Biodiversity of non-marine ostracods (Crustacea, Ostracoda) in the alluvial valley of the upper Paraná River, Brazil

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(With 5 figures)

Abstract

In the present study, we test the relevance of a number of environmental factors on alpha and beta ostracod diversities, at species and family level. Ostracods were sampled from several substrates, including sediment and root systems of various floating aquatic macrophytes, from 48 environments (both lentic and lotic habitats, ranging from the river itself, over connecting channels linking with open lakes, and, finally closed lakes), belonging to four different systems (Paraná, Ivinheima, Baía and Taquaruçu), in the alluvial valley of the Upper Paraná River. The faunistic survey recorded the presence of 54 species of Ostracoda, belonging to the families Cyprididae, Candonidae, Limnocytheridae and Darwinulidae. Various diversity estimators indicated that these recorded levels of specific diversity should be close to true values. Higher values of ostracods species richness (alpha diversity) were observed in the Baía and Ivinheima systems, while lotic habitats were richer than lentic ones. In addition, open lakes appeared to be more affected by the variable 'system' than closed ones, which can to some extend be explained by the putative effects of flood pulse on benthic communities. The two investigated factors have different effects on the four ostracod families. The present study also indicated that there is a large homogeneity within and between systems, as exemplified by the low beta-diversity levels.

Keywords: Ostracoda, diversity, floodplain, Paraná River, South America.

Biodiversidade de ostrácodes (Crustacea, Ostracoda) no vale aluvial do Alto Rio Paraná, Brasil

Resumo

No presente estudo foi testada a relevância de fatores ambientais sobre a diversidade alfa e beta de ostrácodes, bem como, sobre a diversidade de um nível taxonômico mais elevado (família). Os ostrácodes foram coletados em vários substratos, incluindo o sedimento e macrófitas aquáticas flutuantes, de 48 ambientes (habitats lênticos e lóticos, variando desde o próprio rio, conectado a canais, que estão ligados à lagoas abertas e, finalmente, lagoas fechadas), pertencentes a diferentes sistemas (Paraná, Ivinheima, Baía e Taquaruçu), no vale aluvial do Alto Rio Paraná. O levantamento faunístico registrou a ocorrência de 54 espécies de Ostracoda, pertencentes às famílias Cyprididae, Candonidae, Limnocytheridae e Darwinulidae. Vários estimadores de diversidade indicaram que estes níveis de diversidade foram próximos aos valores esperados. Maiores valores de riqueza de espécies de ostrácodes (diversidade alfa) foram observados nos sistemas Baía e Ivinheima, ao passo que os ambientes lóticos foram mais ricos que os lênticos. Além disso, lagoas abertas parecem ser mais afetados pela variável sistema do que as lagoas fechadas, as quais podem ser de alguma maneira explicado por um possível efeito do pulso de inundação sobre as comunidades bênticas. Os dois fatores investigados apresentaram efeitos distintos sobre as quatro famílias de ostrácodes. O presente estudo também indicou que existe uma grande homogeneidade dentro e entre os sistemas como evidenciada pelos baixos níveis de diversidade beta.

Palavras-chave: Ostracoda, diversidade, planície de inundação, Rio Paraná, América do Sul.

1. Introduction

There is a growing awareness of the fact that our world is experiencing an increasing biodiversity crisis, with dozens of species being lost nearly every day, often species that were not even described yet. The species loss in non-marine aquatic environments is the largest: between 1970 and 2002, a mere 30 years, freshwater biodiversity declined with 55%, while that of terrestrial systems and marine systems, each declined with 32% (Naiman, 2008). The Freshwater Animal Diversity Assessment (FADA - Balian et al., 2008) has presented an inventory of all animal species in non-marine aquatic habitats world-wide; more than 125,000 species were recognized. This is about 8% of the total known number of species in the world, yet freshwater only constitutes c. 0.01% of the total surface of the Earth. This discrepancy of 2 orders of magnitude could be described as the 'paradox of freshwater'.

