Consequences of dam construction upstream of the Upper Paraná River floodplain (Brazil): a temporal analysis of the Chironomidae community over an eight-year period

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(With 8 figures)

Abstract

Our study aimed to identify patterns of temporal variation and changes in the structure of the community of Chironomidae larvae in two rivers in the Upper Paraná River floodplain after the construction of a reservoir upstream (Porto Primavera). Samples were taken with a Petersen grab, and were obtained between 2000 and 2007. Chironomidae larvae were identified down to the lowest taxonomic level possible. The high richness of Chironomidae observed in the Paraná and Ivinhema Rivers (100 morphospecies) in comparison to the world average of rivers of the same size (44 species) emphasizes the importance of these habitats for the maintenance of biodiversity. The composition and density of Chironomidae in the years 2000 and 2001 differed from the other years. This period was characterized by extreme changes in the Paraná River flow caused by the closing of the Porto Primavera Dam, which added to a severe dry period in late 2001. The different compositions of morphospecies and the higher similarities in subsequent years are indicative of the recovery and adaptation of the community. In spite of the changes in the composition of morphospecies, diversity was maintained and the community continued to respond to fluctuations in the hydrometric level.

Keywords: temporal and spatial variation, Chironomidae, floodplain, damming.

Conseqüências da construção de um reservatório a montante da planície aluvial do Alto Rio Paraná (Brasil): análises temporais da comunidade Chironomidae em um período de oito anos

Resumo

Este trabalho teve por objetivos identificar padrões de variação temporal e alterações ocorridas na estrutura da comunidade de larvas de Chironomidae de dois rios da planície aluvial do Alto Rio Paraná nos anos subseqüentes ao fechamento de um reservatório à montante, Porto Primavera. As amostras foram coletadas de 2000 a 2007 com um pegador do tipo Petersen, modificado. As larvas de Chironomidae foram identificadas até a menor categoria possível. A elevada riqueza de Chironomidae observada nos rios Paraná e Ivinhema (100 morfoespécies), quando comparada com a média mundial para rios de mesmo porte (44 espécies), ressalta a importância desses ambientes para a manutenção da biodiversidade. Tanto pela dominância, como também pela composição e densidade numérica, verificou-se que os anos de 2000 e 2001 diferiram dos demais. Este foi um período de fortes alterações no fluxo do Rio Paraná causado pela instalação do reservatório Porto Primavera aliado a uma grande seca ocorrida no final de 2001. Uma nova composição de morfoespécies e maior semelhança entre os anos seguintes são um indicativo da recuperação e adaptação da comunidade. Apesar das mudanças na composição de morfoespécies a diversidade foi mantida e a comunidade continua respondendo às flutuações do nível hidrométrico.

Palavras-chave: variações espaciais e temporais, Chironomidae, planície de inundação, represamento.

1. Introduction

Research has demonstrated that the Upper Paraná River floodplain has been severely affected by anthropogenic effects such as the removal of riparian vegetation, biocide loads, discharge of domestic sewage and, most importantly, the construction of dams (Agostinho et al., 2008). Dams have altered the natural flood regime, and consequently the structure and dynamics of the floodplain (Agostinho et al., 2004).

Alterations in the flood regime can be the most serious and continuous risk to the ecological sustainability of a river and its floodplains (Naiman et al., 1995; Sparks, 1995; Lundqvist, 1998; Ward et al., 1995). Regulation of fluvial discharge causes significant changes in the magnitude, duration, periodicity and frequency of flood pulses and in the transport of sediments (Rocha, 2001; Hayakawa, 2007).

Over the past 35 years, the discharge system of the Paraná River has been altered by the operation of dams located upstream. As reservoirs were constructed, the Paraná River became a regulated river (Rocha et al., 1998; 2001; Rocha, 2002). Construction of the Porto Primavera Dam (1998) intensified this control (Silva, 2007). The first filling stage of the reservoir began in December 1998, and the second stage occurred only in March 2001. These filling activities changed the hydrological regime of the Upper Paraná River floodplain. Despite the sequence of reservoirs upstream, flood pulses are still the main factor controlling the structure and function of this ecosystem (Agostinho et al., 2008).

During the historical formation of their life cycles, aquatic species developed strategies that depend on the natural flow regime. Therefore, changes in this regime can reduce the diversity of native species (Bunn and Arthington, 2002). The Chironomidae community is not an exception, and in the Upper Paraná River floodplain temporal variations of this community are directly linked to the hydrosedimentological regime (Takeda et al., 1997; Higuti and Takeda, 2002; Higuti, 2004; Takeda et al., 2004; Rosin and Takeda, 2007).

Chironomidae larvae are of particular interest ecologically because they occur in a wide variety of habitats (Ferrington, 2008) as they are able to survive under several environmental conditions and are often abundant in freshwater (Pinder, 1995). For these reasons, Chironomidae have been included in almost all monitoring and impact assessment programs in aquatic environments (Specziár and Biró, 1998; Fesl, 2002; Piédras et al., 2006).

Based on the hypothesis that the community structure of Chironomidae has changed in terms of its composition, diversity, density and dominance since the construction of the Porto Primavera Dam, our study aimed to: 1) characterize the Chironomidae community with regard to density and taxonomic composition at the sampling sites; and 2) identify patterns of temporal variation and changes in the structure of the community over time.

2. Materials and Methods

Our study is part of a larger project (Long-Term Ecological Research - LTER site 6) entitled: The Upper Paraná River Floodplain: Structure and Environmental Processes.

2.1. Characterization of the study area

The Paraná River is the main river of the La Plata Basin, formed by the rivers Grande and Paranaíba in the Central-South region of Brazil. The first third of its basin (the Upper Paraná River) is located in Brazil and is intensely dammed.

The Upper Paraná River floodplain was originally 480 km in length; however, after the construction of the Porto Primavera Dam (1998) its extent was reduced to 230 km, between Porto Primavera and the Itaipu Reservoir (Agostinho et al., 2008). The Upper Paraná River floodplain also includes many secondary channels, ponds, the Baia River and stretches of the Ivaí and Ivinhema Rivers (Figure 1).

Our study was conducted in two of the main channels of this floodplain: one in Paraná River and one in Ivinhema River. The studied stretch of the Paraná River was located near the City of Porto Rico (Paraná State) on the sandstone of the Caiuá Formation (Souza-Filho and Stevaux, 2004), with a width of approximately 950 m and a mean flow of 0.30 m/s. The high transparency of the water in this stretch is due to the cascade of reservoirs upstream (Rocha and Thomaz, 2004).

The Ivinhema River flows parallel to the Paraná River in its lower stretches (Stevaux et al., 1997), where it has an average depth of 3.9 m and a mean flow of 0.20 m/s. This river has no dams, transports high loads of sediment and nutrients (Agostinho et al., 2004) and presents distinct vegetation on its margins, such as herbaceous vegetation, macrophyte banks and large areas with riparian forests at several different stages of regeneration.

Except for their conductivity values, limnological variables were only slightly different between the rivers. Regarding the hydric phases, values of dissolved oxygen were generally higher in low water periods (the limnophase) and lower in high water periods (the potamophase) (Table 1).

