Ichthyoplankton and limnological factors in the Cinzas River – an alternative spawning site for fishes in the middle Paranapanema River basin, Brazil

Ictioplâncton e fatores limnológicos no Rio das Cinzas – um local alternativo de reprodução para os peixes na Bacia do Médio rio Paranapanema, Brasil

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Abstract: From early spring to late summer 5 samplings were performed to characterize the ichthyoplankton distribution along the Cinzas River, a tributary of Capivara Reservoir. Eggs and larvae were sampled at dusk, midnight and dawn using stationary plankton nets. Adults and juveniles were collected with gill nets and their reproductive activity evaluated through macroscopic gonads analysis. Limnological data were simultaneously obtained. A total of 2572 eggs and 457 larvae were captured, mostly at midnight. Higher absolute number of eggs was found 61.5 km far from the mouth, and the maximum density at the river mouth. Relatively high amount of eggs was also collected in the upper sampling station (120 km from mouth) showing that the entire studied river stretch is used for fish spawning. Among the larvae Siluriformes were dominant, followed by Characiformes and Gymnotiformes. The most representative families were Pimelodidae and Anostomidae. Most larvae were found 31.5 km downstream the station with a maximum number of eggs. This indicates that the embryonic development is completed during the eggs derive. Temporally, the distribution was significantly different for eggs and larvae, and also spatially for eggs. Considering adults and juveniles, 25 taxa of Characiformes, 24 of Siluriformes, 5 of Gymnotiformes and 3 of Perciformes were identified. Correlation between eggs and percentage of sexually mature individuals was positive for most sampling stations. In general, the correlation analyses with the limnological variables demonstrated the coupling of fish reproduction with more productive and high water conditions, determined by intensive rain precipitation. Eggs were positively correlated with pH, nutrients, inorganic suspended solids, velocity, flow rate, turbidity and chlorophyll-*a* and negatively with conductivity and transparency. Larvae were negatively correlated with transparency and positively with inorganic suspended solids, velocity, flow rate and turbidity. A longitudinal degradation gradient (cumulative processes) in the river water quality was identified. This pattern was indicated by downstream increase in electric conductivity, nitrite and silicate and decrease in dissolved oxygen.

Keywords: fish eggs, fish larvae, ichthyofauna, water quality degradation.

Resumo: Desde o início da primavera até o final do verão, foram realizadas 5 amostragens para caracterizar a distribuição do ictioplâncton ao longo do rio das Cinzas, um tributário do reservatório de Capivara. Ovos e larvas foram amostrados ao entardecer, meia-noite e amanhecer, usando redes de plâncton estacionárias. Os adultos e juvenis foram coletados com rede de espera e sua atividade reprodutiva avaliada através da análise macroscópica das gônadas. Dados limnológicos foram simultaneamente obtidos. O total de ovos e larvas capturados foi de 2572 e 457, respectivamente, principalmente a meia-noite. O maior número absoluto de ovos ocorreu a 61,5 km da montante da foz e a densidade máxima na foz do rio. Quantidades de ovos relativamente elevadas também foram coletadas na estação de amostragem mais a montante (120 km da desembocadura), mostrando que todo o trecho estudado é utilizado para desova. Os Siluriformes predominaram entre as larvas, seguidos pelos Characiformes e Gymnotiformes. As famílias mais representativas foram Pimelodidae e Anostomidae. A maioria das larvas foi encontrada 31,5 km abaixo da estação com o maior registro de ovos, indicando que o desenvolvimento embrionário completa-se durante o processo de deriva. Temporalmente a distribuição foi significativamente diferente para ovos e larvas, e também espacialmente para ovos. Considerando-se os adultos e juvenis, 25 táxons de Characiformes, 24 de Siluriformes, 5 de Gymnotiformes e 3 de Perciformes foram identificados. A correlação entre ovos e indivíduos sexualmente maduros foi positiva para a maioria das estações de amostragem. Em geral, as análises de correlação com as variáveis limnológicas demonstraram o acoplamento entre a reprodução dos peixes e condições mais produtivas e de águas altas, determinadas pelo incremento das precipitações. A quantidade de ovos se correlacionou positivamente com o pH, nutrientes, sólidos suspensos inorgânicos, velocidade, vazão, turbidez e clorofila a e negativamente com condutividade e transparência. As larvas correlacionaram-se negativamente com transparência e positivamente com sólidos suspensos inorgânicos, velocidade, vazão e turbidez. Um gradiente longitudinal de degradação (processos cumulativos) na qualidade da água foi indicado por aumentos na condutividade elétrica, nitrito e silicato e decréscimo de oxigênio dissolvido.

Palavras-chave: ovos de peixes, larvas de peixe, ictiofauna, degradação da qualidade de água.

1. Introduction

The neotropical fish fauna is highly diversified as a consequence of a long and complex evolutionary process. Nevertheless, the fish assemblages of Brazilian rivers has been threatened by countless antropic actions, such as the destruction of marginal lagoons, floodplains and riparian forests, eutrophication, contamination and dam construction for hydroelectric power plants (Agostinho et al., 1992; Agostinho, 1994).

The impact of physical obstruction of rivers by dams on fish assemblages depends on the characteristics of the local biota as well as on the characteristics of the reservoir (Agostinho et al., 1999). Ferreira and Caramaschi (2006) reported remarkable reduction in reproductive indicators, gonadosomatic relation and frequency of maturation stages, for migratory species in Serra da Mesa Reservoir, Tocantins River (GO). A major problem for fishes in regulated rivers is the difficulty of downstream populations of migratory fishes to access the upstream spawning sites and appropriated habitats for their initial development. The construction of fish passage facilities (e.g. fish ladders), in order to mitigate the negative impacts of dams, is not a guarantee of a succeeded reproduction and population recruitment (Pelicice and Agostinho, 2008). Additionally, the movement of fishes through these mechanisms is basically unidirectional (Britto and Sirol, 2006).

The main rivers (Paraná, Grande, Tietê, Paranapanema, Iguaçu, and Uruguai) of the upper Paraná basin have been highly affected by the construction of several reservoir cascades. This interference deeply changed the limnological characteristics and the structure of the aquatic communities (Tundisi et al., 1993; Nogueira et al., 2006).

According to Agostinho and Zalewsky (1996), the maintenance of the ichthyofauna in the upper Paraná basin, especially of typical migratory species, is only possible in reservoirs with relatively long upstream free river stretches or receiving appropriated lateral tributaries. Vazzoler et al. (1997) demonstrated the importance of the tributaries free of damming that flow into the Paraná River as routes for several species of fishes. Baumgartner et al. (2004) studying spawning sites and natural nurseries for fishes upstream of Itaipu Reservoir, reinforced the idea of importance of tributaries for the maintenance of fish diversity and stocks in the upper Paraná River. According to Sato and Sampaio (2006) the conditions in the São Francisco River, downstream the Três Marias dam, are inappropriate for fish reproduction due to discharges of anoxic and colder waters from the reservoir hypolimnion. Only after the entrance of the Abaeté River the limnological characteristics (higher temperature and dissolved oxygen and lower transparency) become appropriate for fishes reproduction.

