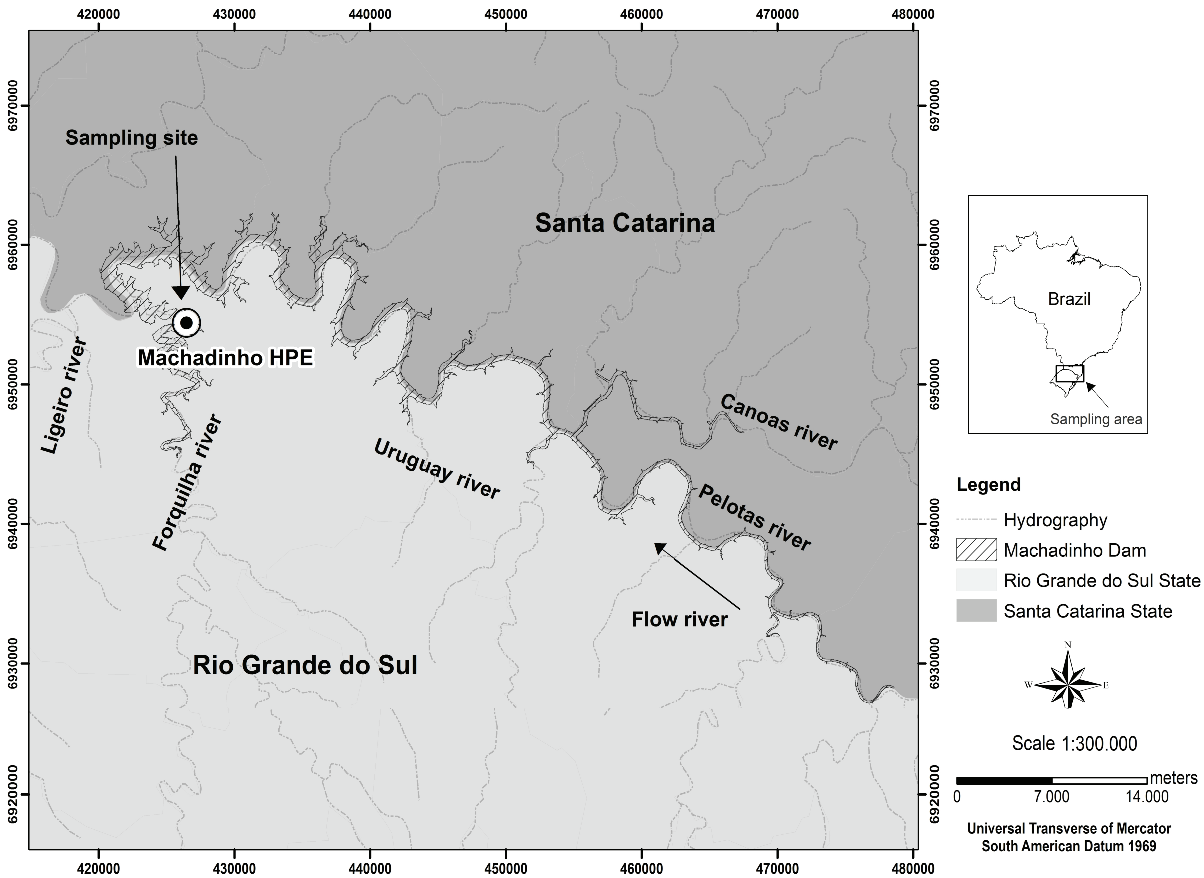

Figure 1. Location of the sampling site at the Forquilha river (Rio Grande do Sul State, Brazil).

Results

Environmental variables

The environmental variables pH and dissolved oxygen showed no significant variations between the profiles. The mean temperature was highest in January (25.8 ± 0.75ºC) and lowest in June (13.3 ± 1.21ºC). The highest rainfall was recorded in July (4.57 ± 0.0 mm) and lowest in January (1.29 ± 0.0 mm). Water flow was higher in colder months and lower in warm months.

Taxonomic composition of ichthyoplankton

During the study period, 200 eggs and 308 larvae were captured. Of the total larvae collected, 59.6% represented the order Characiformes and 38.3% the order Siluriformes. Larvae of the order Perciformes comprised 2.1% of the total. Five groups were identified to the genus level and ten to the species level, which were distributed in eight families. Among the identified families, Characidae showed the highest number of taxa, five species (Table 1).

The predominance of eggs and larvae of small sized species were recorded, followed by those of medium size, like *Hypostomus* spp., *Pimelodus* spp., *Rhamdia quelen* and *Schizodon* aff. *nasutus* (ZANIBONI-FILHO et al., 2004). Large migratory species were not found in this study.