2.2. Sampling and processing

Zoobenthos were collected from 2000 to 2007, with three samplings conducted in 2001, two in 2003 and four between 2004 and 2007. Four samples were taken using a Petersen grab (areas of Petersen = 0.0187 m^2 from 2000 to 2002, and 0.0345 m^2 in the other years) at each sampling site: three for biological analyses and one for sedimentological analyses. Values of water temperature (°C), dissolved oxygen concentration ($mg.L^{-1}$), pH and conductivity ($\mu S.cm^{-1}$) were recorded at each sampling

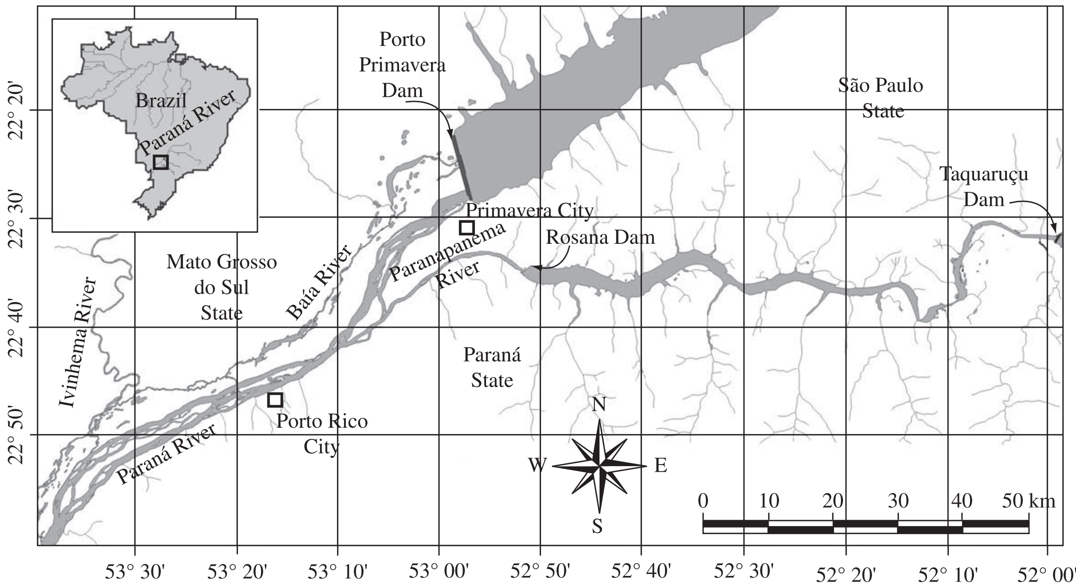

Figure 1. Location of the study area and sample points.

Table 1. Mean ± SD (in parentheses) of the following limnological variables in the Paraná and Ivinhema Rivers between the years 2000 and 2007: water temperature, electric conductivity, pH and dissolved oxygen.

River	Year	Period	Water temperature (°C)	Conductivity (μS.cm^{-1})	pH	Dissolved oxygen (mg.L^{-1})
Paraná	2000	Potamophase	25.95 (1.48)	57.2 (5.98)	7.16 (0.09)	8.95 (0.77)
		Limnophase	23.38 (3.88)	59.25 (3.92)	7.29 (0.25)	8.13 (1.25)
	2001	Potamophase	23.58 (9.61)	41.70 (17.6)	6.80 (0.15)	8.00 (0.87)
		Limnophase	22.1 (1.22)	59.37 (1.62)	7.46 (0.48)	7.75 (0.72)
	2002	Potamophase	27.33 (0.49)	57.97 (3.22)	7.24 (0.10)	7.34 (1.08)
		Limnophase	22.55 (4.35)	53.57 (2.30)	7.18 (0.18)	8.87 (0.19)
	2003	Potamophase	29.33 (0.12)	51.4 (0.01)	7.00 (0.02)	8.19 (0.02)
		Limnophase	20.53 (0.40)	61.27 (3.00)	7.82 (0.76)	8.19 (0.02)
	2004	Potamophase	24.26 (5.00)	56.23 (4.21)	7.22 (0.10)	7.99 (0.51)
		Limnophase	25.02 (1.49)	59.07 (4.22)	6.81 (0.19)	9.12 (0.89)
	2005	Potamophase	25.80 (2.27)	59.00 (4.01)	7.35 (0.13)	7.52 (0.88)
		Limnophase	23.57 (3.40)	68.78 (1.64)	7.40 (0.17)	8.06 (0.22)
	2006	Potamophase	23.70 (3.35)	54.73 (12.71)	6.97 (0.15)	8.03 (0.33)
		Limnophase	24.93 (3.10)	58.43 (8.06)	7.82 (0.33)	8.09 (0.67)
	2007	Potamophase	25.18 (4.40)	55.77 (6.48)	7.54 (0.23)	8.42 (0.91)
		Limnophase	25.95 (1.62)	59.97 (4.05)	7.85 (0.61)	8.21 (0.73)
Ivinhema	2000	Potamophase	25.46 (1.43)	41.33 (2.34)	6.90 (0.24)	7.45 (0.98)
		Limnophase	22.18 (4.51)	42.35 (1.36)	6.82 (0.22)	7.22(0.87)
	2001	Potamophase	27.65 (2.33)	44.83 (0.86)	6.72 (0.10)	6.66 (0.74)
		Limnophase	21.10 (0.01)	40.20 (0.01)	6.26 (0.01)	8.78 (0.01)
	2002	Potamophase	26.89 (0.72)	38.23 (4.48)	7.74 (0.73)	6.53 (0.83)
		Limnophase	23.57 (3.91)	43.72 (9.33)	6.91 (0.27)	7.25 (0.39)
	2003	Potamophase	27.70 (0.01)	49.27 (0.32)	6.64 (0.11)	7.15 (0.37)
		Limnophase	27.20 (1.04)	31.20 (6.78)	6.52 (0.70)	7.09 (1.23)
	2004	Potamophase	23.75 (5.31)	42.42 (3.73)	6.84 (0.85)	6.85 (0.69)
		Limnophase	24.66 (4.09)	45.13 (3.46)	6.51 (0.73)	6.59 (0.72)
	2005	Potamophase	24.75 (4.22)	43.88 (3.09)	7.16 (0.14)	7.24 (0.77)
		Limnophase	23.82 (4.56)	47.72 (3.38)	7.11 (0.03)	7.44 (0.94)
	2006	Potamophase	26.42 (4.24)	44.32 (1.17)	6.73 (0.49)	6.76 (1.15)
		Limnophase	25.65 (3.77)	45.22 (2.22)	7.11 (0.50)	6.97 (1.03)
	2007	Potamophase	25.43 (4.67)	45.75 (2.79)	6.86 (0.43)	5.54 (3.03)
		Limnophase	26.27 (1.58)	44.87 (3.14)	7.26 (0.42)	7.00 (0.73)

site. Data on the hydrometric levels were provided by the ANA (Agência Nacional de Águas).

Sediment samples were dried in an oven at 80 °C. The granulometric texture was determined according to the Wentworth's scale (1922), using the wet method. Organic matter content in the sediment was obtained by calcination of the samples in a muffle at 560 °C for approximately four hours.

Biological material was washed through a set of sieves (2.0, 1.0, and 0.2 mm mesh sizes). The organisms found in the 2.0 and 1.0 mm mesh sieves were immediately fixed in 70% alcohol. The material retained in the 0.2 mm mesh sieve was placed in polyethylene jars containing 70% alcohol. The material was observed under a stereoscopic microscope at Nupélia/UEM Zoobenthos Laboratory.

Chironomidae larvae were identified down to the lowest taxonomic level possible using the identification keys of Epler (1992) and Trivinho-Strixino and Strixino (1995).

2.3. Data analyses

2.3.1. Abiotic variables

Principal Component Analysis (PCA) was used to reduce the dimensionality of the environmental variables and to rank rivers and study months in relation to the following types of organic matter: pebbles, granules, very coarse sand, coarse sand, medium sand, fine sand, very fine sand, and mud. Because of the low variability between environments and months, data on water temperature, dissolved oxygen concentration, pH and conductivity were not included in the analysis. To linearize the relationships and improve the results of PCA, data were processed using an arc-sine transformation. In this analysis, the first two axes were maintained for interpretation, according to the Kaiser-Guttman criterion.

A two-way ANOVA using the factors rivers and months was used to verify significant differences ($\alpha = 0.05$) in PCA scores. For this analysis we used the PC-ORD software program (version 4.0), and the Statistica software (version 7.0).

2.3.2. Biotic variables

Accumulation curves based on richness were used to compare the rivers and measure the efficiency of sampling through the estimators ACE, Jackniffe 1 and Bootstrap. The EstimateS (version 5.01) software was used.

