Structure and dynamics of the cyclopoid copepod (Crustacea) assemblage associated with aquatic macrophytes in two lotic environments of the Upper Paraná river basin, Brazil

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ABSTRACT. Spatial and temporal variation was analyzed in the composition, diversity, and abundance of cyclopoid copepods associated with *Eichhornia azurea* (Swartz) Kunth in two lotic environments of the Upper Paraná river basin. Sixteen cyclopoid taxa were identified. There were no differences in the composition of copepod species between environments or hydrological phases. Cyclopoids were generally more abundant during the low water phase. The most abundant species in both environments were *Macrocyclops albidus albidus* (Jurine) and *Microcyclops finitimus* Dussart. Densities and some measurements of species richness were in general higher in the Ivinheima River, which has many associated floodplain lakes. This fact suggests the importance of associated lentic environments for patterns of abundance and species richness found in lotic environments. Low values for β diversity of the cyclopoid assemblage in both environments seem to indicate that the littoral region has low temporal heterogeneity.

Key words: Cyclopoida, phytophile fauna, ecology, abundance, diversity, species richness.

RESUMO. Estrutura e dinâmica da assembléia de copépodos ciclopóides (Crustacea) associados com macrófitas aquática em dois ambientes lóticos da bacia do alto rio Paraná, Brasil. Analisamos a variação espacial e temporal da composição, diversidade e abundância dos copépodos ciclopóides associados à *Eichhornia azurea* (Swartz) Kunth em dois ambientes lóticos da bacia do alto rio Paraná. Foram identificados dezesseis táxons de ciclopóides. Não foram constatadas diferenças na composição de espécies entre os ambientes ou fases hidrológicas. Os ciclopóides foram, em geral, mais abundantes durante a fase de águas baixas. As espécies mais abundantes nos dois ambientes foram *Macrocyclops albidus albidus* (Jurine) e *Microcyclops finitimus* Dussart. As densidades e algumas medidas de riqueza de espécies foram, em geral, maiores no rio Ivinheima, o qual apresenta muitas lagoas de várzea associadas. Esse fato sugere a importância de ambientes lênticos para os padrões de abundância e riqueza de espécies encontrados em ambientes lóticos. Os baixos valores de diversidade β para a assembléia de ciclopóides nos dois ambientes estudados sugerem que a região litorânea têm uma baixa heterogeneidade temporal.

Palavras-chaves: Cyclopoida, fauna fitófila, ecologia, abundância, diversidade, riqueza de espécies.

Aquatic macrophytes are a favorable habitat for many invertebrate species. They afford physical structure, food, and shelter from predators (Iversen *et al.*, 1985; Lima, N. *et al.*, 1998). Due to such characteristics, the fauna associated with aquatic vegetation is abundant and diverse, and plays an important role in energy transfer and nutrient cycling within the food web (Miura *et al.*, 1978).

Aquatic macrophyte-associated fauna of the middle stretch of the Paraná River in Argentina has already been studied (Neiff and Poi de Neiff, 1979; Amsler, 1983, 1987; Poi de Neiff, 1986, 1990; Poi de Neiff and Neiff, 1989; Poi de Neiff and Zozaya, 1991). However, few research works enumerated cyclopoid species, although cyclopoids form the dominant group in macrophyte-associated fauna (Amsler, 1983, 1987). Up to the present only one study on the subject exists on the Brazilian stretch of the Paraná (Souza-Franco and Takeda, 2000), on a stream in the Paraná floodplain. In this region edges of tributaries and secondary channels are colonized by extensive banks of aquatic macrophytes.

We describe and compared the spatial and temporal variations in composition, abundance, and diversity of the cyclopoid copepod assemblage associated with *Eichhornia azurea* (Swartz) Kunth in a tributary located in the floodplain and in another without floodplain influence lying in a secondary channel of the Paraná River.

Material and methods

Two lotic environments of the Paraná River basin were selected, the Ivinheima river and Cortado shannel (Figure 1). The Ivinheima river (22º49'01"S and 53º33'42" W) is a tributary of the Paraná river, and its lower portion is located in a floodplain with a great number of varzea lagoons. Current speeds range from 0.34 to 0.85 $m.s^{-1}$. On the other hand, Cortado channel (22º47'30" S and 53º24'37" W) lies on the left bank of the Paraná river, is approximately 1.75 km long and receives no influence from varzea lagoons. In this environment water velocity varies from 0.15 to 0.56 $m.s^{-1}$.