Floodplains associated with large rivers, such as the Upper Paraná River floodplain, are excellent model systems to investigate potential drivers of biodiversity change at a wide range of spatial scales. The alluvial valley formed by the Upper Paraná River incorporates various fluvial systems; each of these has a variety of environment types, ranging from the river itself, over connecting channels linking with open lakes, and, finally closed lakes. Moreover, each of these environments has a variety of substrates, which can be either benthic or floating vegetation. The latter is a rather typical feature of South American floodplains, where floating vegetation hosts rich communities of (mostly) invertebrate taxa, associated with the root systems. These communities are referred to as pleuston (Esteves, 1998; Por and Rocha, 1998; Por, 2002). In this way, the ostracods constitute one of these pleuston communities in the Paraná River floodplain (Higuti et al., 2007).

Ostracoda are rarely used for biodiversity studies, as initial identification often requires full dissection of individuals which can be a time consuming enterprise. However, once species identity has been established, often valve morphology is sufficient to allow confident identification within a given region. The Ostracoda of South America are relatively ill known (Martens and Behen, 1994), compared to some other continents: 255 species and 55 genera are thus far known from South America, compared to 455 species and 73 genera in Africa (Martens et al., 2008).

Here, we describe the alpha, beta and gamma diversity of ostracod species, as well as their higher taxonomic diversity, in the alluvial valley of the Upper Paraná River. In addition, we assess the effects of 2 types of factors on these levels of diversity: the factor 'environment', which is here deemed to be local, and the factor 'system', here assumed to be regional because of the regional scale of the regular flood pulses occurring in different ways in different systems. The present study will make a significant contribution towards the knowledge of the biodiversity of Brazilian floodplain. Besides, we test for the relevance of environment type and fluvial system on alpha and beta ostracod diversities, as well as on a higher level taxonomic diversity (family).

2. Material and Methods

2.1. Study area

The Upper Paraná River consists of a large braided channel, with an extensive floodplain and high sediment accumulation in its bed, creating sand bars and islands of diverse sizes (Agostinho et al., 2004). The floodplain, apart from the main channel of the Paraná River, comprises several secondary channels, lakes and tributaries (including Ivinheima and Baía Rivers) (Agostinho et al., 2007). Further away from the main channel, and not connected to it, is the Taquaruçu system which comprises exclusively closed lakes (Souza Filho and Stevaux, 2004) (Figure 1).

2.2. Field sampling and laboratory analysis

Ostracods were collected during March, July and November of 2004 throughout the alluvial valley of the Upper Paraná River. In total, 132 samples from 48 environments were collected. These were divided over 4 fluvial systems (Paraná, Ivinheima, Baía and Taquaruçu) and 5 environment types (closed lake, open lake, river, channel and stream).

Ostracods were sampled using a rectangular net (28 × 14 cm, mesh size c 160 μm) hauled close to sediment-water interface for littoral collections. Floating vegetation was hand collected, and roots were thoroughly washed in a bucket. The residues were washed in the same handnet.

In the laboratory, samples were washed in sieves (2 and 0.250 mm mesh sizes), to facilitate sorting under stereomicroscope. The retained material in the sieve with smallest mesh was preserved in alcohol 70%. Samples were fragmented using a Folsom fractioner, and ¼ of samples was quantified, however, species richness was always estimated from the total sample. Valves and appendages were examined using scanning electron microscopy and optical microscope, respectively. Ostracods were identified at specific level, using available ostracod literature (see Martens and Behen, 1994; Martens et al., 1998; Rossetti and Martens, 1996; 1998; Pinto et al., 2003; 2004; 2005).

Several species and genera are most likely new to sciences (Higuti et al., in press), and are provisionally left here in open nomenclature, until further taxonomic revisions will clarify their status. In the meantime, illustrations of the valves of most of these taxa are available as additional material to the online version of Higuti et al. (in press).

