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On the significance of wetlands: three decades of aquatic macroinvertebrate monitoring programs in a Neotropical floodplain

A importância de planícies de inundação: três décadas de programa de monitoramento de macroinvertebrados aquáticos em uma planície de inundação Neotropical

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Abstract: Aim: Wetland areas have high environmental complexity and support high biodiversity. Therefore, global efforts are required to preserve these areas. Here, we show the results of three decades of monitoring programs regarding macroinvertebrate species from the upper Paraná River floodplain, which is an important wetland conservation area in the neotropics. **Methods:** We searched the literature from 1990 to 2020 and selected studies that addressed questions related to benthic or macrophyte-associated macroinvertebrates in the study area. **Results:** We retained 92 articles that matched the criteria. We noticed that the number of publications increased after 2009, and most studies were related to lentic environments. Sediment was the most studied substrate, showing the highest taxa record and diversity, followed by aquatic macrophytes. We found records of 517 taxa, from which the families Chironomidae, Cyprididae, and Naididae presented the highest taxonomic richness. The taxa richness observed in our study was lower than the bootstrap richness estimated. **Conclusions:** The lack of signs of curve stabilisation through time for both observed and estimated taxa richness could indicate the macroinvertebrate richness from the upper Paraná River floodplain must be underestimated. In this way, once most of the studies reported results related to long-term ecological research, we argue for the continuity of such studies in floodplains as a powerful tool to assess biodiversity, which can provide useful data for the creation of conservation strategies that enhance the maintenance of biodiversity in such areas.

Keywords: aquatic invertebrates; richness; environmental complexity; biological diversity; upper Paraná River floodplain.

Resumo: Objetivo: Planícies de inundação apresentam elevada complexidade ambiental e sustentam a biodiversidade da região. Assim, esforços globais são necessários para preservar essas áreas. Este trabalho sumariza o resultado de três décadas de programas de monitoramento de espécies de macroinvertebrados da planície de inundação do alto rio Paraná, a qual é uma expressiva área de conservação neotropical. **Métodos:** Foi realizada uma busca bibliográfica na literatura de 1990 a 2020 e foram selecionados os estudos que abordavam questões relacionadas a macroinvertebrados bentônicos ou associados às macrófitas aquáticas na área de estudo. **Resultados:** Foram selecionados 92 artigos, os quais seguiam os critérios da busca. Observou-se que o número de publicações aumentou após o ano 2009, e a maioria dos estudos encontrados estava relacionada aos ambientes lênticos. Dentre os substratos analisados nos trabalhos, o sedimento foi o mais estudado, apresentando maior registro e diversidade de *taxa*, seguido pelas macrófitas aquáticas. No total foram encontrados registros de 517 *taxa*, sendo que as famílias Chironomidae, Cyprididae e Naididae foram as que apresentaram a maior riqueza taxonômica. A riqueza de *taxa* observada no estudo foi inferior à estimada pelo Bootstrap. **Conclusões:** A falta de sinais de estabilização da curva ao longo do tempo para a riqueza de táxons observada e estimada pode indicar que a riqueza de macroinvertebrados da planície de inundação do alto rio Paraná deve estar subestimada. Dessa forma, uma vez que a maioria dos estudos reportou resultados relacionados a pesquisas ecológicas de longa duração, defendemos a continuidade de tais estudos em planícies de inundação como uma poderosa ferramenta para avaliar a biodiversidade, os quais podem fornecer dados úteis para a criação de estratégias de conservação que melhorem a manutenção da biodiversidade em tais áreas.

Palavras-chave: invertebrados aquáticos; riqueza taxonômica; complexidade ambiental; diversidade biológica; planície de inundação do alto Rio Paraná.

1. Introduction

The Neotropical region is recognised by its extensive wetlands (Junk et al., 2011), which are important areas for biodiversity conservation because of their high species diversity and productivity (Mitsch & Gosselink, 2000; Junk et al., 2006). Wetlands have high economic value (Emerton & Bos, 2004) and support many ecosystem services (e.g. supporting service: nutrient cycling; provision service: fish biomass), as well as contributes to social and cultural well-being (e.g. recreation and spiritual fulfilment) (Fisher et al., 2009), resulting in several benefits for humans (Mitsch & Gosselink 2007; Agostinho et al., 2008).