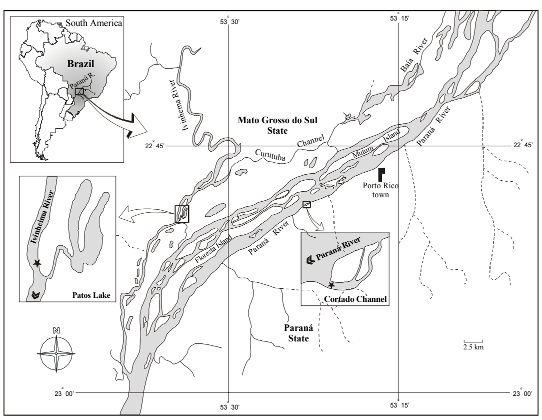

Figure 1. Area and sampling stations

Sampling was undertaken monthly from March 1992 through February 1993. *Eichhornia azurea* was collected in homogeneous stands. One linear meter of plant was pulled out of the water, cut, and each fragment placed in a plastic bag. Invertebrates were collected by washing the plants in two buckets, one containing a solution of formaldehyde and the other plain water. Water was filtered through a net with 300 μm mesh size, and the organisms were stored in 4% buffered formaldehyde solution.

The organisms were identified and counted in a Sedgwick-Rafter chamber using a compound microscope. Plant pieces were oven-dried at 80ºC and weighed. Copepod densities are expressed as number of individuals/100g of plant dry weight.

Copepods were identified using the following references: Dussart (1984a, b), Reid (1985, 1986), Dussart and Frutos (1985, 1986), Reid and Pinto-Coelho (1994), Dussart and Defaye (1995) and Karaytug and Boxshall (1998a and b).

The studied material was deposited at the Zooplankton Laboratory of the Núcleo de Pesquisas em Limnologia, Ictiologia e Aqüiculture (Nupelia) of the State University of Maringá, PR, Brazil. Moreover, the taxonomic and occurrence approach of the species recorded in this study are presented in Lansac-Tôha *et al*. (in press).

The following abiotic environmental variables were determined monthly: depth (cm), water temperature (ºC, by thermistor), pH (portable pH meter), dissolved oxygen (by Winkler method, modified by Golterman *et al.*, 1978), electrical conductivity ($\mu S.cm^{-1}$), using a glass electrode, transparency (cm, Secchi disc), and chlorophyll *a* concentration ($\mu g.l^{-1}$, Golterman *et al*., 1978). Daily water levels of the Paraná river were supplied by the National Department of Water and Electrical Energy (DNAEE).

Principal Components Analysis and Detrended Correspondence Analysis were applied to the abiotic and biotic data, respectively, by ordination of collection site/month ranks based on environmental variables and species abundance. Prior to analysis, abiotic data were standardized and cyclopoid abundance data were log-transformed (log x+1) to minimize the effect of discrepant values. After these treatments a Procrustean Randomization Test - m^2 (Jackson, 1995) was employed, using PCA and DCA scores to evaluate the community-environment concordance.

In order to describe aspects of the species richness of the cyclopoids associated with *E. azurea* in more detail, several methods were used to estimate diversity: α diversity (*S*) represented by the total number of species recorded in each environment and in each month of collection; Shannon-Wiener diversity index (*H'*) (Pielou, 1975); evenness (*E*) (Pielou, 1966); Chao's index (*C*), an extrapolation method that estimates species richness by the expression $S^{*} = S + (L^2/2M)$, where *S* is the number of species recorded and *L* and *M* are the number of species occurring in one and two samples, respectively (Chao, 1984); and β-diversity (Harrison *et al.*, 1992) calculated for the different environments and expressed as $\{[(S/a_{max})-1]/(n-1)\}.100$, where *S* is total richness obtained on site,

a_{max} is the richness in different months, and n is the number of samples (n = 12).

Rarefaction curves, an interpolation method, were also devised to evaluate the expected species richness $E(S_n)$, with the number of individuals previously standardized (Hurlbert, 1971; Gotteli and Graves, 1996).

The statistical programs PC-ORD 2.0 (McCune and Mefford, 1995), Statistica 5.0 (Statsoft, 1996), and Protest 2.0 (Jackson, 1995) were used for analyses.

Results

Two hydrological periods were analyzed in this investigation. The periods from March to May and from November to February were considered the high water period, and the remaining months constituted the low water period (Figure 2).