To characterize the Chironomidae community in the studied rivers and months, Kownacki's dominance index (1971) was calculated, where: Dominant = $10 < d < 100$; Subdominant = $1 < d < 9.99$; and Adominant = $0.01 < d < 0.99$. Only the dominant taxa of each river and each month were listed.

The similarity of the Chironomidae community of rivers and years was measured using a cluster analysis by UPGMA method, using the Euclidian Distance. The cophenetic correlation coefficient (r) was generated using a Mantel's Test. The program NTSYS (version 1.8) was used for this analysis.

To compare the diversity of rivers and months, the Shannon-Wienner (H') index (Shannon and Weaver 1963) was used and the density of each sample was calculated by dividing the number of individuals collected from each sample by the sampled area.

A two-way ANOVA was used to verify significant differences ($\alpha = 0.05$) of density and diversity between rivers and between months. A Spearman's rank ($p < 0.05$) was used with the purpose of analyzing the influence of the hydrometric level on the diversity and density of Chironomidae. The index of Beta Diversity (Whittaker, 1982) was applied to quantify the turnover of morphospecies between months.

3. Results

3.1. Abiotic variables

Summer floods of the Paraná and Ivinhema Rivers were almost simultaneous, except for 2002. The highest floods occurred in 2005 and 2007, and the lowest values were recorded in the second semester of 2001. Variations in 2000, 2001 and 2004 were quite irregular in comparison to the other years (Figure 2).

Granulometric data were summarized in a PCA, where principal components 1 and 2, with eigenvalues 2.34 and 1.74, explained 26.00 and 19.37% of the total variance in the data, respectively. Axis 1 separated the first four years from the others, mainly for Paraná River, because of the high mean percentages of sand and fine sand in the first years. The differences between the Paraná and Ivinhema rivers are evident in axis 2, mainly because of the high percentage of coarse particles in

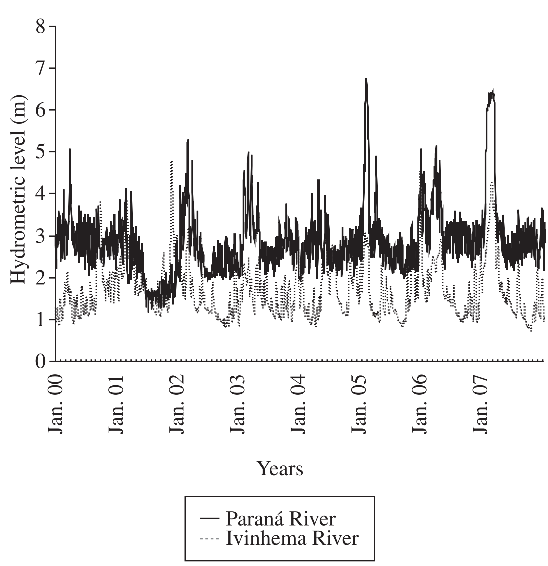

Figure 2. Hydrometric level of the Paraná and Ivinhema Rivers from January 2000 to December 2007.

Paraná River and the fine particles and organic matter in the Ivinhema River (Figure 3). We found only significant ($p < 0.05$) spatial differences and no significant temporal differences (Figure 4).

3.2. Biotic variables

The rarefaction curves indicated that the richness observed coincided with two of the three estimators in both rivers. Few new taxa occurred after September 2006 in the Ivinhema River and after November 2006 in the Paraná River. The application of estimators showed clearly that the samples were sufficient for proper assessment of diversity, providing support for accurate comparisons between the rivers (Figure 5).

We identified 5,761 Chironomidae larvae of 100 morphospecies (78 in the Paraná River and 62 in the Ivinhema River), distributed among 44 genera and three subfamilies (Tanypodinae, Chironominae and Orthocladiinae) (Appendix 1). Chironominae was the most abundant subfamily, corresponding to 71% of all individuals observed.

The Kownacki index showed that *Polypedilum* (*Tripodura*) sp.1 was the most dominant morphospe-

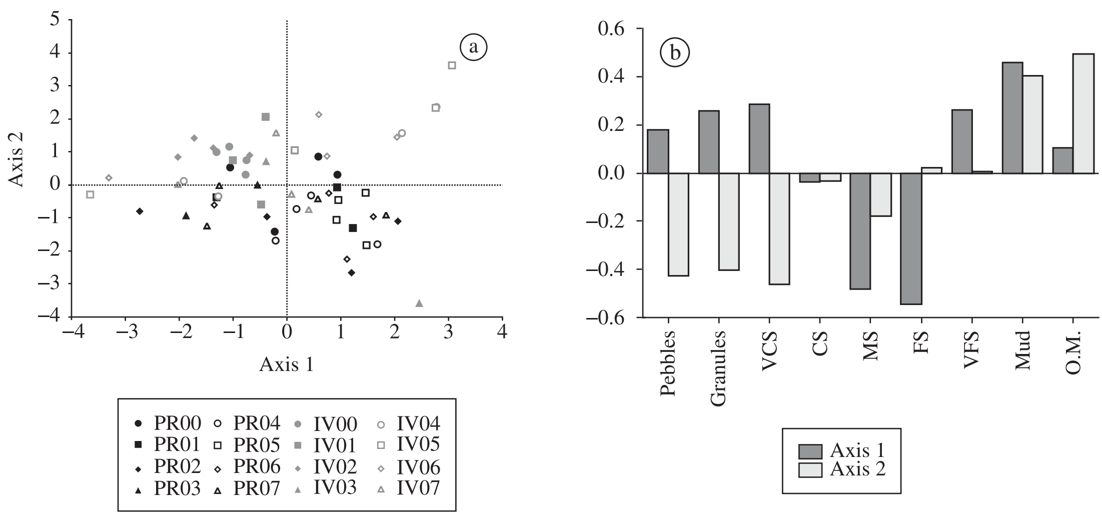

Figure 3. a) Ordination diagram of the first two axes of the PCA analysis. b) Eigenvectors of PCA variables. PR00 = Paraná River (2000); PR01 = Paraná River (2001); PR02 = Paraná River (2002); PR03 = Paraná River (2003); PR04 = Paraná River (2004); PR05 = Paraná River (2005); PR06 = Paraná River (2006); PR07 = Paraná River (2007), IV00 = Ivinhema River (2000); IV01 = Ivinhema River (2001); IV02 = Ivinhema River (2002); IV03 = Ivinhema River (2003); IV04 = Ivinhema River (2004); IV05 = Ivinhema River (2005); IV06 = Ivinhema River (2006); IV07 = Ivinhema River (2007);VCS = very coarse sand; CS = coarse sand; MS = medium sand; FS = fine sand; VFS = very fine sand; and OM = organic matter.

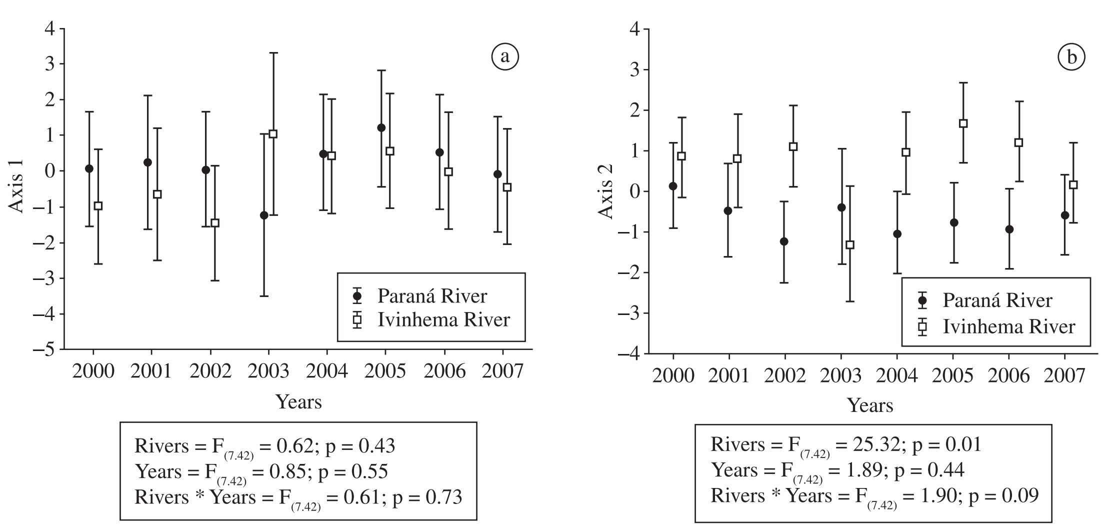

Figure 4. Mean ± SE of the two-way ANOVA with a) axis 1 and b) 2 of PCA for the Paraná and Ivinhema Rivers.