Wetlands can be called floodplain wetlands when they are driven by a flood pulse (Junk et al., 2006, 2014), as is the case of the floodplain area in the upper portion of the Paraná River in South America. This wetland area encompasses a range of aquatic habitats such as temporary and permanent shallow lakes, rivers, and secondary channels (Bonetto, 1993; Agostinho et al., 2009), where flood pulses are controlled by the main stem of the Paraná River. This area represents one of the last dam-free stretches in the Paraná River along the Brazilian territory (Souza-Filho & Stevaux, 1997), and efforts have been made to conserve this area for both biodiversity conservation and the maintenance of ecological functioning of this ecosystem (Agostinho & Zalewski, 1995; Rocha et al., 2009; Junk et al., 2014).

Aquatic macroinvertebrates are essential for wetland functioning because of their role in food webs, in which they promote a link between primary producers and secondary consumers (Murkin & Wrubleski, 1988). For this reason, some species have been considered keystones (Dangles et al., 2004), and such communities have been used to apply management and conservation actions in several locations (McGeoch et al., 2011). Macroinvertebrates are strongly influenced by environmental conditions and show reduced mobility in water (Würdig et al., 2007), making this community an interesting indicator in studies of both spatial and temporal distribution patterns. Macroinvertebrate groups, especially insects, are among the few organisms able to colonise many temporary ponds (Chase & Knight, 2003; Lancaster & Briers, 2008), which are commonly found in wetland areas. Despite their great importance, aquatic macroinvertebrates have been less studied than vertebrates because of a range of factors, including the long time spent in laboratory sorting and identification, difficulty in the taxonomy of the groups, and the low number of researchers interested in the group (Thorp & Covich, 2009).

Macroinvertebrate is one of the most diverse and abundant groups in aquatic communities in the upper Paraná River floodplain (Takeda et al., 2004). Analysing the macroinvertebrate community on a long temporal scale represents a good way to find out possible changes in this wetland area. The results of the long-term research of this

community, even the most simple and descriptive ones, can provide information for future advances regarding macroinvertebrate studies and potential conservation actions. Moreover, long-term research on species occurrence allows geographically explicit descriptions of changes in their distributional ranges (Josephson et al., 2008). In a global scenario where extreme climatic events, biological invasion, and biotic homogenisation are becoming more frequent (Olden, 2006; Seneviratne et al., 2012; Simberloff et al., 2013), long-term research can provide important results for any change in community structure over time, particularly in wetland areas driven by seasonal water level fluctuations.

To synthetize our knowledge and evaluate the status and basic ecological structure of the macroinvertebrate community, we reviewed the literature related to aquatic macroinvertebrate species recorded over the last three decades in the upper Paraná River floodplain. We provide baseline information about the aquatic macroinvertebrate species, which helps to fill the Wallacean shortfall regarding biodiversity (Hortal et al., 2015) and can be useful to increase the efficiency of conservation polices. This is the first review of the current status of macroinvertebrate diversity in this Neotropical wetland area. In addition, we aimed to analyse the types of substrates (sediment, macrophytes, and artificial substrates) and environments (lentic and lotic) where the species were found. Finally, we aimed to compare the observed species richness with estimates provided by statistic models to evaluate the need for continuity in long-term ecological research.

2. Materials and Methods

2.1. Study area

The Paraná River occupies the position of the second longest river in South America (4695 km), the tenth largest river in the world in terms of water discharge, and also the fourth in the drainage area (Agostinho et al., 1995). The Paraná River basin is the region with the highest population density, the main industrial centres, and the most intensive agriculture in Brazil (Agostinho et al., 2004a). However, dams are the most common human interference on the physiography of the region (Agostinho et al., 2004a), and the Paraná River is one of the most regulated rivers around the world (Agostinho et al., 2004b; WCD, 2000).

