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Effect of atypical rainfall on lotic zooplankton: comparing downstream of a reservoir and tributaries with free stretches

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Abstract: To contribute to the knowledge of lotic zooplankton from dammed and free stretches, we tested the hypothesis that the ecological attributes are different between these environments, which are subjected to several effects caused by different hydrological conditions. The study was carried out in the low Iguaçu river, a large hydrographic basin in the south of Brasil. Two samplings were performed, one in the dry period (April/04) and the other in the atypical rainy period (July/04), in five stations downstream a large reservoir, and other 12 stations in four tributaries representing the upper, intermediate and low regions of each river. The observations suggest a clear spatial distribution of zooplankton in lotic stretches subjected or not to damming, mainly due to the effects of physical, chemical and biological variables. Furthermore, the atypical rainfall promoted alterations in community structure when compared to the dry period.

Resumen: Con el fin de contribuir al conocimiento del zooplancton lótico en tramos libres y represados, pusimos a prueba la hipótesis de que los atributos ecológicos difieren entre estos ambientes, los cuales están sujetos a los efectos de diferentes condiciones hidrológicas. El estudio se realizó en el bajo río Iguazú, una gran cuenca hidrográfica del sur de Brasil. Se realizaron dos muestreos, uno en el periodo seco (abril 04) y el otro en el periodo de lluvia atípica (julio 04), en cinco estaciones corriente abajo de un embalse grande y otras 12 estaciones en cuatro tributarios que representan las regiones superior, intermedia y baja de cada río. Las observaciones sugieren una clara distribución espacial del zooplancton en los tramos lóticos dependiente de si están sujetos o no al represamiento del agua, principalmente debido a los efectos de variables físicas, químicas y biológicas. Además, la lluvia atípica causó alteraciones en la estructura de la comunidad en comparación con el periodo seco.

Resumo: Para contribuir para o conhecimento do zooplâncton lótico em trechos com represamentos e trechos livres, testou-se a hipótese de que os atributos ecológicos são distintos entre esses tipos de ambientes, os quais sofrem vários efeitos devido às diferentes condições hidrológicas. O estudo foi realizado no baixo rio Iguaçu, uma grande bacia hidrográfica sub-tropical no sul do Brasil. Foram realizadas duas amostragens, uma no período seco (abril/04) e outra no período chuvoso atípico (julho/04), em cinco pontos a jusante de um grande

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reservatório, e outros 12 pontos em quatro tributários representando as porções superiores, intermediárias e inferiores de cada rio. As observações sugerem que há uma nítida distribuição espacial do zooplâncton em trechos lóticos sob e sem influência de represamento, principalmente através do efeito de variáveis físicas, químicas e biológicas. Adicionalmente, a pluviosidade atípica promoveu alterações na estrutura da comunidade quando comparada ao período seco.

Key words Cladocera, Copepoda, Iguaçu river, reservoir, Rotifera, tributaries.

Introduction

In lotic environments, the factors that influence the structure and dynamics of planktonic communities are generally focused on two categories: (i) factors that affect the drift of these organisms from areas of backwaters, lateral channels, marginal lakes and reservoirs (where higher populations are developed); and (ii) factors that affect their growth and reproduction (for example, high sediment load carried by the river may inhibit phytoplankton production and reduce the availability of resources to zooplankton) (Hynes 1970; Ward 1989).

The dynamics of the ecological attributes of zooplankton are well known in lakes and reservoirs in the neotropics, however, few studies have been conducted in lotic environments. In Brasil, studies on the potamoplankton are particularly rare, except for studies in the Amazon region (Bozelli & Huszar 2003), in Paranapenama river (Casanova & Henry 2004) and in the floodplain of Paraná river (Lansac-Tôha *et al.* 2004). Other studies in lotic environments in the tropical region are from Paggi & José de Paggi (1990) in the intermediate stretch of Paraná river, and Frutos *et al.* (2006) in Paraguay river that compared the flood and drought periods along the entire length of the river.

In these lotic environments, zooplankton is found at low densities and is dominated by protozoans, small cladocerans, rotifers and copepoda nauplii (Paggi & Paggi 2007; Robertson *et al.* 1997). Factors related to the transport and locomotion of plankton (hydrological factors - discharge, residence time) should be taken into consideration since plankton swimming capacity is inefficient and those factors act directly on development and reproduction (Hynes 1970). Besides, there is also the influence of physical (light, temperature), chemical (nutrient concentration) and biotic factors (competition and predation) (Reynolds 1997; Viroux 2002), the seasonal variation being dependent on the hydrological regime (precipitation) (Basu & Pick 1996; Tundisi & Straskaba 1999).

According to Towsend *et al.* (1997), atypical rainfall events (e.g. a heavy rain for hours or days) can amount to considerable disturbance to planktonic communities, causing alterations in the physical environment. High mortality or removal of zooplankton might occur due to the increase in flow and turbidity, followed by a gradual return and re-colonization of the communities, once the environmental conditions are closer to the original state for the site.

Longitudinal gradients are observed in the rivers, according to the continuum proposed by Vannote *et al.* (1980). According to these authors, most environmental variables increase towards the mouth of the river and there is an increase in primary and secondary production in the same direction.

This longitudinal gradient suffers a discontinuity due to the influence of damming (Junk *et al.* 1989) that changes physical and chemical conditions of the water released downstream in the lotic environment (Naliato *et al.* 2009), especially in the retention of suspended solids, temperature and dissolved oxygen. Shifts in zooplankton are also noticed (Mitsuka & Henry 2002) with reduced abundance and increased organism richness in long stretches (Viroux 2002). In rivers where several dams were built in sequence, the cascade systems were formed, and thus, enhanced the limnological alterations (physical, chemical and biological) due to the flooding of areas and modifications in the operational regime of the system (Agostinho *et al.* 1997; Naliato *et al.* 2009; Nogueira *et al.* 2006; Tundisi & Tundisi 2003).