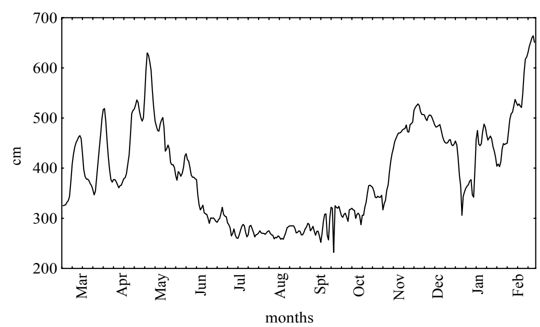

Figure 2. Variation of water level of the Paraná river (source: DNAEE)

Table 1. Average, standard deviation (in brackets) and range (bold) of water in high and low water period of the Ivinheima river and Cortado channel

	Ivinheima River		Cortado Channel	
Variables	High water	Low water	High water	Low water
Depth (m)	4.40 (0.28)	2.81 (1.03)	2.69 (0.72)	1.30 (0.74)
	4.20 - 4.60	1.6 - 5.2	1.8 - 3.6	0.8 - 2.6
Temperature of	23.80 (0.70)	24.60 (4.10)	25.97 (2.27)	22.10 (3.51)
Water (°C)	23.3 - 4.3	18.2 - 29.2	22.0 - 28.0	18.8 - 27.9
pH	6.40 (0.30)	6.70 (0.30)	7.30 (036)	7.14 (0.21)
	6.2 - 6.6	6.1 - 7.1	6.7 - 7.7	6.9 - 7.4
Electrical Conductivity	42.0 (3.50)	43.20 (3.50)	64.14 (4.41)	59.80 (3.56)
($\mu S.cm^{-1}$)	37.0 - 47.0	37.0 - 50.0	59.0 - 70.0	57.0 - 65.0
Total Alkalinity	0.30 (0.04)	0.40 (0.03)	0.49 (0.05)	0.51 (0.04)
($mEq.l^{-1}$)	0.33 - 0.30	0.4 - 0.5	0.4 - 0.5	0.5 - 0.6
Dissolved Oxygen	3.10 (0.90)	6.04 (2.40)	8.58 (0.41)	9.61 (0.72)
($mg.l^{-1}$)	2.5 - 3.8	1.2 - 9.5	8.0 - 9.3	8.6 - 10.6
Secchi Disc (m)	1.10 (0.90)	0.70 (0.20)	0.85 (0.32)	0.80 (0.12)
	0.5 - 1.7	0.4 - 1.2	0.4 - 1.2	0.6 - 0.9
Chlorophyll *a* ($\mu g.l^{-1}$)	3.66 (2.15)	1.26 (0.60)	5.87 (3.53)	2.78 (1.19)
	0.91 - 7.64	0.55 - 2.18	2.18 - 10.58	2.18 - 4.91

The values for abiotic variables of the Ivinheima River and Cortado Channel are presented in Table 1.

Composition. Sixteen species of cyclopoid copepods belonging to 8 genera, 5 genera of the subfamily Eucyclopinae and 3 of subfamily Cyclopinae were identified. Eleven species occurred in both environments. *Thermocyclops decipiens* (Kiefer) occurred only in Cortado channel, whereas *Mesocyclops ogunnus* Onabamiro, *Eucyclops ensifer* Kiefer, *Eucyclops solitarius* Herbst, and *Homocyclops ater* (Herrick) were recorded only in the Ivinheima river. The most frequent species in the Cortado channel and the Ivinheima river were *Macrocyclops albidus albidus* (Jurine), *Microcyclops anceps anceps* (Richard), *Microcyclops finitimus* Dussart, and *Mesocyclops longisetus curvatus* Dussart. *Paracyclops chiltoni* (Thomson) and *Ectocyclops rubescens* Brady were also frequent in the Ivinheima river.

General aspects of abundance. As an average cyclopoid copepods presented greater densities in the Ivinheima river than in the Cortado channel (168 ind/100g dw and 114 ind/100g dw, respectively).

The most abundant species in both environments were *M. albidus albidus* and *M. finitimus. Microcyclops anceps anceps* and *P. chiltoni* were abundant in the Ivinheima river, and *E. rubescens* in the Cortado channel (Figure 3).

Diversity patterns. In general, higher species richness (α diversity) and diversity (H') were recorded in the Ivinheima river. In the Ivinheima, the highest values of diversity, evenness, and richness were recorded mainly during low water. No distinct pattern of seasonal variation was found for the two attributes in the Cortado channel (Figure 4).