Table 2. Dominace values of Kownacki's index and dominants taxa of the rivers Paraná and Ivinhema in every months of sample. Feb00 = February 2000; May00 = May 2000; Aug00 = August 2000; Nov00 = November 2000; Feb01 = February 2001; May01 = May 2001; Aug01 = August 2001; Feb02 = February 2002; May02 = May 2002; Aug02 = August 2002; Nov02 = November 2002; Mar03 = March 2003; Sep03 = September 2003; Mar04 = March 2004; Jun04 = June 2004; Sep04 = September 2004; Dec04 = December 2004; Mar05 = March 2005; Jun05 = June 2005; Sep05 = September 2005; Dec05 = December 2005; Mar06 = March 2006; Jun06 = June 2006; Sep06 = September 2006; Nov06 = November 2006; Mar07 = March 2007; Jun07 = June 2007; Sep07 = September 2007; Dec07 = December 07. *P.* (*Polypedilum*) sp.2 = *Polypedilum* (*Polypedilum*) sp.2; *P.* (*Tripodura*) sp.1 = *Polypedilum* (*Tripodura*) sp.1; *A.* (*Karelia*) sp.1 = *Ablabesmyia* (*Karelia*) sp.1

Rivers	**Months**	***Coelotanypus* sp.1**	***A. (Karelia)* sp.1**	***Djalmabatista* sp.2**	***Axarus* sp.1**	***Apedilum* sp.2**	***Chironomus* sp.1**	***Cladopelma* sp.1**	***Endotribelos* sp.2**
Paraná	Feb00	-	-	-	-	-	-	-	-
	May00	-	-	-	-	-	-	-	-
	Aug00	-	-	-	-	-	-	-	-
	Nov00	-	-	-	-	-	-	-	-
	Feb01	-	-	-	-	-	-	-	-
	May01	-	-	-	-	-	-	-	-
	Aug01	-	-	-	-	-	-	-	-
	Feb02	-	-	-	35.90	-	-	-	-
	Mai02	-	-	-	-	-	-	-	-
	Aug02	-	-	-	-	-	-	-	-
	Nov02	-	-	-	-	-	-	-	-
	Mar03	-	-	-	21.21	-	-	-	-
	Sep03	-	-	-	-	-	-	-	-
	Mar04	14.77	-	-	-	-	-	-	-
	Jun04	-	-	-	-	-	-	-	-
	Sep04	-	-	-	-	-	-	-	-
	Dec04	14.10	-	-	-	-	-	-	-
	Mar05	10.00	20.00	-	-	-	-	-	-
	Jun05	-	-	-	-	-	-	-	-
	Sep05	-	-	-	-	-	-	-	-
	Dec05	-	-	20.37	-	-	-	-	-
	Mar06	14.06	-	-	-	-	-	-	-
	Jun06	-	-	-	-	-	-	-	-
	Sep06	-	-	-	-	-	-	-	-
	Nov06	-	11.59	-	-	-	-	-	-
	Mar07	-	-	-	-	-	-	-	-
	Jun07	-	-	-	-	-	-	-	-
	Sep07	-	-	-	-	-	-	-	-
	Dec07	-	-	-	-	-	-	-	-

***P. (Polypedilum)* sp.2**	***P. (Tripodura)* sp.1**	***Xenochironomus* sp.2**	***Manoa* sp.1**	***Rheotanytarsus* sp.1**	***Rheotanytarsus* sp.2**	***Tanytarsus* sp.1**	***Cricotopus* sp.1**	***Cricotopus* sp.3**	***Lopescladius* sp.1**
-	12.70	-	-	-	-	29.63	-	-	-
15.20	28.27	-	-	-	-	16.53	-	-	-
-	68.25	-	-	-	-	-	-	-	-
-	44.31	-	-	-	-	15.69	-	-	-
-	-	16.67	-	-	-	-	-	-	25.00
-	-	-	-	-	-	-	-	-	-
-	-	-	29.07	-	-	-	-	-	44.64
-	-	-	-	-	-	-	-	-	-
-	18.06	-	-	-	-	26.85	-	-	-
-	-	-	-	-	-	-	-	-	75.60
-	32.31	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	22.78	-	-	-	-	-	-	-	-
-	-	-	-	-	-	26.35	-	-	-
-	-	-	-	-	-	-	-	-	-
-	48.69	-	-	-	-	-	-	-	-
-	-	-	-	-	-	38.21	-	-	-
-	-	-	-	-	-	-	-	-	-
-	34.41	-	-	-	-	-	-	-	-
-	29.06	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	19.18	11.64	-
-	20.56	-	-	-	-	-	-	-	-
-	-	-	11.96	-	-	18.48	-	-	-
-	-	-	-	-	-	-	-	-	20.00
-	54.62	-	-	-	-	-	-	-	-
-	48.28	-	-	-	-	-	-	-	-
-	13.64	-	-	-	-	14.77	-	-	-

Table 2. Continued...

Rivers	Months	***Coelotanypus* sp.1**	***A. (Karelia)* sp.1**	***Djalmabatista* sp.2**	***Axarus* sp.1**	***Apedilum* sp.2**	***Chironomus* sp.1**	***Cladopelma* sp.1**	***Endotribelos* sp.2**
Ivinhema	Feb00	-	-	-	-	13.66	-	-	-
	May00	-	-	-	-	-	-	-	-
	Aug00	-	-	-	-	-	-	-	-
	Nov00	-	-	-	-	-	-	11.27	-
	Feb01	-	-	-	-	-	-	16.09	-
	May01	-	-	-	-	-	-	-	-
	Aug01	-	-	-	-	-	-	-	-
	Feb02	-	-	-	-	-	-	-	-
	Mai02	-	-	-	-	-	-	-	10.00
	Aug02	-	-	-	-	-	-	-	-
	Nov02	-	-	-	-	-	-	-	-
	Mar03	-	-	-	-	-	-	-	-
	Sep03	-	-	-	-	-	-	-	-
	Mar04	-	-	15.15	-	-	-	-	-
	Jun04	-	-	-	-	-	-	-	-
	Sep04	-	-	-	-	-	22.22	-	-
	Dec04	-	-	-	-	-	-	-	-
	Mar05	-	12.83	-	-	-	-	-	-
	Jun05	-	-	-	-	-	-	-	-
	Sep05	-	26.09	-	-	-	-	-	-
	Dec05	-	-	-	-	-	-	-	-
	Mar06	-	-	-	-	-	-	-	-
	Jun06	-	-	-	-	-	-	-	-
	Sep06	11.11	-	-	-	-	-	-	-
	Nov06	13.33	-	40.00	-	-	-	-	-
	Mar07	-	-	-	12.07	-	-	-	-
	Jun07	-	-	-	-	-	-	-	-
	Sep07	-	-	-	-	-	-	-	-
	Dec07	-	22.22	-	-	-	-	-	-