In the present study some ecological attributes of zooplankton were evaluated in the lower portion of the hydrographic basin of Iguaçu river under the influence of damming and its regional tribu-

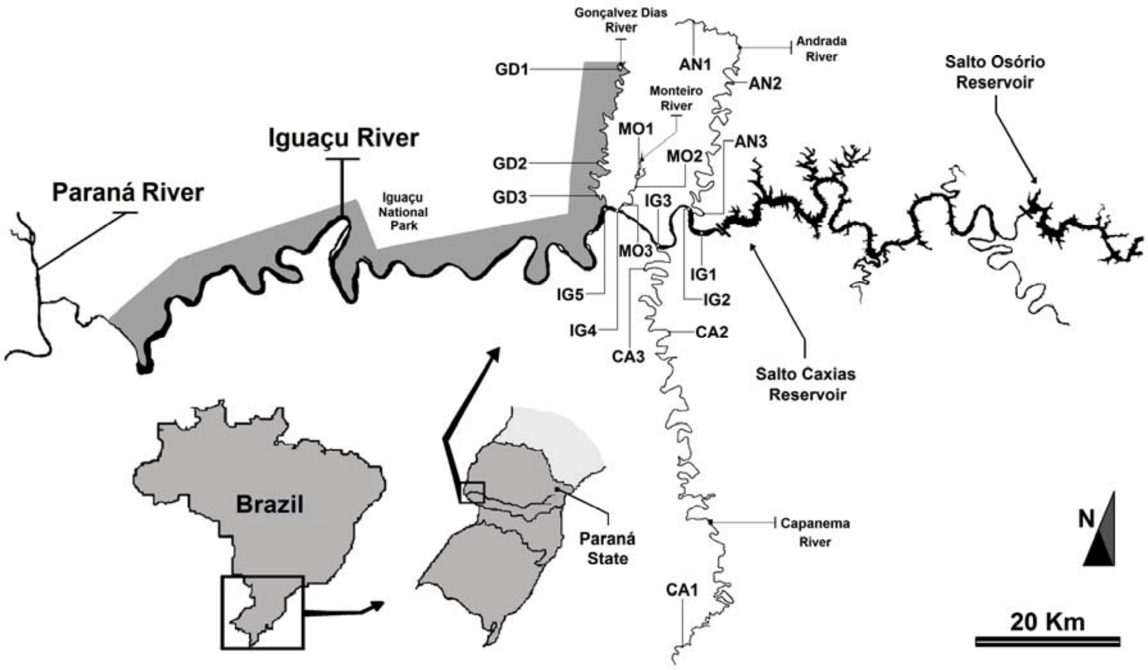

Fig. 1. Map of the study area and sampling stations in Iguaçu River and tributaries.

taries free of damming. We tested the hypothesis that the ecological attributes are different between these types of lotic environments (with and without damming) also exhibiting longitudinal gradients in tributaries towards head-mouth direction. The tributaries are subjected to quick changes under the effects of rainfall in atypical conditions, due to oscillations of the limnological variables and to the hydrology. In the rivers subjected to the damming effects, these variations are lower, even during atypical rainfall.

Material and methods

Study area

The Iguaçu river is the largest in the state of Paraná and one of the main tributaries of the upper Paraná river, with a length of 910 km (Maack 1981). It is formed by the confluence of the rivers Iraí and Atuba in the metropolitan region of Curitiba and its mouth is situated in Paraná river, in the city of Foz do Iguaçu. Close to its mouth, are the Iguaçu Falls, one of the largest waterfalls in the world. Important tributaries of its basin are: Negro, Areia, Jordão, Chopim, Gonçalves Dias and Castro Alves.

There are five large reservoirs for energy generation in Iguaçu river, all of them with up to 80 km^2 of surface area: Foz do Areia, Salto Segredo, Salto Santiago, Salto Osório and Salto Caxias. Together, they total 753.98 km^2 of surface area and an installed generating capacity of 6,644 megawatts (6.54 % of the national production). In general, all are dendritic and deep, varying from 60 m in Salto Caxias to 180 m in Foz do Areia.

The stretch of the hydrographic basin studied was situated downstream Salto Caxias reservoir, the last in Iguaçu river, and extended over 30 km to the upper limit of Iguaçu National Park. Salto Caxias reservoir has an area of 144.2 km^2, mean depth of 15 m and mean residence time around 15 days. The lotic, intermediate and lentic compartments of the central body are quite distinct.

The dominant terrestrial biome is the Atlantic Forest, which represents semi deciduous and mixed ombrofilous (Araucária Forest) vegetation, covering an area of 185,262.20 ha. Koppen's classification indicates the existence of a wet subtropical climate, with pronounced summer (CFA), dry winter and weak possibility of drought in the same season, characterizing a Cw climate type. The average annual rainfall is 1,000 mm. Atypical periods of rainfall may occur, as observed in this study.

Seventeen stations were chosen, five in Iguaçu river and under the influence of Salto Caxias reservoir (25° 31’ 59.30” S - 53° 28’ 53.33” W) and twelve stations distributed in the four major tributaries (Andrada, Capanema, Gonçalvez Dias and

Monteiro Rivers), in the upper (heads), intermediate and low stretches of each one, these stretches being classified according to width (Fig. 1). Two samplings were carried out, in the dry (April/04) and in the atypical rainy period (July/04).

The first station was situated 3.5 km downstream the dam in Iguaçu river, its width varies from 270 m to 950 m and depth from 1 m to up to 20 m in the narrowings. In tributaries, the station in the heads of Capanema river (CA1) was the farthest from Iguaçu river (60 km) and also the station with the smallest width (5 - 7 m). In area, Capanema river basin is the largest and Monteiro river is the smallest compared to the others.