In the case of previously determined densities (5 - 10 individuals/100g dw), rarefaction curves showed that expected richness $E(S_n)$ was greater in the Ivinheima river in almost all months (Figure 5). Chao's index estimate for species richness was also greater for the Ivinheima river (S = 15; C = 19 species) than for the Cortado channel (S = 12; C = 15 species).

The degree of species substitution (turnover) obtained by β diversity throughout the study period was relatively higher in the Ivinheima river, although low values were recorded in both environments (Ivinheima river: β = 4.53; Cortado channel: β = 3.03).

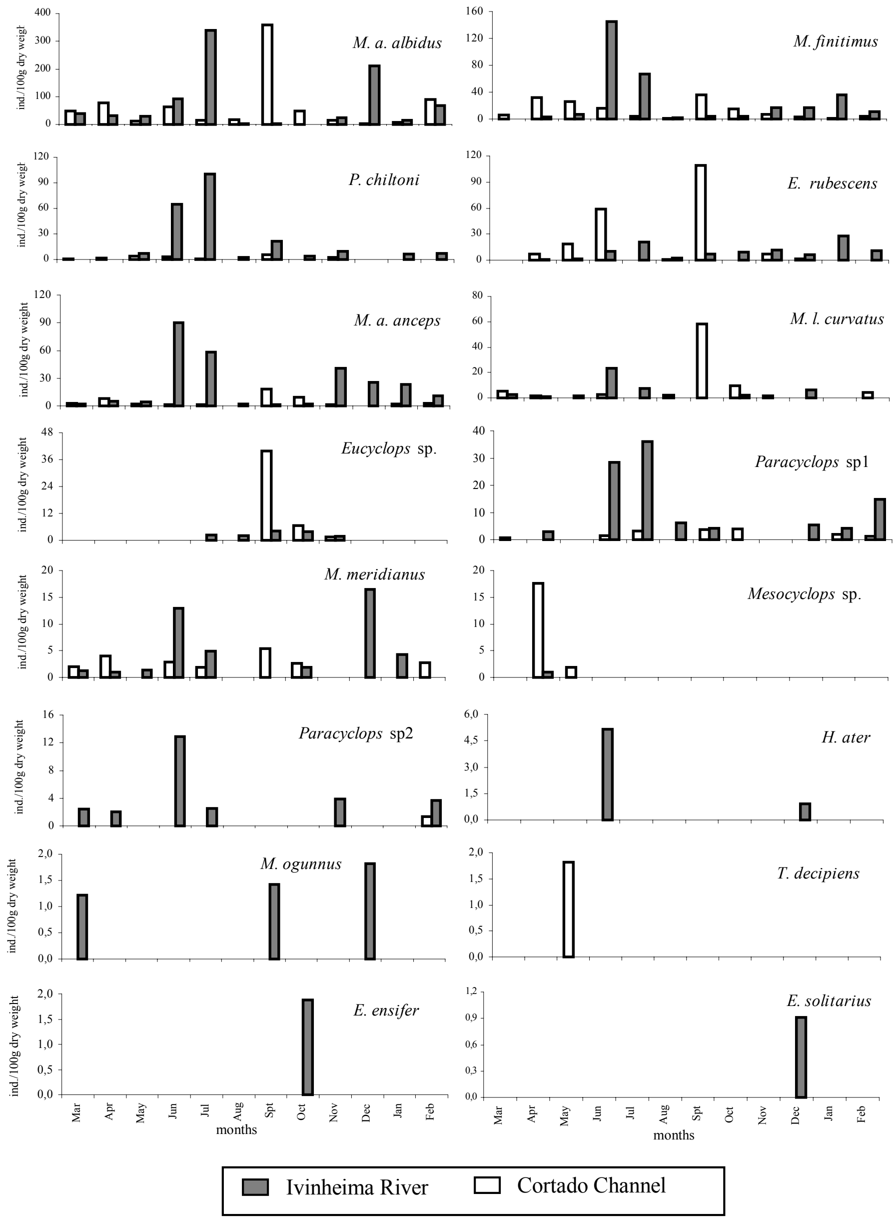

Figure 3. Abundance of cyclopoid species in the Ivinheima river and Cortado channel

Abundance-environment relationships. The first two PCA axes of abiotic variables accounted for 67% of the total variance. The first axis (43%) was negatively correlated with dissolved oxygen (*r* = -0.94), conductivity (*r* = -0.84), alkalinity (*r* =-0.83), pH (*r* = -0.77), and positively with depth (*r* = 0.64). The second axis (24%) was positively correlated with chlorophyll *a* (*r* = 0.80) and water temperature (*r* = 0.77). Or rather, the first axis contrasted Cortado channel and its relatively high values of pH, conductivity, alkalinity, dissolved oxygen, and lower depth, with the Ivinheima river. The second axis contrasted the high water period, characterized by high values of chlorophyll *a* and water temperature, with the low water period (Figure 6).