The construction of eleven cascade reservoirs in Paranapanema River changed the limnological structure and functioning of several river stretches, from typical riverine to lacustrine or semi-lacustrine conditions, and reduced the lotic environments to a few lateral tributaries (Nogueira et al., 2006). The completion of the Canoas Complex (Canoas I and Canoas II Reservoirs), in 1999, interrupted the last large river stretch free of damming (about 200 km) in the middle of the basin. Presently, the Capivara Reservoir, the largest one (576 km^2) of the Paranapanema River and located immediately downstream the Canoas Complex, has its lotic conditions restricted to a few tributaries, mainly the Cinzas and Tibagi. However, for this last river the construction of at least one reservoir for electric power generation has already been planned.

Large reservoirs of the Paranapanema basin are spatially complex systems (Henry and Maricatto, 1996; Nogueira et al., 1999), influencing directly the composition and distribution of the aquatic communities. In case of the fish fauna it has been observed a higher richness and abundance in the reservoirs upper zones (river-reservoir) (Carvalho and Silva, 1999; Britto and Carvalho, 2006).

In this context, the Cinzas River may have a major importance for the maintenance of the middle Paranapanema ichthyofauna. Preliminary investigations, as well as historical and popular reports, pointed to the fact that Cinzas River has an important role in the regional fish fauna preservation, supporting most of the species registered in the Capivara Reservoir (Duke Energy, 2001). The river relatively long course (at least 130 km without any high fall) and the position of its mouth – upstream (tail) zone of Capivara Reservoir and downstream zone of the Canoas I dam, support the hypothesis that the river could be functioning as an alternative route for fishes of the middle Paranapanema basin, especially after the Canoas Complex construction.

Information about a fish assemblage is not complete without adequate information on the species life history, including early stages. Nevertheless, studies on the neotropical ichthyofauna rarely contain information on all development stages (Nakatani et al., 2001; Nakatani et al., 2004). In the upper Paraná River only a few studies conducted by ichthyoplankton taxonomists resulted in a significant fraction of the fish assemblage composition identified in its larval stage (Baumgartner et al., 2004; Bialetzki et al., 2005). However, the interest in investigations on the distribution of fish eggs and larvae is rapidly increasing, mainly due to the high value of this information for the identification of spawning periods, reproductive habitats and nursery areas (Nakatani et al., 1997a; Baumgartner et al., 1997; Castro et al., 2002; Baumgartner et al., 2004; Bialetzki et al., 2005). For the upper Paraná basin, where most species have external fecundation and development and several spawning events (Agostinho et al., 1995; Suzuki et al., 2005), these studies can be useful for implementation of environmental programs focusing on fish conservation. Additionally, it should also be considered that tropical fish larvae can play an important role in the energy and mass transference in the aquatic food webs (Nakatani et al., 2005).

The main aim of the present study was to evaluate the importance of the Cinzas River as a reproductive site for fishes of the middle Paranapanema, through the analyses of the ichthyoplankton (eggs and larvae). The composition and reproductive condition of the ichthyofauna (juvenile and adult individuals) was also assessed. Finally, it was intended to characterize the limnological conditions along the river and its correlations with the abundance of eggs and larvae.

2. Material and Methods

The Cinzas River is one of the main tributaries of the Capivara Reservoir, in the middle Paranapanema basin. This river, located in the north of Paraná State, has a drainage area of 9.658 km^2. Figure 1 shows the position and denomination (abbreviations of local names) of the nine sampling stations. Eight of them were distributed along a 120 km stretch of the Cinzas River and one in the lower Laranjinhas River, its largest tributary. The most upstream sampling station was located 20 km below a natural barrier for fish displacement, a 20 m high fall in Tomazina municipality. The last sampling station was located in the Cinzas mouth, into the Paranapanema River. This point is about 100 km upstream of Capivara Reservoir dam and only 1 km downstream the Canoas I Reservoir dam.

The field work was carried out during five expeditions between September 2003 and March 2004 (spring-summer), with an approximated interval of 45 days. This period of the year comprises the reproductive activity of most species of fishes in the upper Paraná basin (Agostinho et al., 1995).

Eggs and larvae samples were collected at dusk (5:00 PM), midnight and dawn (6:00 AM) using conical plankton nets of 500 µm mesh size and superior aperture of 40 cm in diameter. The net remained exposed in a fixed position during 10 minutes, near the surface of the middle of the river channel. Simultaneously, it was measured (triplicates) the water surface velocity (displacement of a floating object) in order to estimate the sampled volume (area of the net aperture x water velocity). The density of eggs and larvae in the samples were standardized for a volume of 10 m^3 and they correspond to the sum of the 3 samplings (5:00 PM, midnight and 6:00 AM) in each site. The identification of the larvae of fish captured was performed at order and eventually at family level, following Nakatani et al. (2001).

The Kruskal-Wallis test (Statistica 6.0) (Statsoft, 2001) was used for detection of significant differences in the spatial and temporal distribution of eggs and larvae.

Juveniles and adult individuals were captured with gill nets (10 m length and mesh sizes of 30, 40, 50, 60, 70 and 100 mm) exposed from 5:00 PM to 6:00 AM of the next day. Individuals were immediately analyzed - macroscopic observations of the gonads development, in order to characterize their reproductive activity (maturity classes) (sensu Vazzoler, 1996). The following categories were considered: juveniles or with incomplete maturation of the gonads (pre-reproductive stages); with mature gonads (ready for reproduction); in a process of reproductive cells re-absorption (failure in reproduction) and with deteriorated gonads. The fishes identification was based on Britski et al. (1999), Reis et al. (2003) and Graça and Pavanelli (2007).

In each sampling station, at surface in the middle of the river channel, the following variables were measured in the mid afternoon, dusk, midnight and dawn: temperature, pH, dissolved oxygen and electric conductivity (Horiba U-22). In the afternoon it was also measured the water transparency (Secchi Disk), water velocity (displacement of a floating object) and sampled water for analysis of dissolved nutrients (nitrite, nitrate, ammonium, phosphate and silicate) (spectrophotometry), total nitrogen and phosphorus (Valderama, 1981; spectrophotometry), total chlorophyll-*a* (spectrophotometry), suspended solids (gravimetry), biochemical oxygen demand (Oxitop WTW) and turbidity (Tecnopon). An ordination analysis (PCA - Pcord 4.1) (McCune and Mefford, 1999) using limnological data (log_{10} X + 1; except for pH) was performed in order to identify spatial and temporal. The following symbols were used in the analysis: EC (electric conductivity), pH, DO (dissolved oxygen), T (temperature), Tr (transparency), TN (total nitrogen), TP (total phosphorus), PO_4 (soluble reactive phosphate), NO_2 (nitrite), NO_3 (nitrate), NH_4 (ammonium), Si (silicate), BOD (biochemical oxygen demand), IS (inorganic solids) and OS (organic solids). Rainfall and river flow data were provided by the meteorological station located in the municipality of Andirá (PR) (Duke Energy), in the lower Cinzas River basin.