The upper Paraná River floodplain is located between two Brazilian reservoirs, Porto Primavera and Itaipu (Figure 1). The climate according to the Köppen system is classified as Cfa (tropical-subtropical), with an annual average temperature of 22 ºC and annual average rainfall of 1500 mm (Eletrosul, 1986). Its habitats show differences in water velocity, depth, and other physical and chemical variables, summarizing it as a large environmental heterogeneity ecosystem (Roberto et al., 2009). The hydrological regime of the upper Paraná River floodplain is influenced by 26 upstream reservoirs, although the area of study encompasses approximately 230 km of dam-free river (Agostinho et al., 2004c). In this area, as a compensatory measure for dam construction upstream of the upper Paraná River floodplain, three conservation units were created: the Area de Proteção Ambiental das Ilhas e Várzeas do Rio Paraná (1,000,310 ha), the Ilha Grande National Park (78,000 ha), and the Ivinhema River State Park (70,000 ha) (Agostinho et al., 2004c). The entire area was incorporated into the Atlantic Forest Biosphere Reserve by the Man and the Biosphere Programme of the United Nations Educational, Scientific, and Cultural Organization.

2.2. Literature search and data handling

We searched for data on aquatic macroinvertebrates recorded in the upper Paraná River floodplain by reviewing published articles and reports (grey literature). We took data from an extensive literature search at the ISI Web of Knowledge, SciELO, and Scopus websites, using the keyword combination "upper Paraná River" or "Paraná River" and "floodplain" or "wetland" and "macroinvertebrate*" for the search. We selected articles published between 1990 and 2020, given that most of the ecological studies and publications in this study area began in the 1990s. We selected the articles following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model (Liberati et al., 2009) and considered the selection in four steps: (1) the country of the study, (2) the title, (3) the abstract, and (4) the full text. The selection of papers followed some eligible parameters such as type of organisms, study of area, and the presence of taxa data. During the selection, we excluded macroinvertebrates recorded as parasites or those found in studies of vertebrate feeding habits. Articles that contained these two criteria were excluded from the analyses. The articles that remained were analysed regarding the type of substrate where the macroinvertebrates were recorded (i.e., sediment, macrophytes, or artificial