PCA showed that in the Cortado channel the pH, electrical conductivity, and dissolved oxygen did not vary much. However, temperature and chlorophyll *a* did vary widely in the channel. On the other hand, in the Ivinheima river, pH, electrical conductivity, and dissolved oxygen as well as depth varied considerably, with slight variations in water temperature and chlorophyll *a*.

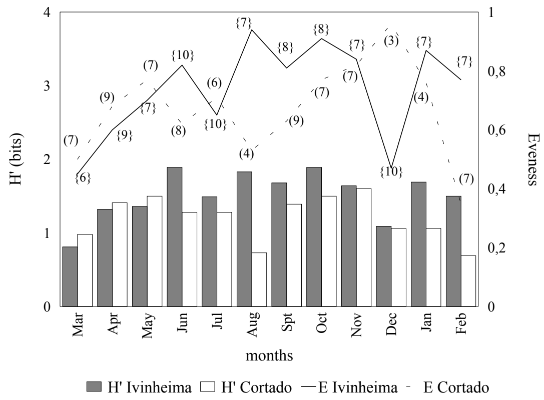

Figure 4. Shannon-Wiener Diversity (H'), Evenness (E), and species richness: Ivinheima river { } and Cortado channel ( )

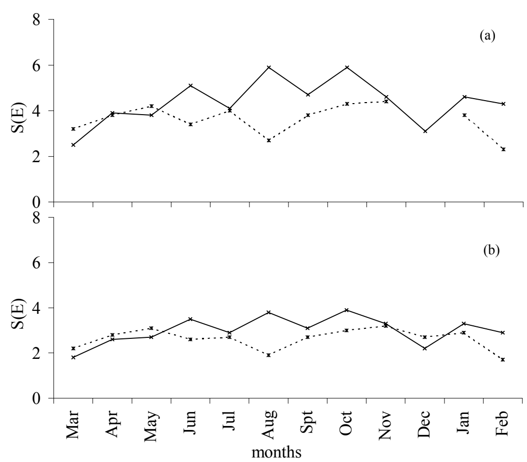

Figure 5. Rarefaction curve: (a) - 5 individuals/100 g dw; (b) - 10 individuals/100 g dw in the Ivinheima river (solid line) and Cortado channel (dashed line)

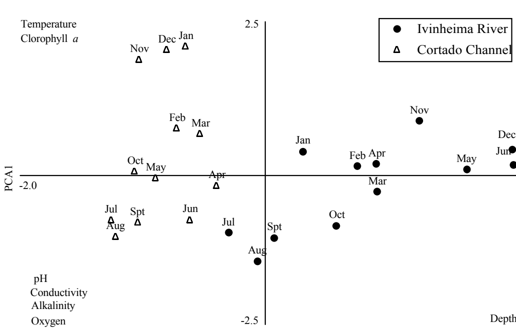

Figure 6. First two axes of the Principal Component Analysis (PCA) ordination diagram

DCA was used to ordinate qualitative and quantitative data of copepods. Species composition and abundance, during high water were similar in Ivinheima river and Cortado channel (Figure 7). However, during low water, this attribute differed in the two environments. Result is shown numerically by a higher variation coefficient of DCA scores for the low water period (72.83%) than that for high water (59.06%).

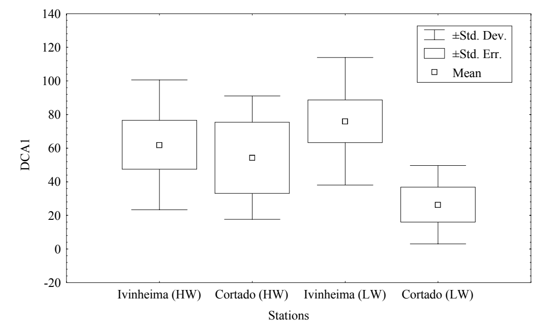

Figure 7. Scores of DCA1 (eigenvalue = 0.22) generated from copepods data for Ivinheima river and Cortado channel during high (HW) and low (LW) water

The m^2 test was applied on PCA and DCA scores to investigate the influence of physical and chemical variables on the structure and the dynamics of the cyclopoid assemblage. Analysis results showed a concordance between limnological parameters and the ordinates of species abundance (m^2 = 0.6734; P = 0.0008). It was only slightly probable that the relationship between the biotic and abiotic data occurred by chance. This suggests that the influence of environmental heterogeneity on the cyclopoid populations was significant (Figure 8).