Pearson correlation (r) among the total amount of eggs/larvae per sampling station and the limnological variables, as well as with total fish with mature gonads, was performed

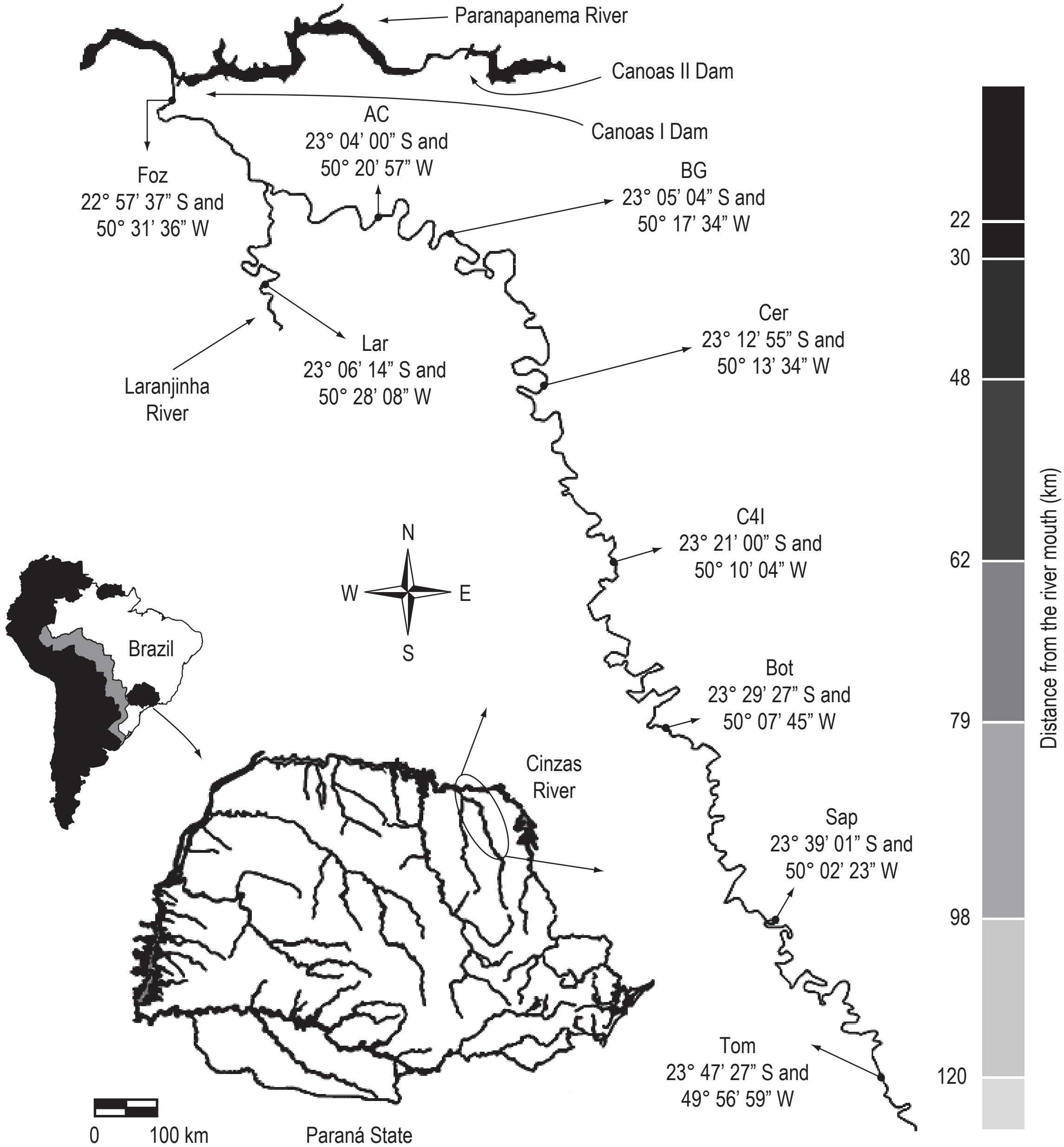

Figure 1. Geographical location of the Cinzas River and positioning of the sampling stations (Tom, Sap, Bot, C4I, Cer, BG, AC, Lar and Foz) in the Paraná State (PR).

(Statistica 6.0) (Statsoft, 2001). Only the significant correlations were mentioned in the results.

3. Results

3.1. Fish eggs

During the study 2572 eggs were collected (Table 1). Most captures occurred at midnight, reaching 99% in the lower Cinzas (stations AC and Foz) (Table 1).

There was a significant difference in the eggs (total captures) among the sampling stations was ($p = 0.041$). The highest number of eggs, 487, was collected at the station C4I, located 61.5 km upstream the mouth, in February and the highest density, 215.2 eggs/10 m^3, was observed in the Cinzas River mouth (station Foz), also in February (Table 1). Nevertheless, relatively high amount of eggs (e.g. 96.2 eggs/10 m^3 in December) was also collected in the most upstream station (Tom) around 120 km from the mouth. The station Bot was the site where eggs were captured in all sampling months, with a minimum of 8.0 eggs/10 m^3 in March and a maximum of 63.8 eggs/10 m^3 in September. At the station BG there was no eggs capture and at Cer it was recorded only 0.4 eggs/10 m^3 in September and 0.7 eggs/10 m^3 in February.

The difference among periods was also significant (p = 0.0081). Higher density of eggs occurred in summer (December) and late summer (February) (Table 1).

3.2. Fish larvae

Among the larvae the Siluriformes were dominant, with 394 captured individuals, followed by 61 Characiformes and only 2 Gymnotiformes (Table 2). Most Siluriformes belonged to Pimelodidae and among Characiformes to Anostomidae.

Most larvae were found at the station BG, 30 km from the river mouth. However, there was no statistically significant difference among the sampling stations (p = 0.19). The highest density of Siluriformes larvae was observed at BG station in February, with 40 ind.10 m^{-3}. At the station located in the lower Laranjinhas River, larvae of this order were captured in all samplings, with the lowest density in March, 0.6 ind.10 m^{-3}, and the highest in February, 16.3 ind.10 m^{-3}(Table 2). Tom was the only station where it was not captured Siluriformes larvae. At the station Lar it was found the largest density of Characiformes larvae, 10.3 ind.10 m^{-3} in February. At the station BG there was no capture of Characiformes larvae. The only two larvae of Gymnotiforms were collected in December at the stations C4I and Foz (Table 2).

Temporally, the difference in the larvae distribution was significant (p = 0.0375), with maximum capture in February (339) and minimum in March (7).

3.3. Fish assemblage composition and reproductive activity

The taxonomic list of the fish (juveniles and adults) captured in the Cinzas River basin during the present study is shown in Table 3. Fifty-seven different taxa (56 generic/infra-generic) were found, being 25 Characiformes, 24 Siluriformes, 5 Gymnotiformes and 3 Perciformes.

The number of captured fish and their reproductive state is presented in Table 4. Fish with mature gonads corresponded to 43.5, 54.7, 58.6, 38.9 and 2.6% of the captures in September, November, December, February and March, respectively. The stations with higher number of fish with mature gonads were BG and Laranjinhas at 30 and 20 km far from the Cinzas mouth, respectively.

3.4. Limnological variables

As seen in Table 5, a higher precipitation was registered during the sampling period of December, with 17.5 mm accumulated during the 3 days of sampling. In terms of river flow, the values in the mid summer (February – rainy season) were 4 folds higher the one in the early spring (September – end of dry season), reaching 82.2 m^3/s.

The limnological measurements are shown in Table 6 and Figures 2 to 5. Considering the first (Tom) and the last (Foz) sampling station the mean values of conductivity

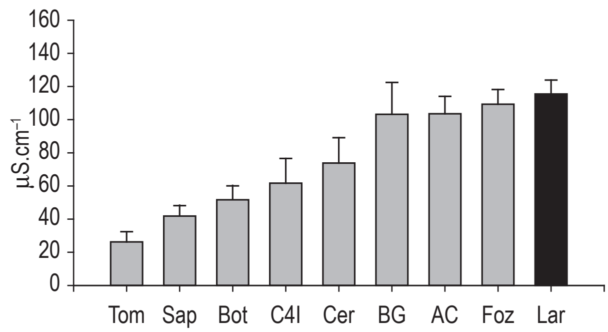

Figure 2. Longitudinal variation of conductivity (mean and standard deviation) (n = 20) in the Cinzas River (PR) (gray bars) and lower Laranjinhas River (PR) (black bar).