2.3. Data analyses

Several estimators were used to describe values of species richness, in order to evaluate whether observed

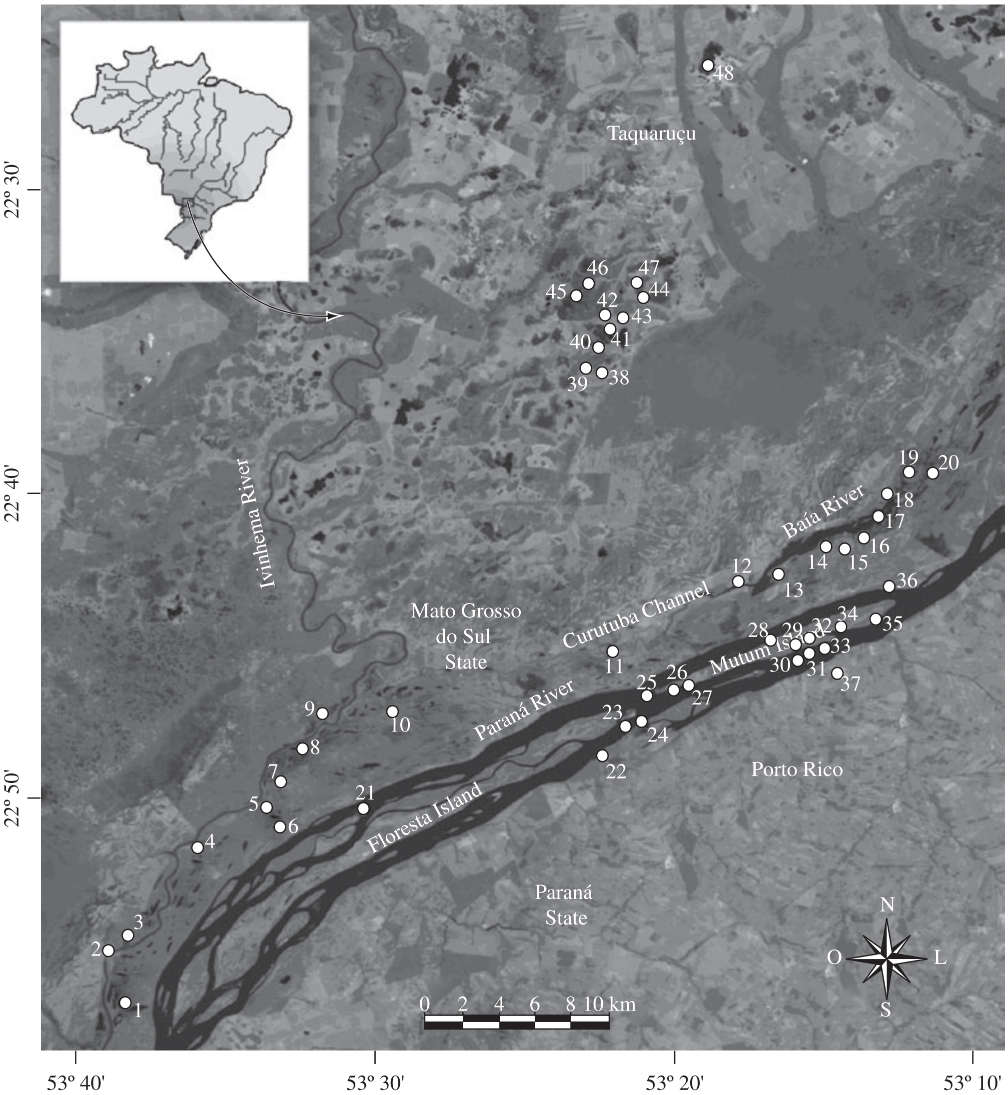

Figure 1. Satellite images (LANDSAT 7 - ETM 1999) of 48 sampled environments from the alluvial valley of Upper Paraná River.

species richness in the present survey is representative of the total ostracod diversity for alluvial valley of the Upper Paraná River. These estimators were Chao 1, Chao 2, first and second orders Jackknife, Bootstrap and ICE. Chao 1 and ACE estimators are based on species abundance and the other species richness estimators are based on species incidence. EstimateS statistical software (Colwell, 1997) was used for this.