Zooplankton was sampled using a 20 L bucket, filtering 200 L of water per sample in a conical plankton net 65 µm of mesh size, in the central channels of the rivers. The material was preserved with formaldehyde (4 %) buffered with calcium carbonate.

Some physical and chemical parameters were measured, such as temperature, pH, dissolved oxygen, and conductivity, using a Horiba U - 10 field meter. Water samples (5 L) were collected for the evaluation of chlorophyll-a, nutrients (silicate, total phosphorus, nitrite, nitrate, and ammonium) and suspended matter. The chlorophyll-a and pheophytin concentrations were determined by filtering 500 mL of the water sample. The extraction was made through manual maceration of the filters (Millipore AP40) in cold 90 % acetone (Talling & Driver 1963). Data of chlorophyll-a and pheophytin can be used as an indicator of phytoplankton biomass (Reynolds 1989) as well as for water quality classification in Brasil (Conama 2005). Silicate, total phosphorus, nitrite/nitrate, ammonium and suspended matter concentrations were measured following the methodologies of Cole (1979), Golterman *et al.* (1978), Koroleff (1976), Marckereth *et al.* (1978) and Strickland & Parsons (1960) (gravimetric method), respectively.

Laboratory and data analyses

The zooplanktonic groups (Rotifera, Cladocera and Copepoda) were identified to the lowest taxonomic level possible using specialized literature, Rotifera: Koste (1978a,b), Cladocera: Smirnov (1996), Korínek (1987), Elmoor-Loureiro (1997), Hollwedel *et al.* (2003), Elmoor-Loureiro *et al.* (2004), Elmoor-Loureiro (2007), and Copepoda: Reid (1985), Matsumura-Tundisi (1986), Dussart & Defaye (1995), Rocha & Güntzel (1999), Santos-Silva (2000), Paggi (2001), and quantified through subsamples using Hensen Stempel pipettes. Bdeloidea rotifers, Harpacticoida copepods as well as nauplii and copepodites of Cyclopoida and Calanoida were quantified only to this taxonomic level. Rotifers and copepod nauplii were counted in Sedgwick-Rafter chambers and adult cladocerans and adult and copepodites of copepods in gridded acrylic Petri dishes, under optical microscope and stereomicroscope, respectively. A minimum of 200 individuals of each zooplanktonic group was quantified and the final density was expressed in individuals per m^3. Samples with low densities were totally analyzed.

Besides individual abundance, taxa richness (number of taxa in samples) and the Shannon-Wiener diversity index ($H' = \Sigma pi.\log_2.p_i$), where, pi is the proportion of taxon $_i$ in the sample, were also evaluated.

The Kruskal-Wallis test (to non-parametric data) was applied to the ecological attributes in order to compare abundance, richness and diversity values in Iguaçu river and tributaries (separately for the upper, intermediate and low regions) and also between dry and rainy periods.

To ordinate physical, chemical and biological variables in a spatial-temporal scale, a principal component analysis (PCA) was applied, after data transformation (logX+1).

In order to correlate zooplankton with the variables above, a canonical correspondence analysis was used (CCA) with 1,000 permutations and a significance level of 0.1. Only significant correlations were shown. To reduce and simplify the scientific names of the species used in CCA, we used the first letter referring to genus and the three next, referring to the species.

Kruskal-Wallis and normality tests were performed using Statistica 6.0 software (Statsoft 2002). The PCA and CCA were performed using the "R" software (R Development Core Team 2009).

Results

Physical, chemical and biological variables were higher in tributaries than in Iguaçu river (Table 1). In tributaries, variables did not differ among sampling stations in the longitudinal axis of each river, except for water temperature that increased downstream during the dry period.

In Iguaçu river, for each evaluated variable and depending on the period, a tendency of increase was noticed towards IG1 → IG5 direction. Thus,

Table 1. Mean (± standard deviation) and eigenvalues of principal component analysis of the physical, chemical and biological variables measured in Iguaçu river and in the tributaries, in dry (D) and rainy (R) periods (atypical rainy period). Codes: Cond = conductivity (μs cm^{-1}); DO = dissolved oxygen (mg L^{-1}); Temp = water temperature (ºc); Chlor = chlorophyll (μg L^{-1}); Pheo = pheophytin (μg L^{-1}); SM = suspended matter (mg L^{-1}); TN = total nitrogen; TP = total phosphorus (μg L^{-1}); $Si(OH)_4$ = Silicate (mg L^{-1}).