In relation to larval development, all the stages were recorded, but the highest proportion was of larvae in the initial stage of development (Figure 2).

Seasonal variation of eggs and larvae and of the main taxa

Throughout the study an average of 0.69 eggs 10 m^{-3} and 1.06 eggs 10 m^{-3} were captured. ANOVA detected significant differences in the temporal distribution of eggs ($F = 3.67$, $p < 0.05$) and larvae ($F = 7.18$, $p < 0.05$). Ichthyoplankton organisms appeared from September to March (Table 1). In general, eggs were collected between October and January, with the highest densities in December (Tukey, $p < 0.05$) (Figure 3A). Larvae were present from September to March, most abundantly in October and January (Tukey; $p < 0.05$) (Figure 3B). The genera with the widest range of temporal distribution were *Astyanax* spp. and *Bryconamericus* spp., recorded in four months. The species found at the beginning of the reproductive period were *Astyanax fasciatus*, *Astyanax* gr. *scabripinnis*, *Bryconamericus iheringii* and *O. jenynsii*, however, *Rineloricaria* sp. was the only one with larvae in March.

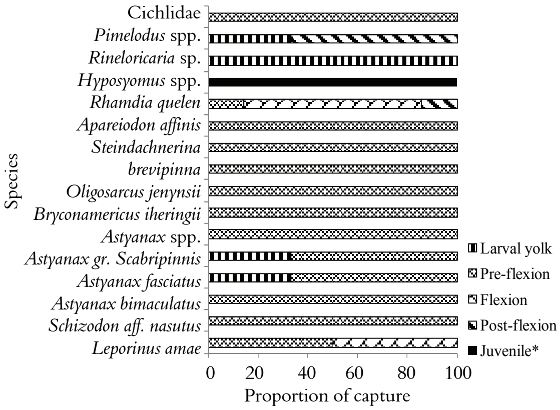

Figure 2. Proportion capture (%) of fish larvae in different stages of development recorded in the sampling site of Forquilha river, between September 2006 and August 2007. *In this study, only juveniles of the genus *Hypostomus* spp. were considered.

Relationship between environmental variables and eggs and larvae

According to the PCA, only axes 1 and 2 showed greater eigenvalues than those generated at random and were retained for interpretation. These two axes together explained 95.9% of data variability. The first axis (PCA1) had an eigenvalue of 2.03 and explained 67.7% of the variability, in which the variable that most positively contributed was water temperature (r = 0.62) and the one that most negatively contributed was water flow (r = -0.67). The second axis (PCA2) had an eigenvalue of 0.84 and explained 28.2% of data variability. In this axis, rainfall (r = 0.90) was the variable that most positively contributed (Figure 4).

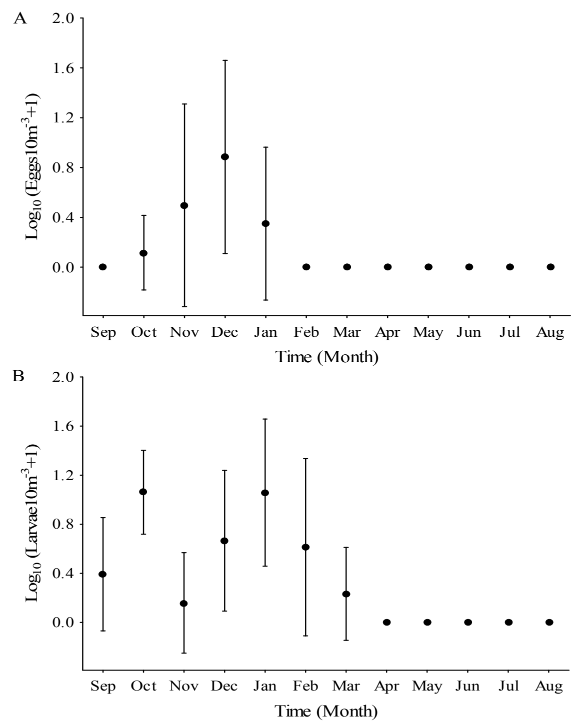

Figure 3. Mean density (± standard error) of eggs (A) and larvae (B) of fish in the Forquilha river (upper Uruguay river / Brazil), from September 2006 to August 2007.

Table 1. Taxonomic composition, reproductive strategy (R.S.) and monthly mean density of fish larvae captured from September 2006 to August 2007 in the Forquilha river (upper Uruguay river, Brazil). SD = Short distance migrant, S = Sedentary and UNK = Unknown.