Due to the differences in abundance among the samples, rarefaction curves were used to compare species richness among systems and environments. Rarefaction curves were computed using the EcoSim Program (Gotelli, 2005).

A parametric ANOVA was performed to test for possible differences in species richness of ostracods among types of system and environment. In case of significant differences, a Tukey test was performed a posteriori. When the homogeneity assumption was not fulfilled, a non-parametric Kruskall-Wallis test was used. The same protocol was used to test differences in species richness of the 4 families of ostracods amongst systems and environments.

The beta diversity index (β2) was applied to quantify changes in species composition among systems and environments. Index β2 was estimated by $\beta2 = [(R/\alpha_{max})-1]/[N-1]$, where α_{max} is the maximum value of species richness in *n* samples and R is the total species number in n samples (Harrison et al., 1992).

3. Results

The present survey recorded 54 species of ostracods, at least 12 of which are new species, while also 3 genera are new. The ostracod community comprised

Table 1. Ostracoda collected from the alluvial valley of Upper Paraná River.

- Class Ostracoda Latreille, 1806
- Subclass Podocopa G.W. Müller, 1894
- Order Podocopida Sars, 1866
- Suborder Podocopina Sars, 1866
  - Superfamily Cypridoidea Baird, 1845
    - Family Cyprididae Baird, 1845
      - *Diaphanocypris meridana* (Furtos, 1936)
      - *Stenocypris major* (Baird, 1859)
      - *Stenocypris* sp. 2
      - *Strandesia psittacea* (Sars, 1901)
      - *S. trispinosa* (Pinto and Purper, 1965)
      - *S. mutica* (Sars, 1901)
      - *S. variegata* (Sars, 1901)
      - *S. bicuspis* (Claus, 1892)
      - *Bradleystrandesia* gr. *elliptica* sp. 1
      - *B.* gr. *elliptica* sp. 2
      - *B.* gr. *elliptica* sp. 3
      - *Bradleystrandesia* sp. 3
      - *Bradleystrandesia obtusata* (Sars, 1901)
      - *Bradleystrandesia* gr. *obtusata* sp. 2
      - *B.* gr. *obtusata* sp. 3
      - *B.* gr. *obtusata* sp. 4
      - *B.* gr. *obtusata* sp. 5
      - *Bradleystrandesia* gr. *obliqua*
      - *Bradlestrandesia* gr. *amati* n.sp.
      - *Cypricercus centrura* (Klie, 1940)
      - *Chlamydotheca deformis* Farkas, 1958
      - *C. colombiensis* Roessler, 1985
      - *C. iheringi* (Sars, 1901)
      - *Paranacypris samambaiensis* Higuti et al., 2009
      - *Cypretta* sp. 1
      - *Cypretta* sp. 2
      - *Cypretta* sp. 3
      - *Cypridopsis vidua* O.F. Müller, 1776
      - *"Cypridopsis"* cf. *vidua* sp. 2
      - *"Cypridopsis"* n.gen. 1 n.sp.
      - *"Cypridopsis"* n.gen. 2 *hispida* (Sars, 1901)
      - *Neocypridopsis nana* (Sars, 1901)
      - *"Neocypridopsis"* sp. 2 n.sp.
    - Family Candonidae Kaufmann, 1900
      - *Candonopsis brasiliensis* Sars, 1901
      - *Candonopsis annae* Mehes, 1914
      - *Candonopsis* sp. 3 n.sp.
      - *Candonopsis* sp. 4 n.sp.
      - *"Candona"* sp. 1 n.sp.
      - *"Candona"* sp. 2 n.sp.
      - *"Candona"* sp. 3 n.sp.

Table 1. Continued...