***P. (Polypedilum)* sp.2**	***P. (Tripodura)* sp.1**	***Xenochironomus* sp.2**	***Manoa* sp.1**	***Rheotanytarsus* sp.1**	***Rheotanytarsus* sp.2**	***Tanytarsus* sp.1**	***Cricotopus* sp.1**	***Cricotopus* sp.3**	***Lopescladius* sp.1**
-	-	-	-	-	-	-	-	-	-
24.60	-	-	-	-	-	-	-	-	-
24.81	-	-	-	-	-	-	-	-	-
16.90	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
10.00	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	27.27
-	-	-	-	-	-	-	-	-	10.00
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	14.06	-	-	-
-	19.05	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	13.33
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	50.00	-	-	-	-	-	-	-	-
-	-	-	-	17.39	-	-	-	-	-
-	-	-	-	-	-	-	-	-	49.06
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	22.22
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	12.07	-	-	-	29.31	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-

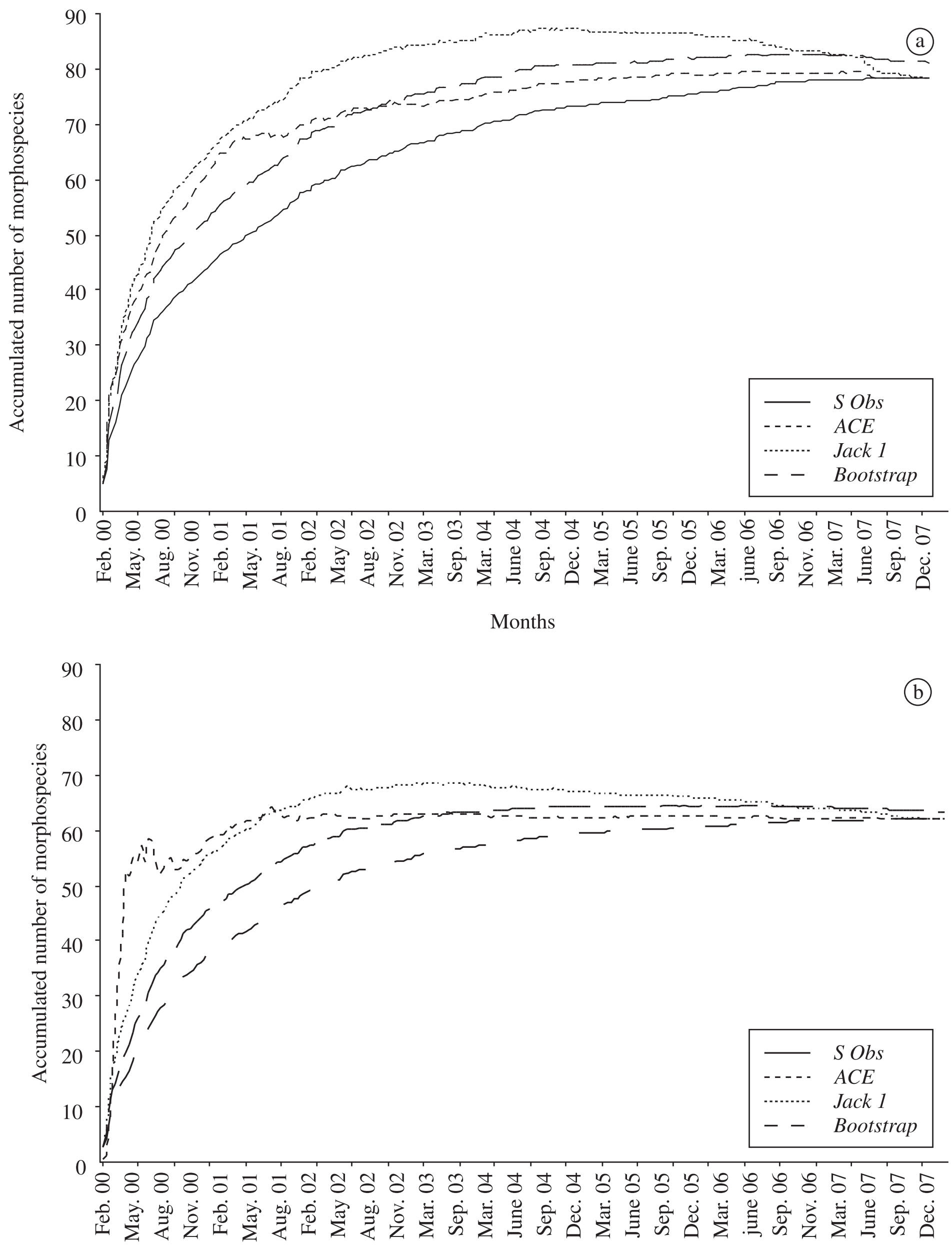

Figure 5. Richness observed (S Obs) and richness estimators ACE, Jack 1, and e Bootstrap for the a) Paraná and b) Ivinhema Rivers.

cies in the Paraná River, while in the Ivinhema River there was a large amount of variation in the dominant taxa and low values of dominance. We also noted that in the years 2000 and 2001, the dominant groups in each river were quite different. In the Paraná River the following species dominated: *Polypedilum* (*Tripodura*) sp.1, *Polypedilum* (*Polypedilum*) sp.2, *Xenochironomus* sp. 2, *Tanytarsus* sp. 1, *Lopescladius* sp. 1 and *Manoa* sp. 1. In the Ivinhema River the following species were dominant: *Apedilum* sp.2, *Polypedilum* (*Polypedilum*) sp.2 and *Cladopelma* sp.1. However, after 2002, the main dominant taxa of the Paraná River (*Polypedilum* (*Tripodura*) sp. 1, *Lopescladius* sp. 1 and *Tanytarsus* sp. 1) also became dominant in the Ivinhema River. In addition, some new taxa have become dominant in both rivers: *Coelotanypus* sp. 1, *Ablabesmyia* (*Karelia*) sp. 1, *Djalmabatista* sp. 2 and *Axarus* sp. 1. (Table 2).

Based on the Euclidian Distance Analysis (UPGMA), we saw major differences in the composition and density of Chironomidae of the Paraná River in the years 2000 and 2001. The Chironomidae community of the Ivinhema River was more similar throughout the study (Figure 6).

In the years 2000 and 2001, diversity patterns were similar for both rivers (Figure 7a). After this period, the values were more divergent because in the first samplings of 2003, 2005 and 2007, the diversity values of the Ivinhema River were much higher than those for the Paraná River. These differences were also indicated in the two-way ANOVA (Figure 7a). We verified that the density of larvae in the Paraná River increased between August and December in most years (all except for 2005). However, significant differences were observed only between the rivers (Figure 7b).

When we correlated the diversity and the density with the hydrometric levels (Spearman's rank; $p < 0.05$), we observed a positive correlation between the diversity of the Ivinhema River and the hydrometric levels ($r = 0.34$) and a negative correlation between the density of organisms in the Paraná River and the hydrometric levels ($r = -0.38$).

The index used to measure the Beta Diversity showed that in 2000 there were few changes in the composition of the community over the months studied. This pattern was not found in any of the following years. The total difference in the composition of morphospecies (1.0) was observed in February 2001 and in June and September of 2004. The greatest similarities were found after the periods of above average floods (Figure 8).

4. Discussion

The combined action of hydrological events in the Paraná and Ivinhema Rivers is primarily responsible for the geomorphological and ecological processes occurring across the floodplain (Rocha 2002). In the years 2000 and 2001 these events were severely affected by the second filling stage of the Porto Primavera Dam and aggravated by low precipitation from 1999 to 2001 (Souza-Filho et al., 2004).