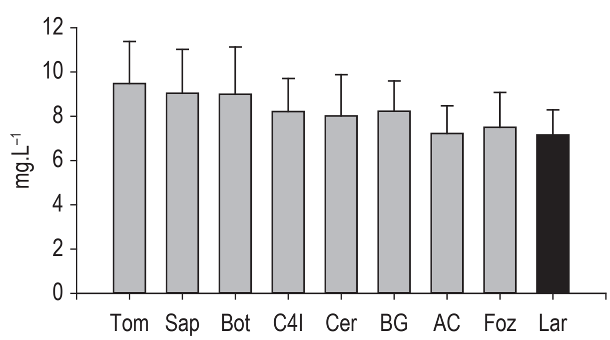

Figure 3. Longitudinal variation of dissolved oxygen (mean and standard deviation) (n = 20) in the Cinzas River (PR) (gray bars) and lower Laranjinhas River (PR) (black bar)

Table 1. Total number of fish eggs, density per 10 m^3 (in parenthesis) and percentage of captures at dusk, midnight and dawn along the Cinzas River (PR) and in the lower Laranjinhas River (PR).

Sampling station	September	November	December	February	March	Dusk (%)	Midnight (%)	Dawn (%)
Tom	0	0	183 (96.2)	1 (1.1)	0	39.1	58.2	2.7
Sap	144 (58.3)	118 (49.2)	214 (63.9)	7 (2.9)	0	9.1	61.7	29.2
Bot	58 (63.8)	22 (9.2)	111 (23.9)	51 (19.4)	24 (8)	23.7	68.0	8.3
C4I	0	0	280 (140.8)	487 (141.7)	1 (0.7)	2.5	84.5	13.0
Cer	1 (0.4)	0	0	3 (0.7)	0	0.0	50.0	50.0
BG	0	0	0	0	0	0.0	0.0	0.0
AC	29 (14.4)	0	257 (91.9)	94 (31.1)	0	0.3	99.4	0.3
Foz	0	0	33 (14)	379 (215.2)	0	1.0	99.0	0.0
Lar	2 (1.5)	1 (1.0)	13 (8.6)	59 (29.1)	0	1.3	22.7	76.0

Table 2. Total number of fish larvae, density per 10 m^3 (in parenthesis) (Siluriformes in italic, Characiformes in bold; Gymnotiformes underlined) and percentage of captures at dusk, midnight and dawn along the Cinzas River (PR) and in the Laranjinhas River (PR).

Sampling station	September	November	December	February	March	Dusk (%)	Midnight (%)	Dawn (%)
Tom	0	1 (**0.9**)	0	1 (**1.3**)	0	39.1	58.2	2.7
Sap	2 (*0.4*; **0.4**)	2 (*0.4*; **0.4**)	30 (*8.4*; **0.6**)	0	0	9.1	61.7	29.2
Bot	3 (**2.2**)	4 (*0.4*; **1.3**)	17 (*4.5*)	1 (*0.8*)	5 (*0.3*; **1.3**)	23.7	68.0	8.3
C4I	1 (*0.6*)	0	1 (<u>0.5</u>)	64 (*27.1*; **0.9**)	0	2.5	84.5	13.0
Cer	1 (*0.4*)	1 (**0.3**)	22 (*3.9*; **1.4**)	8 (*0.9*; **0.9**)	1 (**0.3**)	0.0	50.0	50.0
BG	0	0	3 (*1.9*)	164 (*40*)	0	38.4	0.0	61.6
AC	2 (*0.5*; **0.5**)	0	10 (*2.9*; **0.7**)	31 (*7.3*; **0.3**)	0	0.3	99.4	0.3
Foz	0	0	7 (*1.7*; **0.8**; <u>0.4</u>)	10 (*5.1*; **0.6**)	0	1.0	99.0	0.0
Lar	2 (*1.5*)	2 (*1.0*; **1.0**)	4 (*2.7*)	60 (*16.3*; **10.3**)	1 (*0.6*)	1.3	22.7	76.0

Table 3. Taxonomical composition of the fish (juveniles and adults) assemblage in the Cinzas River.

CHARACIFORMES
- Parodontidae
  - *Apareiodon affinis*
- Curimatidae
  - *Cyphocharax modestus*
  - *Cyphocharax nagelli*
  - *Steindachnerina insculpta*
- Prochilodontidae
  - *Prochilodus lineatus*
- Anostomidae
  - *Leporellus vittatus*
  - *Leporinus amblyrhynchus*
  - *Leporinus elongates*
  - *Leporinus friderici*
  - *Leporinus octofasciatus*
  - *Leporinus striatus*
  - *Schizodon altoparanae*
  - *Schizodon borelli*
  - *Schizodon nasutus*
- Characidae
  - *Astyanax altiparanae*
  - *Astyanax fasciatus*
  - *Moenkhausia intermedia*
  - *Oligosarcus paranensis*
  - *Triportheus angulatus*[a]
- Serrasalminae
  - *Myloplus tiete*
  - *Serrasalmus marginatus*
  - *Serrasalmus maculatos*[b]
- Characinae
  - *Galeocharax knerii*
- Acestrorhynchidae
  - *Acestrorhynchus lacustris*
- Erythrinidae
  - *Hoplias malabaricus*

SILURIFORMES
- Callichthyidae
  - *Hoplosternum littorale*
- Loricariidae
  - *Hypostomus albopunctatus*
  - *Hypostomus ancistroides*
  - *Hypostomus margaritifer*
  - *Hypostomus regani*
  - *Hypostomus* sp. 1
  - *Hypostomus* sp. 2
  - *Hypostomus* sp. 3
  - *Hypostomus* sp. 4
  - *Hypostomus* sp. 5
  - *Loricaria similima*
  - *Loricaria prolixa*
  - *Loricariichthys platymetopon*
  - *Microlepdogaster* sp.
  - *Rhinelepis aspera*
  - *Rineloricaria* sp.
- Heptapteridae
  - *Heptapterus* sp.
  - *Pimelodella* sp.
  - *Rhamdia quelen*
  - *Rhamdia* sp.
- Pimelodidae
  - *Iheringichthys labrosus*
  - *Pimelodus maculatus*
  - *Pinirampus pirinampu*
- Doradidae
  - *Rhinodoras dorbignyi*

GYMNOTIFORMES
- Gymnotidae
  - *Gymnotus carapo*
  - *Gymnotus* sp.
- Sternopygidae
  - *Eigenmannia virescens*
  - *Sternopygus macrurus*
- Apteronotidae
  - *Porotergus ellisi*

PERCIFORMES
- Sciaenidae
  - *Plagioscion squamosissimus*[a]
- Cichlidae
  - *Crenicichla niederleinii*
  - *Geophagus brasiliensis*

[a] = Introduced from other Brazilian basins (Orsi and Agostinho, 1999); [b] = Transposed from middle Paraná region after the Itaipu construction (Bonetto, 1986 apud Agostinho, 1994).