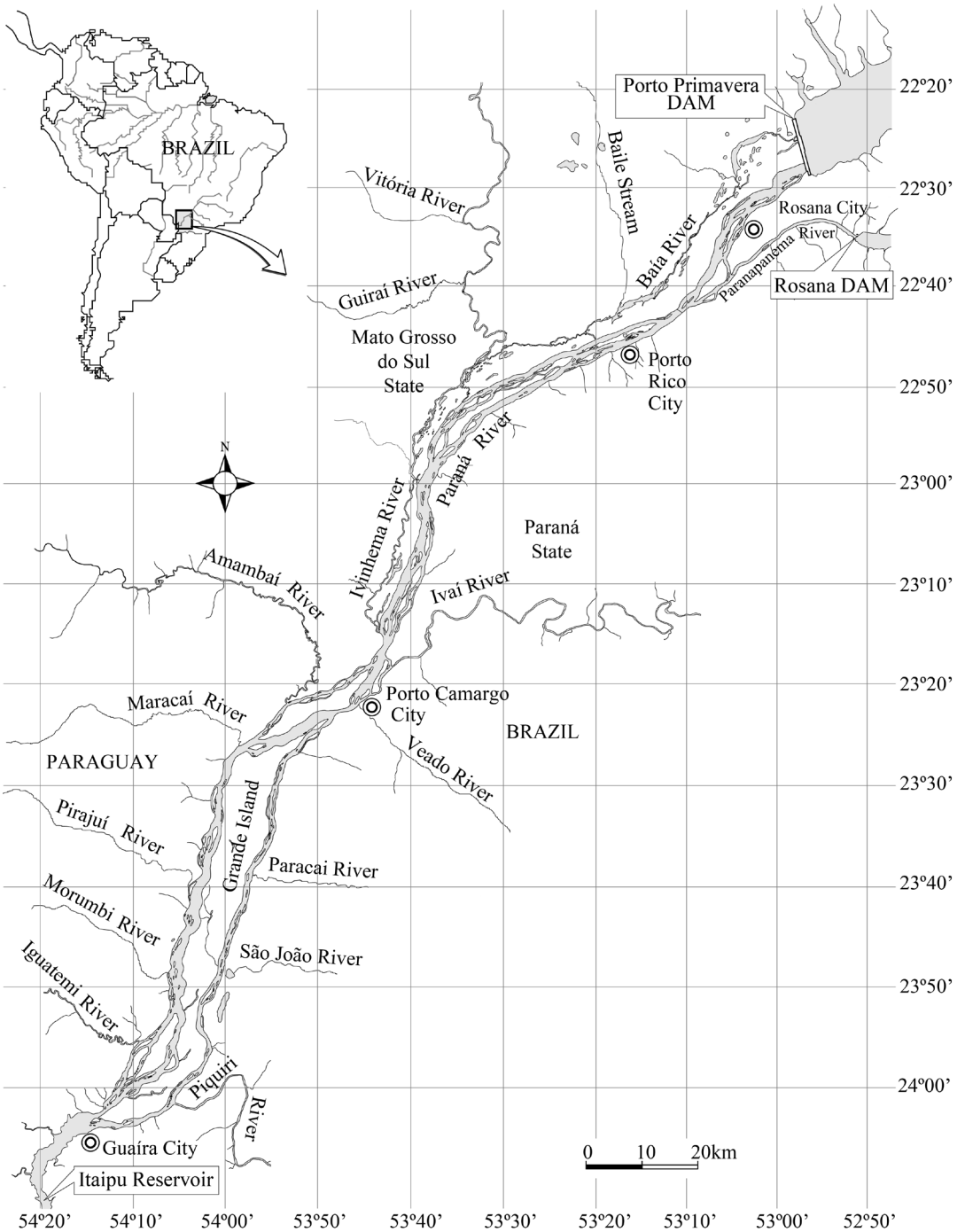

Figure 1. Map showing the upper Paraná River floodplain.

substrates), type of environment where each taxon was found (i.e., lentic or lotic environment), and the year in which each taxon was recorded for the first time in the upper Paraná River floodplain.

We compared the observed taxa richness during the last three decades with the values from richness estimators to evaluate the sampling efforts needed to get closer to the total number of species that could be found. In order to estimate the number of potential taxa to be found in the studied area, we performed the bootstrap (Palmer, 1990) estimator and compared it with the curve of estimated richness over the three decades. Bootstrap was chosen because its estimates are based on the observed frequency of rare species in the community and the addition of the proportion of samples that have a particular species present to correct bias (Smith & Van Belle, 1984). We performed the bootstrap

estimator with the *specpool* function of the '*vegan*' package (Oksanen et al., 2013) in R software (R Core Team, 2018).

3. Results

We found 1,926 published articles in our literature search, but only 92 articles presented macroinvertebrate data from the upper Paraná River floodplain that matched our criteria selection and were retained for analyses (Figure 2). Several excluded articles described biodiversity, but no species/group list was provided. Although the first ecological studies in the upper Paraná River floodplain had started in the 1980s, the first articles were published in the 1990s, and the greatest contribution to biodiversity knowledge occurred after 2009, when there was an increase in the number of published articles (Figure 3). The major peak was reported in 2014, with 10 articles published (Figure 3).

We recorded 87 taxonomic groups/families of benthic or associated macroinvertebrates, totalling 517 taxa. Chironomidae (Diptera), Cyprididae (Ostracoda), and Naididae (Oligochaeta) families had the highest taxa richness during this period, with 223, 59, and 49 taxa per family, respectively. Some taxonomic groups/families presented low taxa richness (Figure 4) and only one or two taxa were recorded for 64 taxonomic groups/families (see dataset available on Zenodo (Bertoncin et al., 2022)).

Among the 92 articles encompassing benthic or associated macroinvertebrates, sediment was the most studied substrate (50 articles), followed by macrophyte substrates (42 articles) and artificial substrates (8 articles). Lentic environment was the most studied habitat (45 articles), followed by the lotic environment (24 articles), while some articles included both lentic and lotic environments (23 articles).