The clustering observed between 2004 and 2007 in axis 1 of the PCA was influenced by the decrease in the percentages of medium and fine sand in the Paraná River, which is probably due to the geomorphological changes caused by the closing of the Porto Primavera Dam (Souza-Filho et al., 2004). The separation of the scores of the Paraná and Ivinhema Rivers, observed only in the second axis of the PCA, and the low percentage

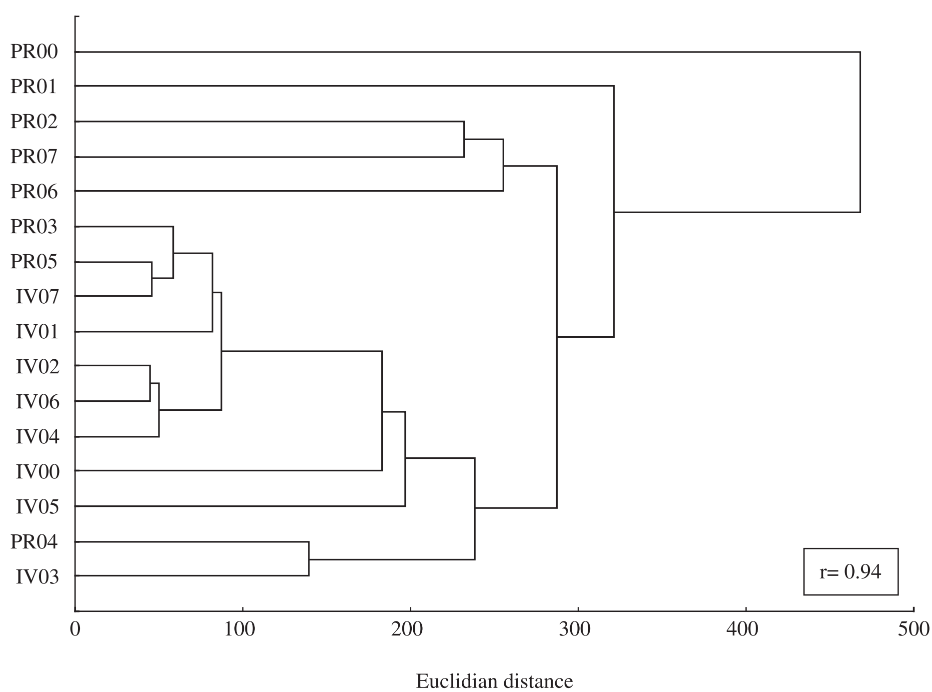

Figure 6. Cluster analyses (UPGMA) of the Chironomidae community of the rivers Paraná and based on Euclidean distance. r = cophenetic correlation (Mantel's test); PR00 = Paraná River (2000); PR01 = Paraná River (2001); PR02 = Paraná River (2002); PR03 = Paraná River (2003); PR04 = Paraná River (2004); PR05 = Paraná River (2005); PR06 = Paraná River (2006); PR07 = Paraná River (2007), IV00 = Ivinhema River (2000); IV01 = Ivinhema River (2001); IV 02 = Ivinhema River (2002); IV03 = Ivinhema River (2003); IV04 = Ivinhema River (2004); IV05 = Ivinhema River (2005); IV06 = Ivinhema River (2006); and IV07 = Ivinhema River (2007)

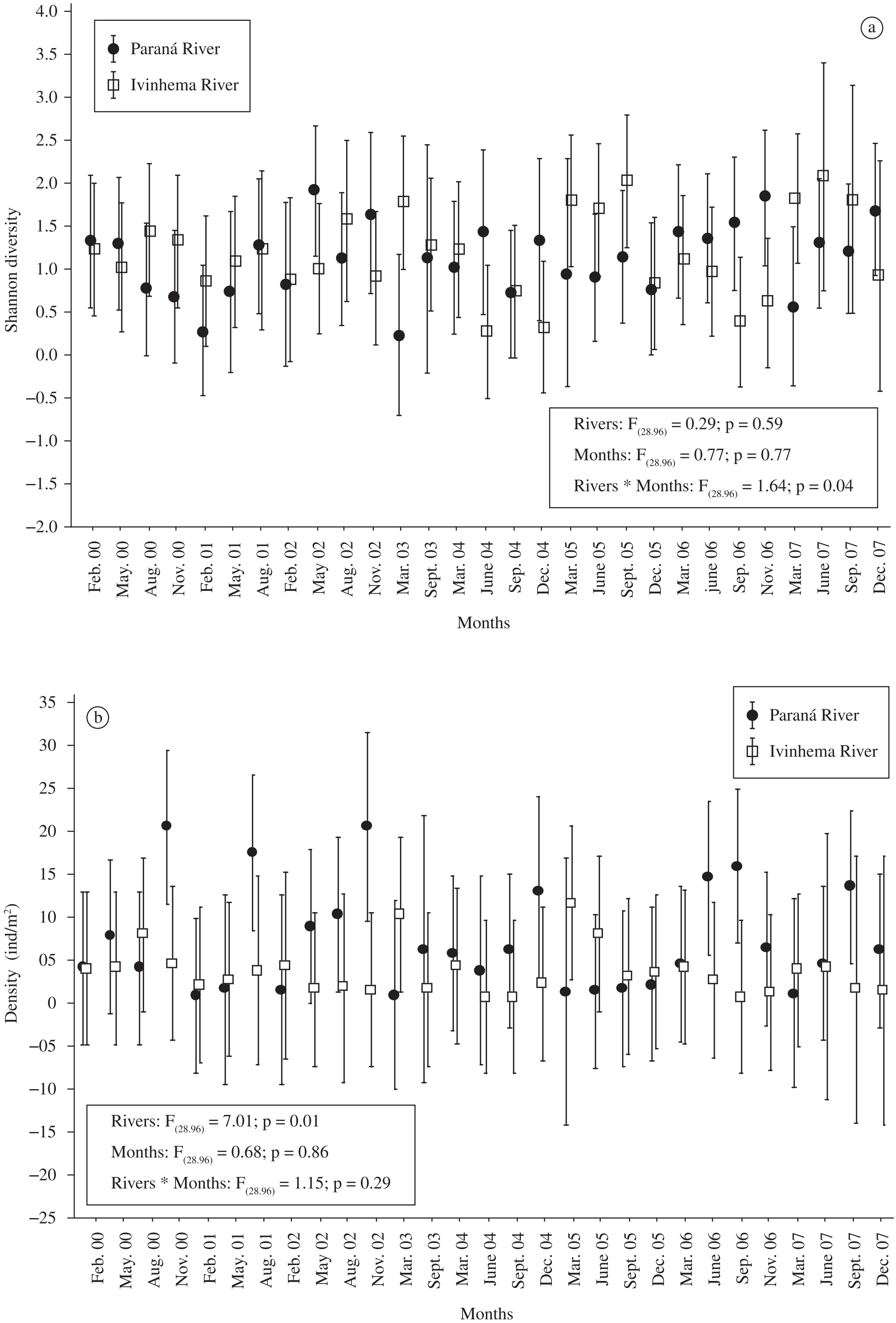

Figure 7. Mean ± SD of a) Shannon-Wiener diversity and b) medium density of the Paraná and Ivinhema Rivers in every months of sampling.

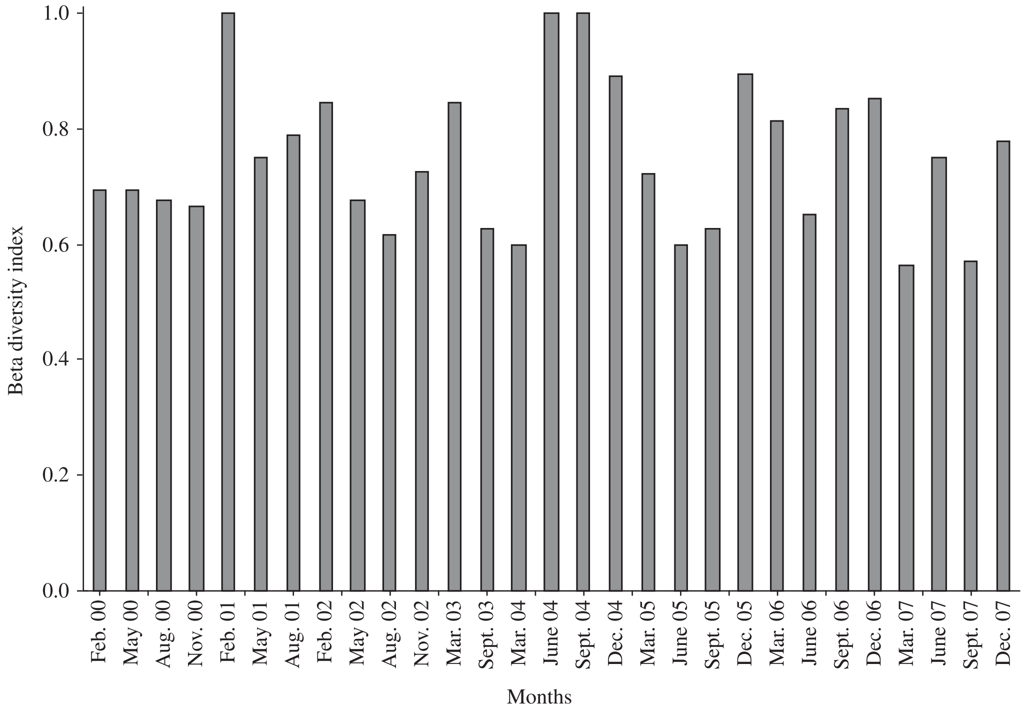

Figure 8. Beta Diversity index for every month of sampling.

of variation explained indicate that the differences in granulometric texture between these two rivers are not influential. However, the highest percentage of fine sediment in the Ivinhema River was a result of the high load of sediment carried by this river.