Table 4. Number of fishes captured along the Cinzas River and lower Laranjinhas River and their reproductive condition. Pre = pre-reproductive stages; Re = ready for reproduction; F = failure in reproduction; D = deteriorated.

Station/Month	Pre	Re	Post	D
Tom Sept.	30	17	0	0
Sap Sept.	23	9	0	0
Bot Sept.	24	26	0	0
4I Sept.	21	26	0	0
Cer Sept.	16	16	0	1
BG Sept.	50	80	17	0
AC Sept.	0	11	0	0
Foz Sept.	3	1	0	0
Lar Sept.	57	34	1	1
Total September	266 (52.5%)	220 (43.5 %)	18 (3.6 %)	2 (0.4 %)
Tom Nov.	4	5	6	0
Sap Nov.	15	4	0	0
Bot Nov.	5	33	18	0
4I Nov.	12	25	1	0
Cer Nov.	0	7	0	0
BG Nov.	42	51	2	0
AC Nov.	13	23	0	0
Foz Nov.	3	9	0	0
Lar Nov.	3	2	0	2
Total November	103 (35.3%)	159 (54.7 %)	27 (9.3 %)	2 (0.7 %)
Tom Dec.	4	1	0	0
Sap Dec.	9	12	1	0
Bot Dec.	7	26	1	0
4I Dec.	19	4	0	5
Cer Dec.	3	6	0	1
BG Dec.	14	17	2	0
AC Dec.	3	3	0	0
Foz Dec.	1	1	4	0
Lar Dec.	1	48	4	4
Total December	61 (30.4 %)	118 (58.6 %)	12 (6.0 %)	10 (5.0 %)
Tom Feb.	2	2	0	0
Sap Feb.	9	12	0	0
Bot Feb.	7	13	1	1
4I Feb.	3	12	8	0
Cer Feb.	1	3	2	0
BG Feb.	9	5	6	0
AC Feb.	12	3	5	1
Foz Feb.	13	6	7	3
Lar Feb.	12	14	7	1
Total February	68 (37.8%)	70 (38.9 %)	36 (20.0 %)	6 (3.3 %)
Tom Mar.	3	0	6	0
Sap Mar.	3	0	6	0
Bot Mar.	5	1	19	1
4I Mar.	12	0	3	2
Cer Mar.	1	1	6	0
BG Mar.	24	2	23	3
AC Mar.	5	1	34	0
Foz Mar.	5	0	17	0
Lar Mar.	0	0	8	0
Total March	58 (30.4 %)	5 (2.6 %)	122 (63.9 %)	6 (3.1 %)

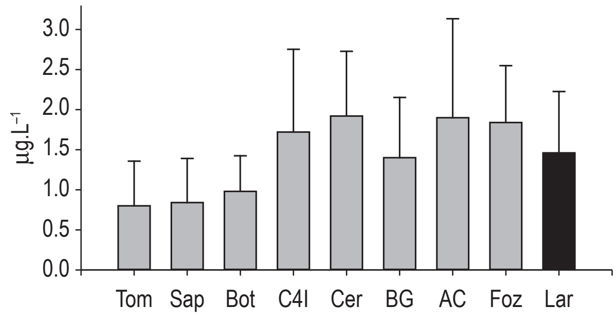

Figure 4. Longitudinal variation of nitrite (mean and standard deviation) (n = 5) in the Cinzas River (PR) (gray bars) and lower Laranjinhas River (PR) (black bar).

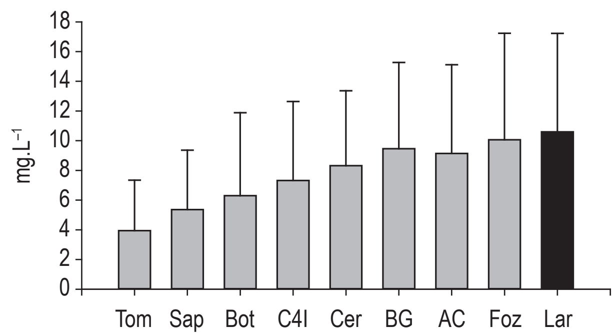

Figure 5. Longitudinal variation of silicate (mean and standard deviation) (n = 5) in the Cinzas River (PR) (gray bars) and lower Laranjinhas River (PR) (black bars).

Table 5. Sampling periods (months/days), precipitation (accumulated during sampling days) and river flow rate (mean among the sampling days). The measurements were taken in the lower Cinzas River (municipality of Andirá, PR).

Variable	September 23-25	November 4-6	December 16-18	February 2-4	March 9-11
Precipitation (mm)	0.0	3.0	17.5	3.8	4.5
Flow rate (m^3/s)	21.0	18.3	57.4	82.2	31.4

Source: Duke Energy.

increased from 24.2 to 110.6 $\mu S.cm^{-1}$, nitrite from 0.8 to 1.8 $\mu g.L^{-1}$ and silicate from 3.9 to 10.1 $mg.L^{-1}$. Despite the tendency of water quality impoverishment along the river the maximum concentrations (mean values) of ammonium (105 $\mu g.L^{-1}$), suspended inorganic solids (56.4 $\mu g.L^{-1}$) N-tot (670.6 $\mu g.L^{-1}$), P-Tot (104 $\mu g.L^{-1}$), BOD (6 $mg.L^{-1}$) and turbidity (47.1 NTU) were observed at Sap, the second most upstream sampling station.

For most limnological variables the day-night variation was not significant, except for the dissolved oxygen in certain periods and sampling stations. The highest amplitude was observed at the station Cer in the February, with a difference of 7.7 mg.L^{-1}. The minimum concentration was measured at the station Foz in the September, with 4.2 mg.L^{-1} at midnight. The stations C4I and AC also presented relatively high variation along the day in the February sampling, with amplitudes of 4.9 and 1.9 mg.L^{-1}, respectively.

In general the limnological characteristics were similar between the Laranjinhas River and the Cinzas River mouth (e.g. conductivity, silicate, dissolved oxygen, ammonium, transparency, N-tot). An association between these both sampling stations, and also with AC, was particularly evident in December, as shown by the PCA analysis (Figure 6). The positioning of these stations in the right inferior quadrant was influenced by higher values of BOD and nutrients (Si, PO_4, TP and NO_2), indicating poorer water quality in the lower basin. The stations of the upper Cinzas basin were distributed in the opposite quadrant during September and November. This group (Tom, Bot and Sap) was also discriminated in February (right superior quadrant).

3.5. Correlation analysis

Excluding stations with very low (or even zero) eggs or larvae, there was a positive correlation between both development stages (maximum r = 0.986 at Lar). Correlation between eggs and percentage of sexually mature fishes was positive for most sampling stations (maximum r = 0.66 at Bot).