	Iguaçu River				Tributaries					
	IG1		IG5		High		Middle		Low	
	D	R	D	R	D	R	D	R	D	R
pH	7.17	7.5	7.83	7.36	7.86 ± 0.17	7.51 ± 0.20	7.94 ± 0.46	7.41 ± 0.20	7.85 ± 0.30	7.42 ± 0.15
Cond	1.65	1.71	1.77	1.71	1.78 ± 0.16	1.75 ± 0.13	1.83 ± 0.18	1.79 ± 0.12	1.82 ± 0.14	1.79 ± 0.10
DO	5.8	7.8	7.9	7.3	7.44 ± 0.25	7.5 ± 0.29	7.23 ± 0.57	7.82 ± 0.39	7.12 ± 0.43	7.62 ± 0.32
Temp	25	18.5	26.1	18.4	25.55 ± 2.11	18.35 ± 1.18	26.07 ± 2.15	18.17 ± 1.26	27.3 ± 1.60	18.37 ± 0.26
Chlor	0.21	0.22	0.25	0.19	0.45 ± 0.46	0.18 ± 0.14	0.53 ± 0.48	0.12 ± 0.10	0.62 ± 0.47	0.21 ± 0.20
Pheo	0.16	0.28	0.18	0.22	0.23 ± 0.14	0.24 ± 0.23	0.27 ± 0.11	0.11 ± 0.10	0.33 ± 0.14	0.22 ± 0.28
SM	0.56	0.98	0.81	0.70	0.73 ± 0.14	1.11 ± 1.11	0.74 ± 0.20	0.88 ± 0.38	0.78 ± 0.21	1.01 ± 0.68
PO_4	0.11	0.09	0.09	0.14	0.26 ± 0.15	0.12 ± 0.06	0.26 ± 0.15	0.12 ± 0.06	0.21 ± 0.13	0.15 ± 0.04
NO_2	0.29	0.12	0.19	0.21	0.43 ± 0.31	0.26 ± 0.19	0.36 ± 0.18	0.43 ± 0.51	0.33 ± 0.17	0.5 ± 0.41
NO_3	1.27	1.37	1.28	1.34	1.22 ± 0.14	1.35 ± 0.07	1.22 ± 0.13	1.33 ± 0.23	0.92 ± 0.55	1.38 ± 0.24
NH_4	1.12	1.73	0.90	1.63	1.5 ± 0.15	1.57 ± 0.65	1.64 ± 0.66	2.2 ± 1.35	1.91 ± 0.87	2.21 ± 0.94
$Si(OH)_4$	2.18	1.94	2.17	1.94	2.35 ± 0.07	2.06 ± 0.01	2.38 ± 0.04	2.1 ± 0.09	2.37 ± 0.09	2.13 ± 0.09
TN	1.44	1.46	1.45	1.48	1.45 ± 0.31	1.52 ± 0.21	1.41 ± 0.25	1.38 ± 0.14	1.38 ± 0.20	1.36 ± 0.31
TP	0.25	0.32	0.31	0.39	1.16 ± 1.21	0.33 ± 0.07	0.42 ± 0.15	0.44 ± 0.24	0.63 ± 0.30	0.92 ± 0.96
N/P	2.42	2.01	2.01	1.78	1.42 ± 0.46	1.89 ± 0.25	1.41 ± 0.40	1.89 ± 0.14	1.34 ± 0.66	1.79 ± 0.20

Table 2. List of zooplanktonic taxa in Iguaçu river and tributaries, with abreviatures to use in the CCA.

Species	Ab.	Species	Ab.
Bdeloidea	Bde	*Proales* sp.	Prsp
Collotheca sp.	Colsp	*Polyarthra dolichoptera* (Idelson, 1925)	Pdol
Conochilus coenobasis (Skorikov, 1914)	Ccoe	*Polyarthra remata* (Skorikov, 1896)	Prem
Conochilus dossuarius (Hudson, 1875)		*Polyarthra vulgaris* (Carlin, 1943)	Pvul
Filinia longiseta (Ehrenberg, 1834)		*Trichocerca bicristata* (Gosse, 1887)	
Filinia opoliensis (Zacharias, 1898)		*Trichocerca capucina* (Wierzejski & Zacharias, 1893)	
Ptygura sp.		*Trichocerca cylindrica chattoni* (De Beauchamp, 1907)	
Hexarthra mira mira (Hudson, 1871)		*Trichocerca insignis* (Herrick, 1885)	Tins
Anuraeopsis navicula (Rosselet, 1910)	Anav	*Trichocerca pusilla* (Lauterborn, 1898)	Tpus
Brachionus calyciflorus (Pallas, 1766)	Bcaly	*Trichocerca similis grandis* (Hauer, 1965)	
Brachionus caudatus caudatus (Barrois & Daday, 1894)		*Macrochaetus sericus* (Thorpe, 1893)	
Brachionus caudatus personatus (Ahlstrm, 1940)		*Trichotria tetractis* (Ehrenberg, 1830)	
Brachionus falcatus falcatus (Zacharias, 1898)		*Acroperus harpae* (Baird, 1843)	
Brachionus mirus reductus (Koste, 1972)		*Alona guttata* (Sars, 1862)	
Brachionus quadridentatus (Hermanns, 1783)		*Alona monocantha* (Sars, 1901)	

Contd...

Table 2. Continued.