The high richness of Chironomidae taxa observed in the Paraná and Ivinhema Rivers in comparison with the world average for rivers of the same size (44 species according to Ferrington (2008)), emphasizes the importance of these environments for the maintenance of diversity. Higuti (2004) highlights that the richness of the lotic environments of the Upper Paraná River floodplain is greater than that found in the lentic environments since it encompasses a large part of the Chironomidae diversity of this ecosystem.

The patterns of dominance of the Ivinhema and Paraná Rivers became more similar after the year 2001. In some cases, the regulation of flow facilitates the dominance of some morphospecies (Munn and Brusven, 1991), which was probably the reason that the following species became dominant (Kownacki index) in the Paraná River and then in the Ivinhema River immediately after the second filling stage of the Porto Primavera reservoir: *Polypedilum* (*Tripodura*) sp.1, *Lopescladius* sp.1, *Tanytarsus* sp.1, *Coelotanypus* sp.1, *Ablabesmyia* (*Karelia*) sp.1, *Djalmabatista* sp.2 and *Axarus* sp.1.

The highest dominance values in the Paraná River are probably consequence of the reduction of the heterogeneity of the channel caused by the dams, since now most of the shapes of the riverbed have disappeared or are limited in size (Souza-Filho et al., 2004). On the other hand, in the Ivinhema River we observed low values of dominance, which may be indicative of an environment with a greater abundance of available resources and a lower influence of competitors and predators (Ricklefs, 2003). *Polypedilum* was the dominant genus in both environments. This can be explained by the fact that this group is cosmopolitan, opportunistic and relatively resistant to adverse conditions (Panis et al., 1996).

We saw that the years 2000 and 2001 differed from the others, not only regarding the dominance, but also the in their composition and density (indicated in the Euclidian distance analysis). According to Rocha (2002), these years correspond to a period of strong changes in the flow of the Paraná River caused by the construction of the Porto Primavera Dam. An intense drought in late 2001 was probably also an influential factor. The new composition of morphospecies and the greater similarity of the following years are indicative of the recovery and adaptation of the community. The Chironomidae family is extraordinarily rich in species and has a high ecological plasticity, which gives makes this group successful in colonizing several types of environments (Cranston, 1995).

Through the Shannon-Wienner diversity index and the Spearman Rank, we confirmed that there is a connection between the events in the Paraná and Ivinhema Rivers after an above-average flood such as those in 2005 and 2007. We saw higher values of diversity in the Ivinhema River, while a decrease in density was observed in the Paraná River. These decreases in density in the Paraná River are likely related to increases in flow that can have deleterious effects on the benthic biota, and could even eliminate much of this community due to the "Shear Stress" (Layzer et al., 1989; Bunn and Arthington, 2002). However, in the Ivinhema River, the major floods seem to act as an incentive to the community, which responds by increasing the diversity of organisms.

Regardless of annual variations, there was an increase in the density of larvae in the Paraná River each spring. Rosin (2007) reports that this period is an important time of reproduction for these insects, and that they can even be multivoltinuous. In addition, in periods of low water, there is a reconstruction of habitat, favoring the permanence of the benthic community.

The values of Beta Diversity and the hydrometric levels were negatively correlated. This means that in the years that the flooding reached over 5.5 m, the composition of the community was more similar (lower values of Beta Diversity). The caused an increase in the connectivity between environments and a drift of organisms during periods of high waters. Similar results were found by Amoros and Bornette (2002) for the zoobenthic community.

It was evident that the major structural changes in the Chironomidae community occurred immediately after the end of the second filling stage of the Porto Primavera Dam and that in subsequent years the community has adapted to the new conditions, entering into new cycles and patterns of dominance.

Despite the sequence of damming, the Chironomidae community continues to respond to fluctuations in the hydrometric levels, maintaining periods of diversity and reproduction even when there are differences in composition. We can also consider that, despite being free of dams, the Ivinhema River is also influenced by the events occurring in the Paraná River because the diversity increases in the Ivinhema River after flood periods.

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Appendix 1. Morphospecies list and relative frequency of Chironomidae taxa (%) in the Paraná and Ivinhema Rivers. PR 00-01 = Paraná River (2000-2001); PR 02-03 = Paraná River (2002-2003); PR 04-05 = Paraná River (2004-2005); PR 06-07 = Ivinhema River (2006-2007); IV 00-01 = Ivinhema River (2000-2001); IV 02-03 = Ivinhema River (2002-2003); IV 04-05 = Ivinhema River (2004-2005); and IV 06-07 = Ivinhema River (2006-2007).

	PR 00-01	**PR 02-03**	**PR 04-05**	**PR 06-07**	**IV 00-01**	**IV 02-03**	**IV 04-05**	**IV 06-07**
TANYPODINAE								
Tanypodinae spp.	0.11	0.00	0.00	0.26	0.00	0.00	0.00	0.00
Coelotanypodini								
Clinotanypus sp.1	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00
Coelotanypus sp.1	0.11	0.17	14.59	1.74	3.02	4.20	2.30	3.24
Pentaneurini								
Ablabesmyia (*Karelia*) sp.1	0.44	1.52	4.20	5.37	0.23	0.35	10.54	5.09
Larsia sp. 1	0.00	0.00	0.00	0.05	0.23	0.00	0.00	0.00
Procladiini								
Djalmabatista pulcher (Johannsen, 1908)	0.11	0.17	0.12	0.15	2.09	0.35	0.19	0.00
Djalmabatista sp.2	0.55	0.51	4.82	1.74	1.62	5.94	4.21	8.80
Djalmabatista sp.3	0.00	0.00	0.00	0.00	0.00	3.50	1.92	0.00
Djalmabatista sp.4	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00
Procladius sp.1	0.00	0.00	0.00	0.00	0.00	0.70	0.77	0.46
Tanypodini								
Tanypus sp.1	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00
CHIRONOMINAE								
Chironomini								
Apedilum sp.2	0.00	0.00	0.00	0.00	6.26	0.00	0.00	0.00
Axarus sp.1	0.55	3.86	0.00	0.00	6.26	1.05	4.98	4.63
Beardius sp.1	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00
Beardius sp.2	0.00	0.00	0.00	0.00	0.23	0.00	0.38	0.00
Chironomus spp.	0.55	0.34	0.00	0.00	0.70	0.70	0.38	0.46
Chironomus antonioi (Correia and Trivinho-Strixino, 2007)	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Chironomus fittkaui (Correia and Trivinho-Strixino, 2007)	0.11	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Chironomus gr. *salinarius* sp.1	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00
Chironomus gr. *decorus* sp.1	0.00	0.51	0.12	0.00	0.00	0.00	0.00	0.00
Chironomus sp.1	0.00	0.00	0.00	0.00	0.70	1.05	0.96	0.93
Chironomus sp.2	0.00	0.00	0.00	0.00	0.70	0.35	0.00	0.00
Cladopelma sp.1	0.00	0.00	2.22	1.79	11.14	0.35	0.19	0.00
Cladopelma sp.2	0.00	0.00	0.00	0.00	2.32	1.05	0.96	0.00
Complexo Harnischia spp.	0.11	0.00	0.00	0.00	0.23	0.00	0.00	0.46
Cryptochironomus sp.1	1.66	0.34	1.85	0.20	2.32	0.00	0.19	1.39
Cryptochironomus sp.2	0.00	5.10	1.48	4.19	0.00	0.35	1.53	4.63
Demicryptochironomus sp.1	1.88	0.00	0.62	0.00	0.00	0.00	0.00	0.00
Demicryptochironomus sp.2	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dicrotendipes spp.	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dicrotendipes sp.1	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00
Dicrotendipes sp.3	0.11	0.00	0.00	0.10	0.00	0.00	0.00	0.00
Endotribelos sp.1	0.00	1.18	0.25	0.10	0.00	0.00	2.49	0.00
Endotribelos sp.2	0.44	0.60	0.37	0.15	0.93	2.80	0.38	1.39
Fissimentum dessicatum (Cranston and Nolte, 1996)	0.00	1.11	0.12	0.00	2.09	0.00	0.19	0.00