The amount of eggs was positively correlated with pH (maximum of 0.91, 0.89 and 0.77 at Cer, C4I and AC, respectively), nitrate (maximum of 0.84 and 0.78 at AC and C4I), total phosphorus (maximum of 0.89 and 0.85 at C4I and AC), silicate (maximum of 0.97, 0,82, 0.79 and 0.70 at Sap, AC, Bot and Tom), inorganic suspended solids (maximum of 0.94, 0.84 and 0.78 at AC, Bot and C4I), velocity (maximum of 0.90, 0.75, 0.71 and 0.70 at Tom, Sap, AC and Lar), turbidity (maximum of 1.0, 1.0, 0.99,

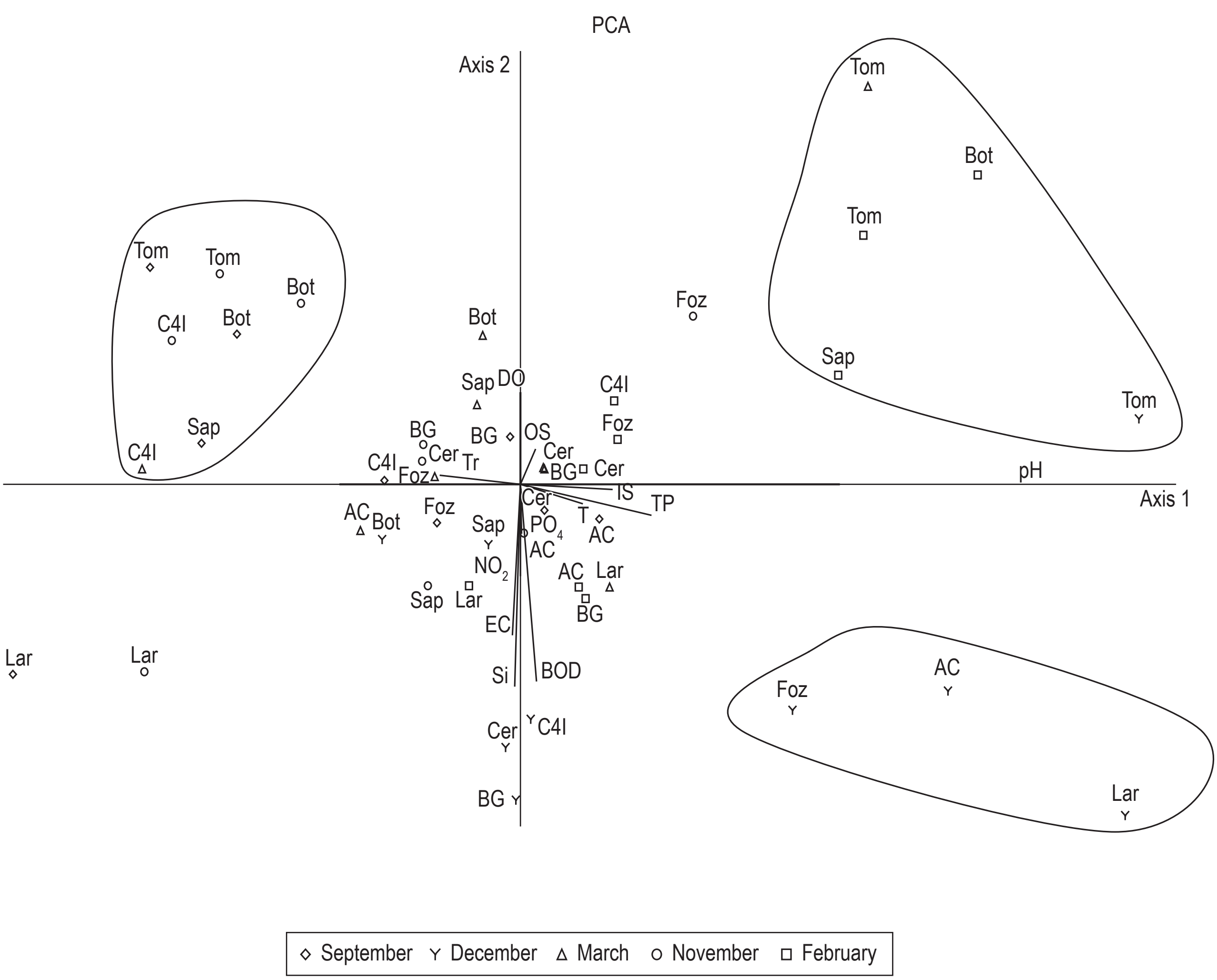

Figure 6. Graphical results of PCA analysis on the basis of the limnological variables. See text and Figure 1 for variables and sampling stations denominations, respectively.

Table 6. Values of pH, temperature, transparency, velocity, nutrients, chlorophyll-*a*, suspended inorganic solids, BOD and turbidity along the Cinzas River (PR) and in the lower Laranjinhas River (PR). Maximum and minimum values in bold.