      - *"Candona"* sp. 4 n.sp.
      - *Physocypria schubarti* Farkas, 1958
      - *Physocypria* sp. 2 n.sp.
  - Superfamily Cytheroidea Baird, 1850
    - Family Limnocytheridae Klie, 1938
      - *Cytheridella ilosvayi* Daday, 1905
      - *Limnocythere* sp. 1
      - *Limnocythere* sp. 2
  - Superfamily Darwinuloidea Brady and Norman, 1889
    - Family Darwinulidae Brady and Norman, 1889
      - *Darwinula stevensoni* (Brady and Robertson, 1870)
      - *Microdarwinula inexpectata* Pinto et al., 2005
      - *Microdarwinula* sp. 2 n.sp.
      - *Alicenula serricaudata* (Klie, 1935)
      - *Vestalenula pagliolii* (Pinto and Kotzian, 1961)
      - *V. botocuda* Pinto et al., 2003
      - *Penthesilenula brasiliensis* (Pinto and Kotzian, 1961)
      - *P. aotearoa* (Rossetti et al., 1998)

4 families, Cyprididae, Candonidae, Darwinulidae and Limnocytheridae, represented by 33, 10, 8 and 3 species, respectively (Table 1).

Results from the species richness estimations showed values that were always close to the observed results. ACE and Chao 1, based on species abundance, followed by Bootstrap, based on the species occurrence, were the estimators which best approached the observed species richness. Therefore it appears that total number of expected species converges closely to the 54 species presently observed (Figure 2).

Rarefaction curves demonstrated higher richness of ostracods in the Baía system and lower in Taquaruçu. When analyzing different environments, higher values were observed in open lakes, rivers and channels (Figure 3).

ANOVA results showed significant differences for species richness when comparing systems and environments. When analyzing different systems, significantly higher values of species richness were found in the Baía system compared to Taquaraçu ($p = 0.0059$). Considering the different environments types, significantly lower values for richness were found for closed lakes compared to open lakes, rivers and channels ($p = 0.0000$).

All beta diversity values were relatively low, meaning that there is a great similarity within and amongst systems and environments. Ivinheima and Taquaruçu had the highest beta diversity values while the lower values were recorded in the Baía system. In relation to environment types, higher values were observed for closed lakes, open lakes and rivers (Figure 4).

Among the 4 families, Cyprididae is by far the most diverse, and the richness of this family was significantly affected by system (Ivinheima, Baía and Paraná differ from the Taquaruçu) and environment (open lakes, rivers and channels differ from the closed lakes).

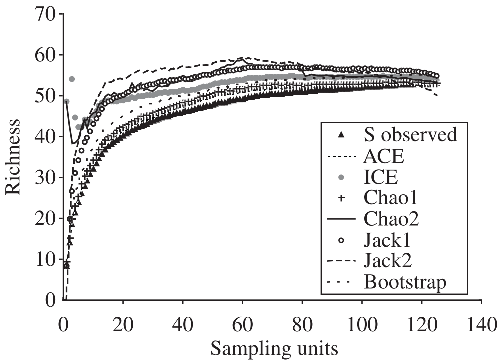

Figure 2. Accumulation curve of ostracods species resulting from different species richness estimators of the alluvial valley of Upper Paraná River.

Candonidae and Limnocytheridae showed significant effects by system and Darwinulidae only by environment (Figure 5).

4. Discussion

Fifty four species were recorded in one of the most extensive surveys of freshwater ostracods to be undertaken in South America. Yet, considering that almost 50 water bodies, representing different types of environment, were sampled, this gamma diversity is not very high. Nevertheless, several richness estimators suggest that the sampling effort was sufficient to reveal the true, standing gamma diversity. Also beta diversity was relatively low, as similarity in ostracod communities between the various lakes, rivers and channels was high. This is illustrated by the community of Manezinho, a relatively small backwater of the main Paraná River channel, where the pleuston (root systems) of *Eichhornia crassipes* (only one of several possible host plants) turned out to comprise 27 species, half the total gamma diversity of the entire alluvial valley (Higuti et al., 2007).