Species	Ab.	Species	Ab.
Kellicottia bostoniensis (Rousselet, 1908)		*Chydorus eurynotus* (Sars, 1901)	
Keratella americana (Carlin, 1943)		*Oxyurella ciliata* (Bergamim, 1931)	
Keratella cochlearis (Gosse, 1851)	Kcoc	*Leydigia* sp.	
Keratella lenzi (Hauer, 1953)		*Bosmina hagmanni* (Stingelin, 1904)	
Keratella tropica (Apatein, 1907)		*Bosmina longirostris* (Müller, 1785)	Blong
Platyias quadricornis quadricornis (Ehrenberg, 1832)	Pqua	*Bosminopsis deitersi* (Richard, 1895)	Bdeit
Platyonus patulus var. *macranthus* (Daday, 1905)	Pmacr	*Ceriodaphnia cornuta* (Sars, 1886)	Ccor
Lepadella patella (O. F. Müller, 1786)		*Ceriodaphnia laticaudata* (Müller, 1867)	Clati
Lepadella tenella (Wulf, 1942)		*Ceriodaphnia silvestrii* (Daday, 1902)	
Euchlanis dilatata (Ehrenberg, 1832)	Edil	*Daphnia gessneri* (Herbst, 1967)	
Euchlanis meneta (Myers, 1930)		*Diaphanossoma* sp.	
Ascomorpha ovalis (Bergendahl, 1892)	Aova	*Macrothrix paulensis* (Sars, 1900)	
Gastropus hyptopus (Ehrenberg, 1838)		*Moina minuta* (Hansen, 1899)	
Lecane bulla (Gosse, 1851)	Lbul	*Moina reticulata* (Daday, 1905)	
Lecane cf. *crepida* (Harring, 1914)		*Notodiaptomus conifer* (Sars, 1901)	
Lecane cornuta (Müller, 1786)		*Notodiaptomus* cf *deitersi* (Poppe, 1981)	
Lecane curvicornis (Murray, 1913)	Lcurv	*Notodiaptomus iheringi* (Wright, 1935)	
Lecane elegans (Harring, 1914)		*Notodiaptomus henseni* (Dahl, 1891)	
Lecane elsa (Hauer,1931)	Lels	*Acanthocyclops robustus* (G. O. Sars, 1863)	
Lecane hornemanni (Ehrenberg, 1834)		*Eucyclops serrulatus* (Fisher, 1851)	
Lecane ludwigii (Eckstein, 1883)		*Metacyclops* sp.	
Lecane luna (O.F.Müller, 1776)	Lluna	*Metacyclops mendocinus* (Wierzejski, 1892)	
Lecane lunaris (Ehrenberg, 1832)	Llun	*Mesocyclops longisetus curvatus* (Thiébaud, 1914)	
Lecane thienemanni (Hauer, 1938)		*Microcyclops anceps anceps* (Richard, 1897)	Mian
Lecane cf. *urna* (Nogrady, 1962)		*Microcyclops finitimus* (Dussart, 1984)	
Mytilina bisulcata (Lucks, 1912)		*Microcyclops ceibaensis* (Marsh, 1919)	
Mytilina ventralis (Ehrenberg, 1832)	Mvent	*Microcyclops* sp.	
Cephalodella gibba (Ehrenberg, 1838)	Ceph	*Thermocyclops decipiens* (Kiefer, 1929)	Tdec
Manfredium eudactylota (Gallagher, 1957)		*Thermocyclops minutus* (Lowndes, 1934)	
Notommata sp.		*Tropocyclops prasinus prasinus* (Fisher, 1860)	Tpra
Ploesoma triacanthum (Levander, 1894)	Ptri	Harpacticoida	

only the values of these two stations are shown in Table 1. pH, conductivity, OD, water temperature, chlorophyll, pheophytin, suspended matter and total phosphorus were higher in the dry period and increased towards IG5 station, and PO_4, NO_2 and NH_4 decreased. In the rainy period, values of variables decreased at IG5, except by an increase of PO_4, NO_2, nitrogen and total phosphorus.

The zooplanktonic community was composed of 92 taxa (Table 2), of which 58 were rotifers and 34 belonged to microcrustaceans, 17 taxa of Copepoda and 17 taxa of Cladocera. Rotifers dominated in all community attributes compared to microcrustaceans.

Among Rotifera, taxa with high frequency of occurrence in samples were: *Proales* sp. (100 %), *Keratella cochlearis* (91 %), *Lepadella patella* (88 %), *Lecane cornuta* (79 %), *Lecane bulla* (76 %)

Table 3. Richness, abundance and diversity among stations and periods. S = richness; H = diversity; Ab = abundance; Nca = Calanoida nauplius; Ncy = Cyclopoida nauplius; Cca = Calanoida copepodite; Ccy = Cyclopoida copepodite; Ad = Adults individuals.

	Rotifera			Cladocera			Copepoda						
Dry	S	H	Ab	S	H	Ab	S	H	NCa	NCy	CCa	CCy	Ad
IG1	23	2.65	3,065	8	1.84	1,090	3	0.95	220	550	1,705	330	139
IG2	25	2.86	1,481	7	1.71	1,171	6	1.58	508	70	1,978	140	212
IG3	23	2.78	2,188	3	0.84	45	0	0	0	0	60	5	0
IG4	26	2.83	1,528	4	1.16	55	0	0	10	5	10	5	0
IG5	25	2.83	2,385	2	0.69	10	4	1.33	15	0	30	0	25
AN1	18	2.53	600	1	0	5	0	0	10	0	0	0	0
AN2	22	2.48	5,417	0	0	0	0	0	5	0	10	5	0
AN3	15	1.94	1,900	2	0.69	10	1	0	10	0	0	5	5
MO1	15	2.03	2,825	2	0.69	10	3	0.48	4,200	69,000	0	5,100	9,200
MO2	19	2.26	773	0	0	0	2	0.67	630	292	0	408	1,283
MO3	23	2.69	888	2	0.69	10	3	1.05	30	60	0	50	25
GD1	19	2.62	600	2	0.69	20	0	0	40	10	5	10	0
GD2	25	2.82	1,025	2	0.69	10	1	0	365	165	0	105	5
GD3	19	2.31	750	4	1.38	20	2	0.69	215	135	15	45	10
CA1	18	2.50	1,683	0	0	0	1	0	40	0	0	10	5
CA2	17	2.26	1,375	1	0	5	2	0.32	60	10	0	0	50
CA3	18	2.36	6,840	7	0.49	1,166	2	0.69	185	25	5	40	10
Rainy	S	H	Ab	S	H	Ab	S	H	NCa	NCy	CCa	CCy	Ad
IG1	11	1.90	8,400	4	1.16	50	0	0	35	5	0	20	0
IG2	20	2.44	8,450	8	1.71	105	2	0.69	35	55	25	35	10
IG3	18	2.10	16,485	7	1.42	220	3	1.04	60	110	20	5	20
IG4	15	2.21	9,295	7	1.56	245	3	1.09	130	95	110	65	15
IG5	12	1.95	9,450	9	1.80	400	6	1.68	900	788	158	833	205
AN1	18	2.62	2,111	2	0.69	20	1	0	0	10	0	20	10
AN2	23	2.63	5,940	0	0	0	1	0	0	20	0	0	10
AN3	14	2.23	460	1	0	40	2	0.69	0	0	0	10	10
MO1	14	2.16	1,824	2	0.69	10	1	0	0	10	0	5	5
MO2	19	2.46	1,894	1	0	5	0	0	0	10	0	5	0
MO3	16	2.17	1,090	1	0	5	0	0	0	5	0	0	0
GD1	15	2.53	510	0	0	0	4	1.38	0	20	0	5	20
GD2	18	2.52	240	5	1.60	25	0	0	5	0	0	5	0
GD3	17	2.49	240	1	0	5	0	0	5	0	0	0	0
CA1	16	2.22	370	1	0	10	0	0	0	5	0	5	0
CA2	15	2.34	215	1	0	5	0	0	0	5	0	5	0
CA3	24	2.59	420	2	0.50	25	0	0	25	10	10	15	0