Local Period	pH*	Temp.* (°C)	Transp.* (m)	Vel.* (m/s)	Ntot. (µg.L^{-1})	NO_3 (µg.L^{-1})	NH_4 (µg.L^{-1})	PO_4 (µg.L^{-1})	Ptot (µg.L^{-1})	Chl. (µg.L^{-1})	In.Sol. (mg.L^{-1})	BOD (mg.L^{-1})	Turb. NTU
Tom Sept.	6.4	23.0	1.00	0.25	574.0	175.3	82.5	**6.3**	**33.2**	**	12.0	1.0	4.1
Tom Nov.	6.7	**22.1**	0.50	0.26	532.0	**332.1**	88.4	34.3	46.7	0.63	48.0	**0.0**	15.0
Tom Dec.	8.0	25.5	0.85	0.45	672.0	215.5	93.4	28.8	90.3	0.58	53.0	4.0	27.0
Tom Feb.	8.4	25.0	**0.14**	0.31	504.0	227.1	85.8	9.5	145.1	0.59	48.0	6.0	**
Tom Mar.	7.8	25.8	0.20	0.19	672.0	160.6	55.8	34.6	108.5	0.42	52.0	**0.0**	**
Sap Sept.	6.8	24.0	1.00	0.58	658.0	192.0	112.1	10.0	61.0	**	28.0	3.0	5.3
Sap Nov.	6.9	22.2	0.35	0.56	686.0	204.7	**180.0**	25.8	94.3	0.87	**96.0**	**11.0**	**84.0**
Sap Dec.	7.2	25.2	0.20	0.79	749.0	232.7	85.7	20.4	126.7	0.33	46.0	6.0	52.0
Sap Feb.	8.0	26.6	0.26	0.56	700.0	251.9	96.1	30.1	149.0	1.05	72.0	6.0	**
Sap Mar.	7.4	27.4	0.26	0.56	560.0	207.2	51.3	60.0	89.6	0.27	40.0	4.0	**
Bot Sept.	6.9	24.4	1.20	0.21	686.0	125.1	78.4	9.4	43.6	**	12.0	1.0	4.2
Bot Nov.	7.0	24.2	1.20	0.56	406.0	189.2	67.8	34.2	40.8	0.35	8.0	**0.0**	5.4
Bot Dec.	6.9	25.5	0.30	0.89	630.0	264.8	73.8	24.9	105.3	0.68	40.0	2.0	44.0
Bot Feb.	**6.1**	27.5	0.30	0.62	602.0	250.8	91.1	18.3	101.0	0.44	28.0	**0.0**	**
Bot Mar.	7.1	27.8	0.30	0.70	448.0	239.3	46.7	46.4	128.5	0.44	16.0	2.0	**
C4I Sept.	7.1	24.3	0.90	0.41	644.0	171.0	77.9	11.4	52.0	**	40.0	4.0	9.2
C4I Nov.	6.7	24.4	0.80	**0.13**	448.0	194.9	72.7	57.3	62.05	0.40	8.0	**0.0**	10.2
C4I Dec.	7.3	26.9	0.20	**0.13**	**812.0**	217.3	91.6	63.8	165.2	0.11	50.0	5.0	52.0
C4I Feb.	7.5	27.5	0.30	0.81	700.0	208.8	85.0	42.6	147.6	0.57	52.0	3.0	**
C4I Mar.	6.8	28.2	0.60	0.35	518.0	177.2	46.2	21.9	69.9	0.84	16.0	3.0	**
Cer Sept.	7.4	24.5	0.90	0.54	770.0	145.5	131.1	11.1	71.9	*	28.0	4.0	5.6
Cer Nov.	7.2	22.7	0.80	0.83	518.0	224.3	73.6	59.6	62.25	**0.09**	16.0	1.0	9.5
Cer Dec.	7.4	26.2	0.20	0.83	798.0	235.6	81.9	59.8	147.5	0.23	40.0	6.0	55.0
Cer Feb.	7.6	28.0	0.40	**1.04**	420.0	242.8	82.3	47.8	92.2	0.88	28.0	4.0	**
Cer Mar.	7.3	28.7	0.67	0.68	**406.0**	184.4	48.9	23.2	68.4	0.32	**7.0**	4.0	**
BG Sept.	7.6	25.1	0.85	0.41	644.0	148.9	92.4	12.1	49.6	**	12.0	2.0	4.2
BG Nov.	7.6	24.3	0.85	0.37	504.0	220.2	73.2	57.5	62.85	0.37	16.0	1.0	9.8
BG Dec.	7.6	26.2	0.20	0.37	672.0	210.7	62.8	**79.3**	156.4	0.15	50.0	8.0	46.0
BG Feb.	7.6	28.4	0.33	0.83	476.0	234.7	86.5	42.1	119.0	0.35	32.0	6.0	**
BG Mar.	7.6	**29.2**	0.88	0.26	532.0	144.7	63.2	15.7	71.6	0.75	10.0	3.0	**
AC Sept.	7.6	24.4	**1.40**	0.47	770.0	175.8	85.7	24.7	52.8	*	12.0	4.0	5.1
AC Nov.	7.9	23.5	**1.40**	0.22	490.0	168.8	80.8	31.4	47.5	0.36	8.0	5.0	5.6
AC Dec.	8.3	27.0	0.20	0.66	700.0	266.7	62.8	21.3	**170.4**	0.43	63.0	6.0	64.0
AC Feb.	7.6	28.5	0.26	0.71	504.0	259.5	73.1	41.1	161.4	0.31	48.0	5.0	**
AC Mar.	7.2	29.2	1.00	0.42	455.0	127.0	39.7	28.4	73.3	**1.20**	10.0	4.0	**
Foz Sept.	7.4	25.3	0.70	0.44	630.0	157.8	98.8	23.8	63.2	*	32.0	2.0	6.6
Foz Nov.	8.1	24.3	1.05	0.19	504.0	**44.9**	90.6	23.2	43.2	0.43	8.0	**0.0**	6.2
Foz Dec.	8.3	26.9	0.20	0.37	728.0	227.4	59.6	45.3	152.0	0.10	46.0	4.0	46.0
Foz Feb.	7.5	29.0	0.20	0.41	581.0	243.6	103.5	28.9	143.0	0.11	40.0	1.0	**
Foz Mar.	7.1	**29.2**	0.75	0.74	462.0	122.8	**26.6**	15.0	112.2	0.65	**7.0**	2.0	**
Lar Sept.	6.7	24.7	0.80	0.30	630.0	93.3	83.0	46.2	55.4	*	8.0	4.0	**3.0**
Lar Nov.	7.1	23.7	0.75	0.23	567.0	133.3	94.5	48.8	55.1	0.52	16.0	6.0	7.6
Lar Dec.	**8.7**	28.0	0.50	0.35	672.0	233.5	56.9	41.6	74.3	0.45	30.0	4.0	19.0
Lar Feb.	7.5	28.8	0.40	0.48	434.0	256.7	96.9	42.2	106.1	0.46	12.0	5.0	**
Lar Mar.	7.4	28.8	0.60	0.42	588.0	236.9	62.9	19.4	110.0	0.29	**7.0**	4.0	**

* = Mean among afternoon, dusk, midnight and dawn; ** = missing data.

0.94, 0.9 and 0.88 at C4I, Foz, AC, Lar, C4I and Tom) and chlorophyll-*a* (0.96 and 0.96 at Bot and Cer). The correlations were negative with conductivity (minimum of –0.86 and –0.75 at Lar and Cer) and transparency (minimum of –0.84, –0.81and –0.79 at C4I, AC and Lar).

Larvae were negatively correlated with transparency (minimum of –0.91, –0.91, –0.76 and –0.72 at Foz, Cern, AC and Lar) and positively with nitrate (maximum of 0.85, 0.78 and 0.77 at Foz, Tom and AC), total phosphorus (maximum of 0.99, 0.81 and 0.78 at Cer, Foz and AC), silicate (maximum of 0.90, 0.88 and 0.86 at Bot, C4I and Sap), inorganic suspended solids (maximum of 0.80, 0.78 and 0.70 at Cer, Foz and Bot) velocity (1.0, 0.97 and 0.79 at Sap, BG and AC) and turbidity (maximum of 1.0, 1.0, 1.0, 0.99, 0.98 and 0.96 at Foz, Cer, Bot, BG, AC and Lar).

Considering data of all sampling stations per sampling period there was a high correlation between total eggs and total larvae with the river flow rate (r = 0.90 and 0.93, respectively).

4. Discussion

The amount of eggs, 2572, and larvae, 457, collected in the Cinzas River during the present study (between September and March) can be considered relatively high. Suiberto (2005) collected 934 eggs and 308 larvae during an entire year of field work in the region of the upper Paranapanema basin (river channel and 2 lateral lagoons located upstream of Jurumirim Reservoir). Nevertheless, a higher number of larvae, 3480 individuals, were captured by Castro et al. (2002) at one site in the upper Paraná River floodplain, also during a year (monthly samples). Baumgartner et al. (2004) captured an even higher number of eggs, 20376, and larvae, 13338, studying 12 different sites in Itaipu Reservoir. Similar high values were obtained by Bialetzki et al. (2005), 12152 larvae, at 16 sites (lotic and lentic environments) in the Baía River, also in Upper Paraná floodplain, along 13 months.

In terms of ichthyoplankton density expressive high values were found in the Cinzas River, with the maximum of 215.2 eggs.10 m^{-3} and 40 larvae.10 m^{-3}. Similar values, considering mean density of larvae (36.8 larvae.10 m^{-3}), were obtained by Castro et al. (2002) in the upper Paraná floodplain. The maximum density found by Suiberto (2005) in the upper Paranapanema was 63.2 eggs.10 m^{-3} and 44.0 larvae.10 m^{-3}. Nakatani et al. (1997b) registered relatively low values, 8.0 eggs. 10 m^{-3} and 5.0 larvae. 10 m^{-3}, in the Iratim River, a tributary of Segredo Reservoir (Iguaçu River) compared to the Cinzas in term of size and flow.

In spite of the importance of comparing quantitative ichthyoplankton data among different environments of the upper Paraná basin, it must be considered that the sampling designs conducted by the different authors can be too variable, strongly interfering in the obtained results.

There was a significant difference in the capture of the ichthyoplankton (eggs and larvae) among the sampling periods, with higher density of eggs and larvae in summer (December) and late summer (February). Others authors observed in the Paranapanema and upper Paraná River the presence of eggs and larvae during the whole year but with a noticeable increase in captures in spring and summer (Castro et al., 2002; Suiberto 2005; Baumgartner et al., 2004; Bialetzki et al. 2005). This pattern is expected, as this period of the year comprises the reproductive activity of most species of fishes in the upper Paraná basin (Agostinho et al., 1995). In the Capivara Reservoir basin, a clear seasonality in the reproductive activity of fishes, between November and February, was observed in the Tibagi River by Orsi et al. (2002).