Sediment was the substrate that encompassed the higher number of taxa reported (Figure 5A) and was composed mainly of Chironomidae and Oligochaeta groups. In the macrophyte substrates,

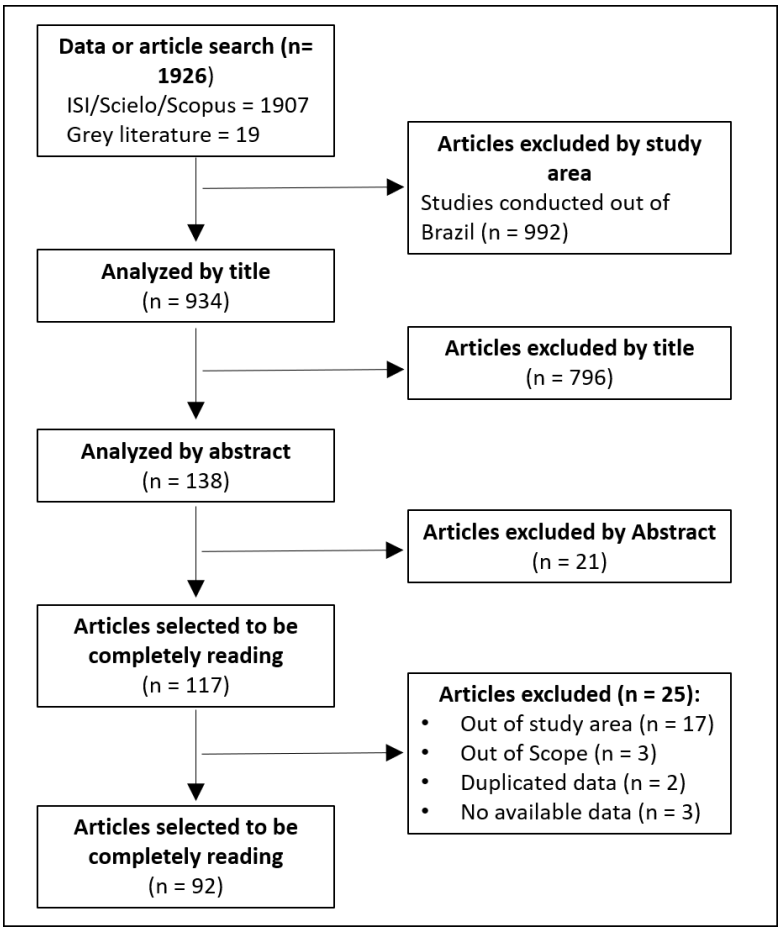

Figure 2. Flowchart based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model for selection of papers to be analysed.

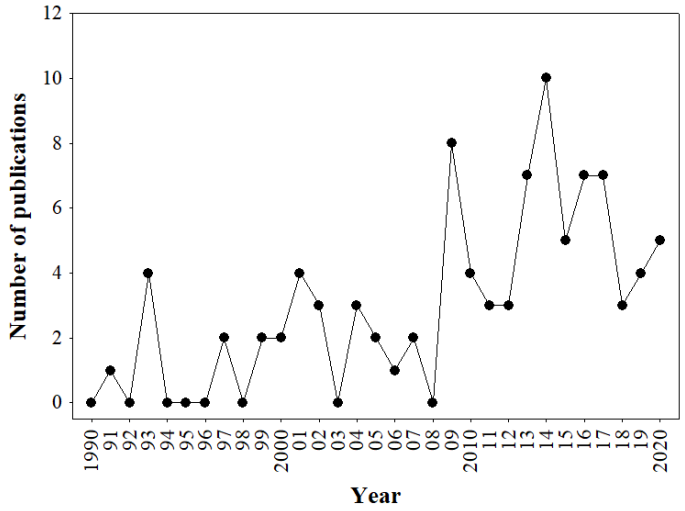

Figure 3. Number of publications per year of invertebrate's studies from the upper Parana river floodplain.