and Bdeloidea order with 94 %. Among rotifers, 51 % of the taxa were considered accidental (< 25 %). For microcrustaceans, *Ceriodaphnia cornuta, Ceriodaphnia laticaudata* and *Bosmina hagmanni* showed 35 % frequency of occurrence and *Microcyclops anceps anceps, Tropocyclops prasinus prasinus* 29 %, followed by *Notodiaptomus henseni* (18 %).

In general, higher richness, diversities and abundances were found in the dry period, mainly in Iguaçu river. Significant differences between the periods were found only for rotifer richness (H´ = 7.78; *P* = 0.00) and diversity (H´ = 4.48; *P* = 0.03) and abundance of Calanoida nauplii (H´ = 8.09; *P* = 0.00). Increased rotifer richness and diversity values were eventually found in the intermediate and low stretches of some tributaries, but these values for total zooplankton did not show any directional tendency of variation. Amongst the sampling stations, significant differences occurred in rotifer abundance (H´ = 12.04; *P* = 0.00), richness (H´ = 17.96; *P* = 0.00) and diversity (H´ = 17.80; *P* = 0.00), Cladocera abundance (H´ = 18.77; *P* = 0.00), copepods diversity (H´ = 8.11; *P* = 0.04) and abundance of Calanoid copepodites (H´ = 20.04; *P* = 0.00).

The maximum values of richness for rotifers were registered in Iguaçu river, corresponding to 26 and 25 species in the dry and rainy period, respectively. In tributaries, 25 species were found in the dry and 24 in the rainy period. For cladocerans, maximum values were found in Iguaçu river and at CA3 station in Capanema river in the dry period, and for Copepoda, maximum values were found in Iguaçu river (Table 3).

An increase of rotifer diversity towards IG5 station was observed in the dry period in Iguaçu river, but not for microcrustaceans. The lowest diversity index registered in the tributaries was found in Monteiro river, at MO-1 station (2.05 bits.ind^{-1}), with peak abundance of *Keratella americana*. In Iguaçu river, relatively higher values were registered at IG2 station (2.36 bits. ind^{-1}). At AN2 station, Cladocera and Copepoda were not found in the rainy period.

The higher mean densities for rotifers were found in Iguaçu river, however, an abundance peak of Cyclopoida nauplii occurred at MO1 station (69,000 ind.m^{-3}), much higher compared to the highest value for rotifers (>16.000 ind.m^{-3}) at IG3 station in the rainy period, when *Collotheca* sp. was dominant (4,725 ind.m^{-3}). In the dry period, *Keratella cochlearis* was dominant in Iguaçu river and *Lecane luna* and *Euchlanis dilatata* in the tributaries, where the higher density was registered at AN2 station (5,040 ind.m^{-3}), in the rainy period, with dominance of *Proales* sp. (1,080 ind.m^{-3}).

Cladocerans had low densities in all of the tributaries in the rainy period, and in the rivers Andrada, Monteiro and Gonçalves Dias, in the dry period. In the latter period, the higher abundance peak was registered at IG2 station (1,383 ind.m^{-3}) in Iguaçu river, with higher densities for *Moina minuta* (338 ind.m^{-3}). In the rainy period, abundance increased downstream, with a peak at IG5 station (605 ind.m^{-3}) and dominance of *Bosmina hagmanni* (135 ind.m^{-3}), however, abundance was low in tributaries, and the highest value was only 50 ind.m^{-3} at AN3 station, dominated by *Bosmina longirostris* (40 ind.m^{-3}).

For copepods, abundance was higher only at IG1 and IG2 stations in Iguaçu river, in the dry period, with a marked decrease at the other stations downstream, contrary to the trend observed in the rainy period, when higher abundances were found downstream. In tributaries, copepods were less represented in Andrada river, in the dry period, and in all of the rivers in the rainy period. The highest abundance peak in tributaries was found at MO1 station, in the dry period, with dominance of *Thermocyclops decipiens* (7,800 ind. m^{-3}).

The principal component analysis (Fig. 2A) of the environmental variables explained 63 % of variance in the data. The analysis grouped Iguaçu, Andrada and Capanema rivers in the dry period and Iguaçu, Andrada and Gonçalves Dias, in the rainy period. In Iguaçu river some stations formed a group in the dry period, and among tributaries, Monteiro river formed another group in the rainy period. In the first component, N/P ratio was positively associated with the tributaries in the rainy period, and in stations of Iguaçu river, in both periods. On the other hand, chlorophyll, pheophytin, $Si.(OH)_4$ and PO_4 were positively correlated among themselves in stations located in tributaries, in the dry period. In the second component, stations in the tributaries were positively associated with conductivity and $Si.(OH)_4$, although to a low extent, in the two periods, and the latter were inversely correlated with suspended matter in some stations in the tributaries (most part in Andrada river) and in Iguaçu river, in the rainy period.