For the reofilic species the reproductive processes are synchronized with the cycle of the floods, being trigged by environmental factors such as photoperiod, temperature and, especially, increase of the fluviometric level (Vazzoler et al., 1997). In the Cinzas River the maximum flow was registered in February, 82.2 m^3/s, and this variable had a high positive correlation with the ichthyoplankton (r = 0.90 for eggs and r = 0.93 for larvae).

Another evidence of a seasonal reproductive pattern was provided by the gonads analysis. Higher percentage of the fishes captured in the Cinzas River with mature gonads was observed in November (54.7%) and December (58.6%). In late summer, March, there was a pronounced decrease of this condition (only 2.6%).

In the present study 79.3% of the egg captures occurred at midnight. Higher captures during the night is a recurrent pattern, as observed by other studies carried out in the basin (Baumgartner et al., 2004; Suiberto, 2005), probably due to spawning at the sunset when water is warmer.

Spatially it was observed a significantly difference in the eggs distribution along the Cinzas River. Higher numbers of eggs (280 in December and 487 eggs/10 m^3 in February) occurred at the station C4I located 61.5 km far from the mouth. But high density of eggs (approximately 100 eggs/10 m^3) was also collected in the first sampling station (120 km from the mouth). This result shows that the entire studied river stretch is used for fish spawning. Conversely, only few species of fish use the last 65 km of the River Tibagi for reproduction (Orsi et al., 2002). This may be related to the differential position of these rivers mouths in relation to the Capivara Reservoir dam.

The importance of eggs transport in the development and dispersion of neotropical fishes have been discussed in the literature (Vazzoler et al., 1997; Araujo-Lima and Oliveira, 1998). In our study most larvae were found at the station BG, 31.5 km downstream the station where it was found a maximum number of eggs (C4I). This indicates that the embryonic development occurs during the eggs drift towards the river mouth. Relatively high amounts of larvae (26.6 larvae.10 m^{-3} in February), but not of eggs, in the lower Laranjinhas River is also an indicative of the influence of this coupled physical-biological process.

In terms of composition and life cycle strategies the aquatic environments of the upper Paraná River basin sustain a diversified fish fauna. In the region between the Paranapanema mouth and the Itaipu Reservoir it has been registered 182 species (Graça and Pavanelli, 2007). Luiz et al. (2005) observed that among the reservoirs of the State of Paraná, the ones in the Paranapanema River (border with São Paulo State) have a higher number of fish species and also exhibit more diverse reproductive strategies. Along the Paranapanema River, considering the high and medium-low stretches, it is observed an increasing tendency in richness from about 50 to 80 fish species when (Britto and Carvalho, 2006).

In the present study it was identified 57 taxa of fish. The migratory species were represented by *Pinirampus pirinampu*, *Pimelodus maculatus* and *Rhinelepis aspera*, among the Siluriformes, and *Leporinus elongatus* and *Prochilodus lineatus*, among the Characiformes. The number of species found in the Cinzas River corresponds to 72% of the total richness found in the Capivara Reservoir, 79 according to Orsi (2005). The Cinzas River contribution for the fish fauna diversity in the middle Paranapanema could be even higher than the one of the Tibagi River. This is the largest tributary of the Paranapanema River whose mouth is also located in the Capivara Reservoir. In a long term study (36 sampling months from 1990 to 1998) in the last 65 km of the Tibagi River, 44 species were identified (Bennemann and Shibatta, 2002; Orsi et al., 2002).

The limnological analyses of the Cinzas River showed that some variables exhibited an expected tendency from upper to lower stretches. The temperature increased, due to the progressive heat transference and water mass accumulation, and the suspended organic solids decreased, due to the diminution of the influence of terrestrial plant detritus in the lower (higher order) stretches. This study also showed the existence of a longitudinal gradient in the water quality. This pattern was evidenced by downstream increases in conductivity, silicate, nitrite, BOD and total phosphorus and decrease in dissolved oxygen. The progressive river degradation is a consequence of cumulative processes. Along the studied river, there is the negative influence of several municipalities. Pollution sources (urban and industrial sewage) and other human activities in the basin promote the input of allochthonous material into the river, changing its original physical, chemical and biotic characteristics. In case of the Cinzas River there are also evident signs of water quality deterioration due to intensive pressure of agricultural activities, simplification of marginal vegetation and excessive sand extraction. The limnological similarity between the Cinzas River mouth and the Laranjinhas River shows that the lower stretch of this tributary also reflects the influence of cumulative impacts along its basin.

Low transparency values registered in the period of intensive rains is another evidence of the negative effects of intensive soil use. In February the maximum transparency registered along the river did no exceeded 0.40 m (Cer and Lar). Besides the decrease in transparency the soil surface runoff caused increases in total phosphorus, turbidity, inorganic suspended solids and silicate.

The higher eutrophic condition found in the middle Paranapanema basin, especially in the Capivara Reservoir, when compared to the upper and lower stretches, is certainly influenced by the entrance of the Cinzas and Tibagi Rivers (Nogueira et al., 2002). Feitosa et al. (2006) verified that the tributaries coming from the north region of the Paraná State contribute with high loads of material (sediment and nutrient) to the Paranapanema River. According to the authors the Cinzas River was the tributary with the highest value of conductivity during the winter sampling and highest value of chlorophyll-*a*, suspended solids, phosphorus and nitrogen during the summer sampling.

Despite the longitudinal tendency of water quality impoverishment it is also important to note that the maximum peaks of ammonium, BOD, N-tot; P-tot, suspended inorganic solids and turbidity were observed in the second most upstream sampling station (Sap). This indicates the existence of local discharges. In case of the Sap station the negative influence is probably caused by industrial effluent of dairy plants (municipality of Tomazina). The lowest mean value of dissolved oxygen calculated for the AC sampling station is another evidence of point-source pollution. In this case due to the entrance of an effluent from an alcohol and sugar cane industrial plant (municipality of Bandeirantes, PR). Some remarkable nocturnal decreases in oxygen concentration can also be considered as an eutrophication signal, especially if considered that the Cinzas River has a relatively high water flow.

The correlation analyses of fish eggs and larvae with the limnological variables demonstrated the coupling of fish reproduction with more productive and high water conditions, determined by intensive rain precipitation. Eggs were positively correlated with pH, nutrients, inorganic suspended solids, velocity, flow rate, turbidity and chlorophyll-*a* and negatively with conductivity and transparency. Larvae were negatively correlated with transparency and positively with inorganic suspended solids, velocity, flow rate and turbidity.

5. Conclusions

The alterations in the aquatic ecosystems caused by human activities, including the deterioration of the water quality and dam obstruction, have a direct effect on the aquatic biota. In case of large reservoirs, constructed to attend the hydroelectric plants, there is a direct interruption in the migratory routes of fishes.

The results of this work indicate that the fish species of the middle Paranapanema (Capivara Reservoir) are using the Cinzas River for spawning. However, the limnological analyses indicate a gradient of degradation along the river, what can interfere negatively in the effective recruitment of the fish populations. Thus, the implementation of a comprehensive environmental protection and recovery program in the Cinzas River basin is highly recommended for the regional conservation of the aquatic fauna.

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