Appendix 1. Continued...

	PR 00-01	PR 02-03	PR 04-05	PR 06-07	IV 00-01	IV 02-03	IV 04-05	IV 06-07
Fissimentum sp.2	0.22	0.51	0.12	0.20	0.70	0.00	0.19	0.00
Fissimentum sp.3	0.78	0.17	0.00	0.15	0.00	0.00	0.00	0.00
Goeldichironomus luridus (Trivinho-Strixino and Strixino, 2005)	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00
Goeldichironomus xiborena (Reiss, 1974)	0.00	0.00	0.00	0.00	0.00	1.05	0.00	0.00
Goeldichironomus gr. *pictus* sp.1	0.00	0.00	0.00	0.00	2.09	1.05	0.19	0.00
Pelomus sp.1	0.00	0.00	0.00	0.00	0.23	0.35	0.00	0.00
Lauterborniella sp.1	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00
Nilothauma sp.1	0.22	0.17	0.00	0.10	0.00	0.00	0.00	0.00
Nilothauma sp.2	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.00
Parachironomus spp.	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parachironomus sp.1	0.00	0.68	1.48	0.10	0.23	1.05	1.92	3.70
Parachironomus sp.2	0.00	0.00	0.12	0.00	0.00	0.00	0.96	0.00
Parachironomus sp.4	0.00	0.00	0.12	0.20	0.00	0.00	0.00	0.00
Paralauterborniella sp.1	0.00	0.00	0.12	2.40	0.00	0.70	0.96	0.00
Phaenopsectra sp.1	0.11	0.17	0.00	0.61	0.00	0.00	0.00	0.00
Phaenopsectra sp.2	0.44	0.00	0.00	0.77	0.00	0.00	0.00	0.00
Polypedilum (*Asheum*) sp.1	0.00	1.02	0.00	0.05	0.23	0.00	1.15	0.00
Polypedilum (*Polypedilum*) sp.1	0.11	0.00	0.00	0.36	6.03	1.05	1.34	0.00
Polypedilum (*Polypedilum*) sp.2	4.32	5.60	0.62	4.85	28.31	0.70	1.72	0.46
Polypedilum (*Polypedilum*) sp.3	0.00	0.00	0.00	0.00	0.00	1.75	0.77	0.93
Polypedilum (*Tripodura*) sp.1	38.80	27.49	24.35	31.32	3.48	8.39	20.31	6.48
Polypedilum (*Tripodura*) sp.2	0.00	3.06	0.00	2.96	0.00	0.00	0.00	0.00
Robackia sp.1	0.33	0.51	0.00	0.15	9.51	0.35	0.38	0.46
Robackia sp.2	0.00	0.00	0.00	0.00	1.39	0.00	0.19	0.00
Saetheria tylus (Townes, 1945)	0.67	0.00	0.25	0.10	0.00	0.00	0.00	0.00
Saetheria sp.1	0.00	0.34	0.74	0.15	0.00	1.75	0.96	2.31
Saetheria sp.2	0.00	0.17	0.87	0.00	0.00	0.00	0.00	0.00
Stenochironomus sp.1	0.00	0.00	0.00	0.15	0.00	0.00	1.72	1.39
Xenochironomus sp.2	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zavreliella sp.2	0.00	0.00	0.00	0.00	0.00	0.35	0.38	1.85
Pseudochironomini								
Pseudochironomini spp.	0.11	0.00	0.00	0.15	0.00	0.00	0.00	0.00
Aedokritus sp.1	0.00	0.17	0.12	0.05	0.23	1.75	0.77	0.00
Manoa sp.1	9.31	1.69	1.98	3.53	0.00	0.00	0.00	0.00
Pseudochironomus sp.1	0.22	0.17	0.25	0.26	0.00	0.00	0.00	0.00
Pseudochironomus sp.2	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00
Pseudochironomus sp.3	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
Tanytarsini								
Tanytarsini spp.	0.22	0.00	0.00	0.41	0.00	0.00	0.00	0.00
Caladomyia spp.	0.00	0.00	0.00	0.05	2.78	0.00	0.57	0.00
Caladomyia castelnaiu (Säwedal, 1981)	0.00	0.00	0.00	0.00	0.23	0.70	0.19	0.93
Caladomyia ortoni (Säwedal, 1981)	0.44	0.00	0.12	0.26	0.00	0.00	0.00	0.46
Caladomyia riotarumensis (Reiff, 2000)	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caladomyia sp.1	0.00	0.17	0.12	0.56	0.00	0.00	0.00	0.00
Caladomyia sp.2	0.00	0.00	0.00	0.05	0.00	0.00	0.57	0.00
Caladomyia sp.3	0.00	0.00	0.00	0.00	1.62	3.85	3.45	0.00

Appendix 1. Continued...

	PR 00-01	PR 02-03	PR 04-05	PR 06-07	IV 00-01	IV 02-03	IV 04-05	IV 06-07
Rheotanytarsus sp.1	0.00	0.00	0.00	0.20	0.00	0.00	8.62	0.00
Rheotanytarsus sp.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.19
Stempellina sp.1	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00
Stempellinela sp.1	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00
Tanytarsus spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00
Tanytarsus rhabdometis (Trivinho-Strixino and Strixino, 1991)	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00
Tanytarsus sp.1	15.63	12.79	29.30	9.76	1.86	25.87	1.15	0.93
Tanytarsus sp.2	0.00	0.17	0.12	0.26	0.00	0.00	0.00	1.39
Tanytarsus sp.3	0.00	0.68	0.00	0.20	0.00	0.70	0.00	1.39
Tanytarsus sp.4	0.00	0.00	0.00	0.87	0.00	0.00	0.00	0.00
ORTHOCLADIINAE								
Orthocladiinae spp.	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Corynoneura sp.1	0.00	0.00	0.12	0.00	0.00	0.35	0.38	0.00
Corynoneura sp.2	0.00	0.00	0.00	0.00	0.00	0.00	0.19	3.70
Cricotopus sp.1	3.66	1.18	2.10	10.32	0.00	0.35	0.19	0.00
Cricotopus sp.2	0.11	0.00	0.00	0.66	0.00	0.00	0.00	0.00
Cricotopus sp.3	1.55	3.38	1.48	7.66	0.00	1.40	0.77	0.93
Lopescladius sp.1	14.86	23.63	4.20	1.89	0.00	22.73	15.90	29.63
Nanocladius sp.1	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.00
Onconeura sp.1	0.00	0.00	0.00	0.15	0.00	0.00	0.00	1.39
Thienemanniella sp.1	0.00	0.00	0.00	0.05	0.00	0.35	0.00	0.00
Thienemanniella sp.3	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00