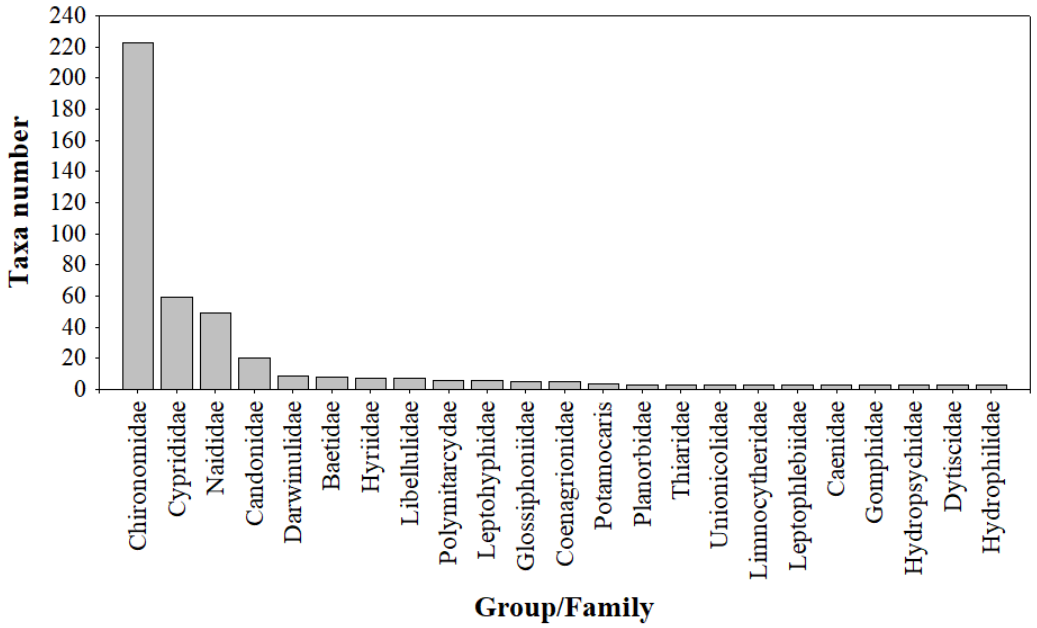

Figure 4. Number of taxa per group/family recorded in the upper Paraná River Floodplain through the revised period.

we found 185 taxa belonging mainly to Ostracoda, Arachnida, and Coleoptera groups. Finally, in artificial substrates, we found 90 taxa belonging mainly to Chironomidae, Ephemeroptera, and Oligochaeta. Comparing the accumulated taxa richness in these articles, we found higher taxa richness in lentic habitats than in lotic habitats (Figure 5B; see also dataset available on Zenodo (Bertoncin et al., 2022 for more details).

We found that the number of taxa recorded per year varied during the period, and there were years with no records of unseen taxa; in other years, several unseen taxa were recorded, with a peak of record of unseen taxa in 2013 (Figure 6A). The taxa accumulation curve presented a trend of increase with no signal of stabilization. The difference in the observed and estimated species richness tended to increase in recent years (Figure 6B).

4. Discussion

The continuity of ecological research in the upper Paraná River floodplain led to an increasing number of records of macroinvertebrate taxa from 1990 to 2020, as a result of the increase in the number of published articles that refined taxonomic resolution, particularly regarding the Chironomidae, Ostracoda, Oligochaeta, and

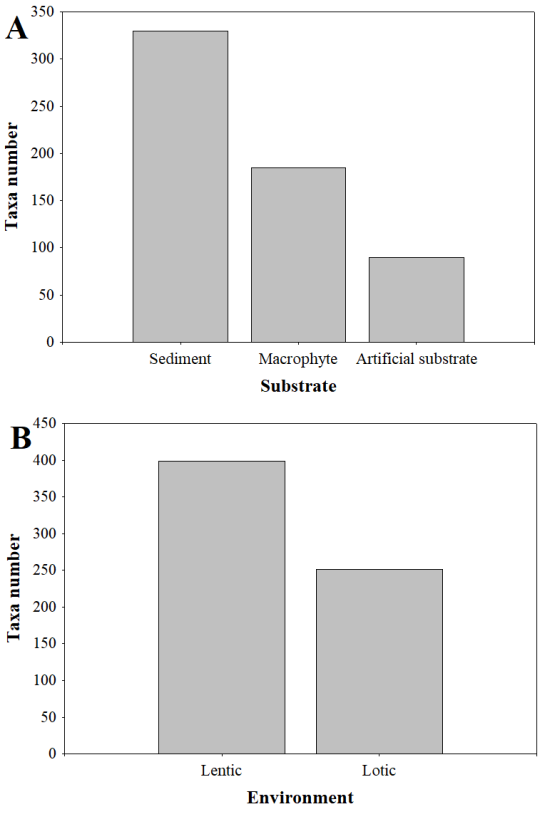

Figure 5. Number of taxa found in (A) each environment and (B) substrate type in all papers analysed.