Taxonomic composition	R.S.	Monthly mean density (number of larvae 10m³)[1]						
		Sep	Oct	Nov	Dec	Jan	Feb	Mar
Characiformes								
Anostomidae								
Leporinus amae	SD		0.029			0.042		
Schizodon aff. *nasutus*	S				0.042			
Characidae								
Astyanax bimaculatus	S		0.083		0.042	0.029	0.375	
Astyanax fasciatus	S	0.083			0.042			
Astyanax gr. *scabripinnis*	SD	0.042	0.029		0.029	0.042		
Astyanax spp.	UNK				0.042			
Bryconamericus iheringii	SD	0.042						
Bryconamericus spp.	UNK		0.125		0.042			
Oligosarcus jenynsii	S	0.029	0.042					
Curimatidae								
Steindachnerina brevipinna	SD		0.042				0.042	
Parodontidae								
Apareiodon affinis	SD		0.042					
Siluriformes								
Heptapteridae								
Rhamdia quelen	SD		0.042	0.083	0.167			
Loricariidae								
Hypostomus spp.	UNK		0.042			0.542	0.333	
Rineloricaria sp.	S							0.125
Pimelodidae								
Pimelodus spp.	UNK		0.083		0.042	0.042		
Perciformes								
Cichlidae	UNK		0.042					

[1]There was no capture of eggs and larvae from April to August.

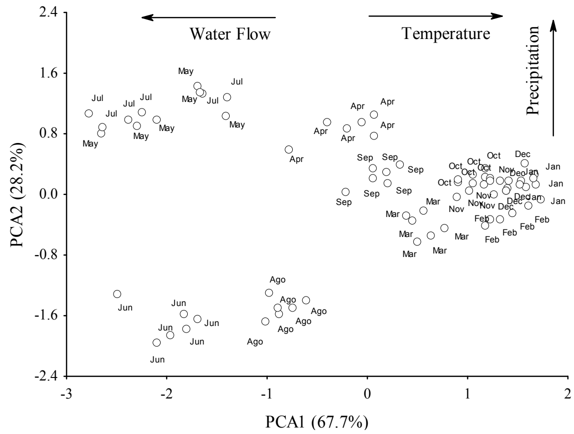

Figure 4. Principal Component Analysis (PCA) of the environmental variable matrix recorded in the Forquilha river (upper Uruguay river / Brazil), from September 2006 to August 2007. Months of the year: Jan = January, Feb = February, Mar = March, Apr = April, May = May, Jun = June, Jul = July, Aug = August, Sep = September, Oct = October, Nov = November, Dec = December.

Water temperature was positively correlated with increased density of eggs ($r = 0.26$, $p < 0.05$) and larvae ($r = 0.51$, $p < 0.05$). Water flow was negatively correlated with the abundance of eggs ($r = -0.35$, $p < 0.05$) and larvae ($r = -0.52$, $p < 0.05$) and rainfall had an inverse relationship only with the abundance of larvae ($r = -0.26$, $p < 0.05$), showing no significant relationship with the density of eggs ($r = 0.14$, $p > 0.05$). Among the species, *O. jenynsii* and *B. iheringii* presented a direct relationship with increased flow ($r = 0.44$, $p < 0.05$ and $r = 0.71$, $p < 0.05$, respectively) and lower temperature values ($r = -0.39$, $p < 0.05$ and $r = -0.42$, $p < 0.05$, respectively). The representatives of the genus *Hypostomus* sp. and *A. bimaculatus* were directly related to water temperature ($r = 0.64$, $p < 0.05$, $r = 0.55$, $p < 0.05$, respectively) and inversely to flow ($r = -0.41$, $p < 0.05$ and $r = -0.37$, $p < 0.05$, respectively).

Discussion

In the upper Uruguay river, although many studies have been conducted in the main river channel and several tributaries, few sites were considered to be larvae drift and nursery areas (SILVA et al., 2012). In the region of the Uruguay river, studies show a greater abundance of eggs compared to larvae in the different sampled habitats (CORRÊA et al., 2011; HERMES-SILVA et al., 2009; SILVA et al., 2012), and capture mean rate in the upper basin is 94% of eggs and only 6% of larvae (REYNALTE-TATAJE et al., 2008). The lack of environments with larvae or low rates on this stage has raised doubts about the presence of rearing areas in the upper basin, or about the characteristics of such areas. Reynalte-Tataje et al. (2008) suggested that depending on the morphology and hydrodynamics of the lower tributaries, they may serve as spawning or nursery environments.