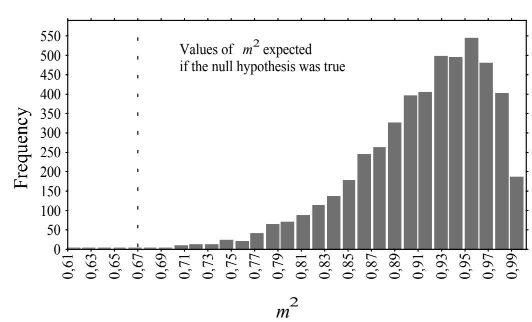

Figure 8. Distribution of m^2 based on 4999 randomised matrices of correspondence analysis results rotated to the geographic matrix

Our results demonstrated patterns of variations in limnological factors separating the environments and hydrological periods. These patterns influenced the composition and abundance of the cyclopoid species, since many species reached higher densities during the low water period. Although the intervening environmental parameters were the same, their values were relatively higher in the Cortado channel.

Discussion

Total of 16 taxa of cyclopoids associated with *E. azurea* was higher than the number of species collected in plankton within the same environments (Lima *et al.*, 1996; Lansac-Tôha *et al.*, 1997). Many cyclopoids are associated preferentially with littoral vegetation. Paggi (personal communication) suggests that there is a transverse gradient of abundance in which cyclopoids increase in richness and abundance from the open central water toward the shores.

Most species of *Thermocyclops* are characteristically planktonic, and this justifies the fact that only a single individual of *T. decipiens* was caught in the study.

Previous studies of the plankton in the floodplain of the Paraná River (Bonecker and Lansac-Tôha, 1996; Lansac-Tôha *et al.*, 1997; Lima, *et al.*, 1998) suggested that there is significant faunal interchange between the littoral zone and open water, because of washing of vegetation and the spatially restricted environment. However, we found a significant difference in the number and composition of cyclopoid species between the macrophyte-associated fauna and the plankton.

Chao's index showed that the expected total richness of cyclopoid species in both environments under analysis was nearly reached. This suggests that the sampling procedure was satisfactory to survey species richness of copepods associated with *E. azurea*.

The use of the rarefaction curve is relevant to the comparison of the species richness patterns, since it excludes the effect of density. Since abundances were similar for both environments, the results for expected richness obtained by the rarefaction curves followed the trends described by other diversity measurements showed a high diversity of species in the Ivinheima river.

These results may be related to the fact that this river, with many floodplain lakes along its entire course, harbors a large pool of species for colonization. The lakes may export fauna to the associated lotic environments. This hypothesis is supported by results obtained for estimates of β-diversity (species turnover) for the two environments, as the estimated turnover during the study period was higher in the Ivinheima river.

β-diversity was low in both environments. Velho (2000) recorded lower turnover for protozoans in the littoral zone than in plankton, in the Paraná floodplain. Harrison *et al.* (1992) suggested a rise in β-diversity with an increase in environmental dissimilarity. Therefore, the littoral zone seemed to be a less heterogeneous environment throughout the study period, i.e., it was less vulnerable to disturbances by flood pulses.

Macrocyclops albidus albidus, a large species, was, in general, dominant. Initial studies of macrophyte-associated cyclopoids of the Middle Paraná river have shown that this species is dominant in lentic environments (Poi de Neiff and Zozaya, 1989).

Although there was a significant relationship between organisms and environmental parameters in the present study, water level seems to be the preponderant factor in determining both patterns of abundance of cyclopoid species and limnological variables. Higher densities of aquatic macrophyte-associated cyclopoids during low water were probably a result of lower current velocities at that time. Macrophytes may have protected the cyclopoids, many of which are large, from predation by visual-feeding fish.

The greater abundance of cyclopoids in the Ivinheima river may be explained by a greater exposure of macrophytes in Cortado channel to the water current, since the macrophytes in the Ivinheima river develop in backwaters.

The results for DCA, corroborated by variation coefficient of their score, showed a greater dissimilarity between the environments in the low water period. This shows that the flood pulse exerts a homogenizing effect on the environments of the Paraná river floodplain, as flooding does for the limnological variables (Thomaz *et al.*, 1997).

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