The canonical correlation analysis (Fig. 2B) explained 41 % of variance in the dataset, separating the dry and rainy periods in the first canonical variable (VC1) and the Iguaçu river and tributaries in the second (VC2). The ordination indicated higher heterogeneity in the dry period, mainly for Monteiro river because the stations in Iguaçu river were grouped, in general, in the two periods, as well as in PCA.

In VC1, positive correlations were found only between the taxa *Thermocyclops decipiens*, *Microcyclops anceps*, Cyclopoida and Calanoida nauplii

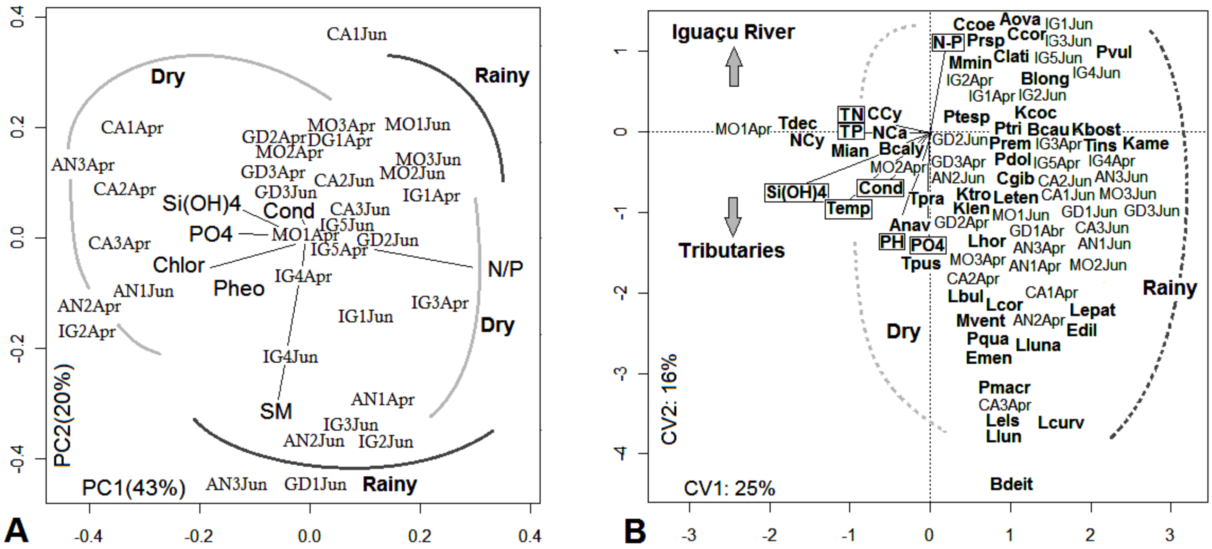

Fig. 2. A. Principal component analysis of chemical, physical and biological variables. B. Canonical correspondence analysis of environmental variables (physical, chemical and biological) and the zooplankton abundance (only the 47 species with higher abundances). Codes: NCa = nauplii of Calanoida; NCy = nauplii of Cyclopoida; CCy = copepodit of Cyclopoida.

and Cyclopoida copepodites and the variables phosphorus and total nitrogen; Si.$(OH)_4$, temperature and conductivity were related to the abundance peak at MO1 station in the dry period, and slightly so at the MO2 station, in the same period. In the positive VC1 quadrant no significant correlation with any environmental variable was found.

In VC2, the species Aova, Ccoe, Ccor, Clati, Prsp, Pvul, Mmin and Blong at the stations in Iguaçu river, in general, were positively correlated with the N/P ratio. On the other hand, Si.$(OH)_4$, temperature, pH, NH_4 and PO_4 were positively correlated with the species Bdeit, Llun, Lcurv, Lels, Pmacr, Emen, Lluna, Pqua, Edil, Mvent, Lcor, Lepat, Lbul, Tpus, Lhor, Anav, Tpra, Ktro, Klen, Leten and Cgib (see Table 2 for abbreviations).

All the significant correlation values generated in the CCA are shown in Table 4.

Discussion

Our results revealed higher zooplankton richness and abundance in Iguaçu river compared to the tributaries, indicating that the organisms drift from reservoir to downstream, adding to the own contribution of tributaries situated in the studied stretch.

The contribution of tributaries to Iguaçu river was clearly recognized for rotifers in the rainy period, when the observed values for Iguaçu and tributaries were similar with each other. Rotifers have a shorter life cycle and multivoltine populations (Allan 1995), resisting better to oscillations of precipitation levels. Microcrustaceans showed low diversity indices and abundance in the rainy period when compared to the values of Iguaçu river, especially in the dry period.

Low flow and dry period conditions favour zooplankton rise. Also, under these conditions, the downstream decrease in zooplankton in the Iguaçu river corroborated the findings of Mistuka & Henry (2002) in Jurumirim reservoir who studied a stretch situated 30 km downstream and found organism's dilution, caused probably due to hydrodynamics reasons. Casanova & Henry (2004) studied a 13 km lotic stretch of the central channel of the same river and observed a decrease in copepod abundance downstream of the associated lakes and the abundance was negatively correlated with water velocity and suspended solids. Contrary to our results, these authors found higher abundance in the rainy period. Thus, the low temperature that was present in this study might have affected organism metabolism, besides the increase of suspended solids and water velocity resulting from precipitation, among other factors.

In the dry period, we found an increase in temperature downstream the reservoir, rising at IG1 and IG5 stations. Considerable alterations were also found in pH, dissolved oxygen and suspended matter. In the case of deep reservoirs,

Table 4. Results of CCA analysis, with values of adjusted canonical coefficients (r^2) and level of significance (*P*), separated for zooplanktonic species abundances and environmental variables (Codes for species in Table 2; Codes for environmental variables in Table 1).