Differently to that found in other environments in the upper Uruguay river, the environment of Forquilha river shows a greater abundance of larvae compared to eggs. Due to the large proportion of larvae captured in the initial stages of development, this place can be considered as a larval drift area. However, it can also serve as a nursery area for some species, as *Pimelodus* spp. and *R. quelen*, since their specimens were found in advanced developed stages. In other basins, the lower portion of the rivers can also be used as rearing areas, since they have food and shelter to ensure growth, survival and success in recruiting (COPP, 1992; CORRÊA et al., 2011). Thus, capture rates of different phases of the early stages of fish may vary according to sampling sites. This was demonstrated by Baumgartner et al. (2004), who stated that two tributaries of the Paraná basin are used as spawning grounds, while the reservoir and channel areas of the Paraná river are locations for juvenile development.

Several studies in the Prata basin showed that ichthyoplankton drift is highly seasonal, with highest densities in spring and summer (BIALETZKI et al., 2005; REYNALTE-TATAJE et al., 2011). Greatest reproductive activity of fish in the upper Uruguay river, during spring and summer, was reported by Hermes-Silva et al. (2009) and Reynalte-Tataje et al. (2012), who noted that the period from October to February was the most intense.

In this study, the components of ichthyoplankton presented differences in their temporal distribution. Thus, while larvae were found in seven months of the year, eggs were found only in the peak of the reproductive period (October-January). The lack of eggs out of this period, as well as seasonality, may be related to the inefficiency of the sampling methodology used to capture fish dense eggs, such as *A. bimaculatus* and *Hypostomus* spp., which have extensive reproductive period and spawn in the marginal area. The regular equipment, used in this work, is more efficient in capturing semi-dense or free eggs that are in the drift.

Ichthyoplankton temporal distribution is directly related to environmental variables, given the influence on physiological and behavioral responses of organisms (VAZZOLER et al., 1997). Variables such as the photoperiod, the hydrodynamics of the river and water temperature are essential to determine the occurrence, density and growth in the early stages of fish life (HUMPHRIES et al., 1999; REYNALTE-TATAJE et al., 2011). In the environment studied, the abundance of eggs and larvae showed a significant seasonal variation, coinciding with the highest values of water temperature (when the photoperiod is longer) and inversely related to river flow.

In the Prata basin there are watersheds, as those from the Paraná basin, where floods coincide with the highest temperatures of the year (REYNALTE-TATAJE et al., 2011). However, there are also regions, such as the upper Uruguay river, where floods occur when water temperature is still low (REYNALTE-TATAJE et al., 2008). In the first case, fish spawning and larval development could take advantage from the effect of floods, which promote the input of nutrients (LOWE-MCCONNELL, 1999) and expansion of space, with greater availability of sites for growth and protection. In the second case, the species seem to prefer to spawn when the temperature is high, regardless of water flow. In the Forquilha river, the presence of eggs and larvae is directly related to increased temperature, indicating that for most of those species, this factor acts as a key trigger. This pattern has been observed for most of the rivers located in the upper Uruguay (HERMES-SILVA et al., 2009; CORRÊA et al., 2011) and upper Paraná (VAZZOLER et al., 1997).

However, despite the general existing trends for the fish community, the differences among the reproductive strategies within a community, allow populations to respond to environmental variables at a regional level (REYNALTE-TATAJE et al., 2008). When the abundance of each species was separately correlated with environmental variables, some of them presented correlations. *B. iheringii* and *O. jenynsii* showed higher densities with increased water flow and low temperature. The greatest occurrence of larvae of these species in late winter and early spring, when water flow values are usually high, was also recorded by Reynalte-Tataje et al. (2008).

Larvae of *Hypostomus* and *A. bimaculatus* had the greatest number of larvae under different environmental conditions. The larvae of these species were particularly abundant in the summer months, when the flow was reduced and water temperature was high. This fact can be related to their reproductive strategy, where the spawning of small groups of these species at different moments may increase the possibility that some larva find adequate environmental conditions to grow, and may also reduce intrinsic resource competition between individuals of the same species (REYNALTE-TATAJE et al., 2011). The positive relationship between water temperature and abundance of larvae of other species such as *Hypophthalmus edentatus, Plagioscion squamosissimus, Hoplias.* aff. *malabaricus, Pterodoras granulosus, S. nasutus* and *Leporinus friderici* was observed in other rivers of the Prata basin (BAUMGARTNER et al., 1997).

Due to the lack of eggs / larvae of large migratory species in this study, it is not clear the environmental factors that would allow these species to spawn in the upper Uruguay river. What seems clear is that, for most of small and medium-sized species, increased water temperature is crucial for the occurrence of reproductive activity.

Conclusion

This study allows us to conclude that the lower region of the Forquilha river is important larval drift and nursery areas for fish from the upper Uruguay river, especially for small and medium-sized species, that have a sedentary behavior or short reproductive migration. In the year of this research, the reproductive period for most species was well-defined and occurred from October to January, coinciding with increased water temperatures and reduced river flow. However, the response of reproductive intensity to environmental variables may vary according to the species.

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