The most speciose ostracod family in the different environments of the alluvial valley of Upper Paraná River is

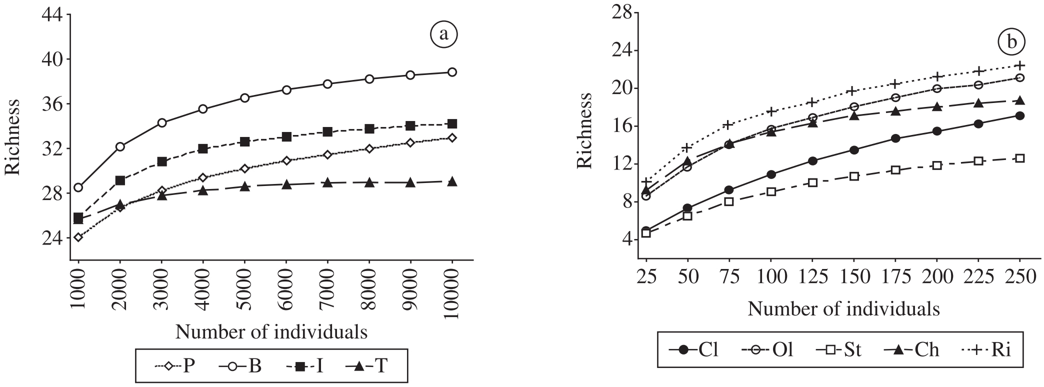

Figure 3. Rarefaction curves of ostracods species in different a) systems; and b) environments of the alluvial valley of Upper Paraná River. (B = Baía, I = Ivinheima, P = Paraná, T = Taquaruçu, Cl = closed lake, Ol = open lake, Ri = river, Ch = channel, St = stream).

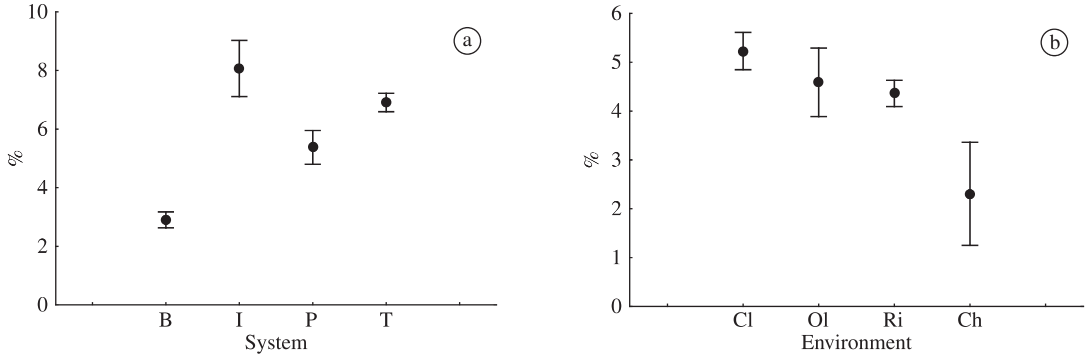

Figure 4. Beta index based on species richness for a) systems; and b) environments in the sampling period (B = Baía, I = Ivinheima, P = Paraná, T = Taquaruçu, Cl = closed lake, Ol = open lake, Ri = river, Ch = channel).