Species	r^2	*P*	Species	r^2	*P*
Anav	0.41	0.12	Prem	0.41	0.00
Bcaly	0.53	0.00	Pvul	0.32	0.01
Kcoc	0.35	0.00	Prsp	0.15	0.08
Pmacr	0.32	0.01	Tins	0.19	0.05
Pqua	0.27	0.04	Tpus	0.47	0.00
Ceph	0.31	0.03	Blong	0.19	0.05
Ccoe	0.42	0.00	Bdeit	0.23	0.03
Edil	0.24	0.04	Ccor	0.18	0.07
Aova	0.18	0.09	Clati	0.16	0.07
Lbul	0.40	0.00	NCa	0.74	0.00
Lcurv	0.24	0.03	NCy	0.58	0.00
Lels	0.29	0.03	CCy	0.66	0.00
Llun	0.38	0.23	Mian	0.79	0.00
Lluna	0.38	0.03	Tdec	0.58	0.00
Mvent	0.24	0.04	Tpra	0.19	0.07
Ptri	0.40	0.00			
Pdol	0.16	0.06			
Enviromental variables					
Cond	0.20	0.03	N/P	0.37	0.00
PO_4	0.42	0.00	pH	0.47	0.00
$Si(OH)_4$	0.65	0.00	Temp	0.42	0.00
TN	0.20	0.02	TP	0.26	0.03

spillway and/or turbine discharges downstream are obtained from deeper layers with redox characteristics that can damage lotic biota, besides the turbulence experienced by the biota as they pass through the dam.

Naliato *et al.* (2009) suggest that these operational dam features significantly influence many limnological variables, such as temperature, pH and dissolved oxygen that can indirectly affect zooplankton. The suspended matter increased towards IG5 station after receiving the discharges of tributaries. This increment of particles increases the competition for food, where selective organisms (rotifers) have higher efficiency in ingesting nutritional particles when compared to cladocerans and copepods (Basu & Pick 1996).

Organisms drift downstream to the permanent or temporary lentic systems (Hynes 1970; Paggi & José de Paggi 1990; Ward 1989; Viroux 2002). Considering the length of Iguaçu river (up to 1,000 km), variation in species richness is not expected, supporting the drift downstream. Studies carried out in other stretches of Iguaçu river show similar species composition in Iraí (upper Igauçu) (Ghidini *et al.* 2009; Lopes *et al.* 1997; Perbiche-Neves *et al.* 2007) and Salto Caxias reservoir (Serafim-Júnior 2002). In other rivers with many cascade reservoirs, similarities in composition are also found (Nogueira *et al.* 2008; Silva & Matsumura-Tundisi 2002). It must be remembered that some organism's produce resistant eggs and that, in the same place, composition can vary greatly in a 20 year interval (for example, Matsumura-Tundisi & Tundisi 2003).

All identified taxa are common to the region of the upper Paraná river basin, and are also similar to the Uruguay river basin. Taxa with large distribution in the neotropical region and some cosmopolitans were also found. Littoral taxa had a significant contribution at the stations situated in the tributaries whereas in Iguaçu river, planktonic species predominated, and perhaps originated from the reservoir. Microcrustaceans were greatly influenced by phytoplankton composition, although, slightly correlated with chlorophyll and pheophytin pigments, indicators of production, but correlated well with the N/P ratio which, in most cases, is a stimulus for increased production. Paggi & José de Paggi (1990) and Serafim-Júnior *et al.* (2003) pointed out positive correlations between phytoplankton and nutrients, and also the dominance of Cyanophyceae at most of the sampling stations situated in the same stretch studied in the present work, which could be harmful to the development of most part of the zooplankton because these algae are considered low quality food. According to the same authors, higher phytoplankton densities were found at the stations AN2 (Andrada river), CA3 (Capanema river) and MO2 and MO1 (Monteirinho and Monteiro rivers), resembleing a peak of copepod abundance in the last station. At MO1 station, *T. decipiens* was the dominant copepod species and *Pseudoanabaena mucicola* and *Microcystis protocystis* were the dominant algae. The numeric abundance of Cyclopoida as compared to Calanoida, in general, is probably due to the feeding ability of the first group, since most of the species are omnivorous and with a raptorial feeding mode. On the other hand, in Calanoida, most of the species are herbivorous and selective feeders.

For rotifers, dominance of the families Brachionidae and Lecanidae is probably due to the wide plasticity of these organisms in relation to the limnological conditions and to the available food. The species of these families have been found in rivers and tropical lakes (Paggi & José de Paggi 1990; Serafim-Júnior *et al.* 2003).

As mentioned earlier, another factor that may have affected the composition of microcrustaceans was the high sediment load observed in the tributaries in the rainy period. The studied region has an intense agricultural influence, which contributes in most part to the input of nutrients and suspended matter to tributaries, besides the proximity to urban centers. The single exception in the study is the Gonçalvez Dias river, which has the right margin totally covered with native forest of the Iguaçu National Park, and for this reason, this river was inversely associated with suspended matter in the PCA and was also situated contrary to the nutrients in CCA, which are higher in rivers with absence of border forest. The relation of turbidity and zooplankton dynamics was recently demonstrated by Thorp & Mantovani (2005), showing the influence of turbidity on spatial and temporal distribution and the difference of the communities among the rivers. In the present study, this variable (evaluated on the basis of concentration of suspended matter) showed similar effects.

The conclusion of the study is that in addition to the higher values of the ecological attributes found in the dry period, zooplankton was more heterogeneous and several species were more abundant when compared to the atypical rainy period. The atypical rainfall promoted a strong reduction in zooplankton, but this was probably intensified by the low temperature, since this occurred in winter. Except for water temperature, a longitudinal gradient was not observed in tributaries. The reservoir influenced zooplankton downstream, mainly in the dry period, with the tendency of a decrease downstream, whereas in the rainy period, tributaries exerted more influence and a decrease downstream was not observed.

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