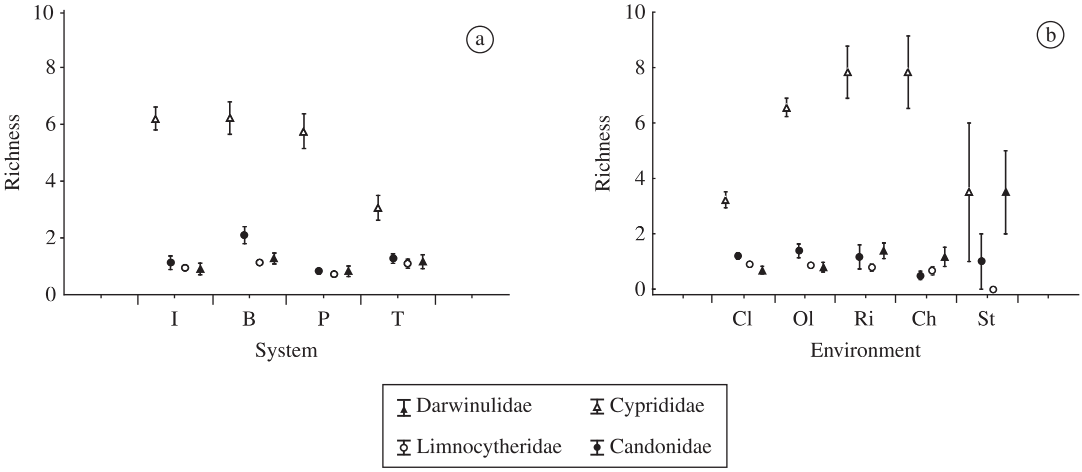

Figure 5. Effects of a) systems; and b) environments on species richness of the four extant families. One-way ANOVA (if allowed) or non-parametric Kruskal-Wallis test were performed to asses significance of differences. (B = Baía, I = Ivinheima, P = Paraná, T = Taquaruçu, Cl = closed lake, Ol = open lake, Ri = river, Ch = channel, St = stream).

Cyprididae, a pattern also observed by Würdig and Freitas (1988). Furthermore, Cyprididae may comprise more than 80% of all freshwater species in most tropical regions (Martens, 1998). On a global scale, Cyprididae hold about 1000 species, more than half of all described living non-marine ostracod species (Martens et al., 2008). Yet, with 33 out of 54 species (>60%), Cyprididae in the Paraná alluvial valley comprise more than half of all species.

Alpha diversity is to a large extent affected by local factors such as 'environment', and to a lesser extent by the regional factor 'system'. Beta diversity seems equally affected by both, but is in general low in our study.

Higher values of ostracod species richness, as observed in the Baía and Ivinheima systems, were probably related to higher environmental heterogeneity presented by these systems, compared to the others. On the other hand, the beta diversity showed that the ostracod fauna of the Ivinheima system is less homogeneous than that of the Baía system.

Species richness was also higher in rivers and channels. Other studies in the Upper Paraná River floodplain have also demonstrated higher values of species richness and diversity in lotic environments (Higuti, 2004; Lansac-Tôha et al., 2004; Train and Rodrigues, 2004). Lansac-Tôha et al. (2004) suggested that the high richness in lotic environments are due to the fact that these environments also receive the fauna from all lentic habitats, which are connected amongst themselves, e.g. open lakes.

Also differences between open and closed lakes, significant at several levels, are most likely at least partly regionally driven, as open lakes experience larger effects from flood pulses, through their connection with rivers and channels. Such pulses may cause faunal flow amongst the river and these lakes.

Flood pulses have been recognized as main drivers of biodiversity in the Upper Paraná system for various groups, eg. benthos, phytoplankton, zooplankton, fish and/or macrophytes (Thomaz et al., 2004). However, Higuti et al. (2007) argued that meiobenthic groups, such as ostracods, in pleuston (floating root systems) might actually be buffered from the putatively detrimental effects of sudden flood pulses, as floating plants will simply follow changing water levels with minimal changes in environmental conditions. Therefore, flood pulses are expected to mainly affect benthic habitats (including the littoral), and the fact that most habitats in the present study are indeed floating plants might explain the lower relevance of the regional factor 'system'.

Water levels of closed lakes can only be affected by floods through groundwater level fluctuations and through direct input from local rains, and these will be less related to floods, the further away these lakes are from the river system(s). According to this logic, the closed lakes of Taquaruçu should experience minimal to no effects of flood pulses.

The effect of the systems and environments on richness of the 4 families is mixed: the most diverse Cyprididae appear to be influenced by both factors, on the other hand, Candonidae and Limnocytheridae have a larger regional input (system), and Darwinulidae showed effects only for the environment, as they especially occur in lotic environment (Higuti et al., 2009).

5. General Conclusion

Both factors, system and environment, appear to drive different levels of specific biodiversity (alpha and beta diversities), but no clear cut patterns emerge. This might be due to the following reasons: 1) different species in the floodplain communities have sometimes opposite requirements, which obscures any patterns at higher biodiversity levels; and 2) relative uniformity between communities (as exemplified by low beta diversity values) hampers the identification of isolated drivers of diversity, especially of local, but also of more regional, factors.

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