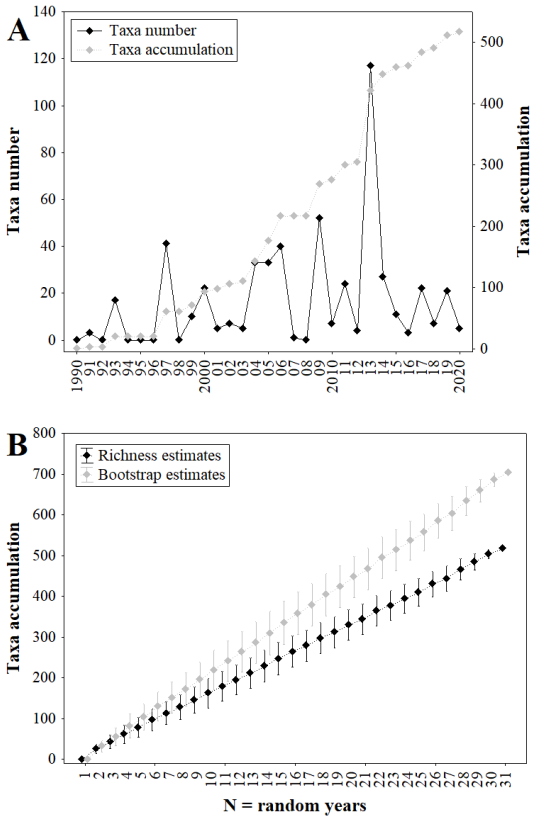

Figure 6. (A) The sum of the observed taxa number per year with its accumulation curve, and (B) Curves of estimated richness and Bootstrap over the sampled random years (N).

Ephemeroptera groups. Moreover, the observed and estimated taxa accumulation curves presented no signs of saturation, indicating that the sampling efforts could be increased or that the ecological studies should continue in the wetland area because there are potential new taxa to be found.

Besides the long-term researches in area we face the problem of scarcity of specialised researchers working with macroinvertebrates in the upper Paraná River floodplain or the scarcity of specialised literature to refine the taxonomic resolution of aquatic macroinvertebrates (Merritt et al., 1984; Roque et al., 2007; Jones, 2008). Those combined factors resulted in the great number of articles we were not able to use. The frequent occurrence of immature stages of insects, for example, makes it hard to identify to species level (Marshall et al., 2006). The peaks of taxa records observed in 1990, 2005, and 2013 were represented by published articles about Oligochaeta, Ostracoda, and Chironomidae, respectively. In recent years, efforts have been made to refine the taxonomic resolution of such groups in ecological studies performed in the upper Paraná River floodplain. The first macroinvertebrate studies of the upper Paraná River floodplain were only descriptive and observational (e.g. Takeda et al., 1991; Higuti & Takeda, 2002), and researchers have introduced ecological theories and applied themes such as habitat complexity and heterogeneity (e.g. Mormul et al., 2011; Ragonha et al., 2014a; Bilia et al., 2015; Pressinate-Junior et al., 2016), biological invasions (e.g. Mormul et al., 2010, Michelan et al., 2014; Ernandes-Silva et al., 2016; Gentilin-Avanci et al., 2020), metacommunities (e.g. Petsch et al., 2015, 2017), evaluations of damming effects (e.g. Rosin et al., 2009; Pinha et al., 2013; Ragonha et al., 2014b), and climatic changes (Bertoncin et al., 2019).

Research related to conservation and environmental monitoring generates better insights when using taxonomic resolution at the genus or species levels (Lenat & Resh, 2001). Furthermore, for some groups such as Chironomidae, a more accurate taxonomic resolution is indicated for many applications in ecological research (Vasquez et al., 2022), to indicate phylogenetic structure (Baranov et al., 2021), and for the status

of conservation or the biodiversity of some areas, given that there is a large number of morphospecies belonging to a single genus (Lenat & Resh, 2001; Roque et al., 2007).

Our findings showed that a higher number of taxa were found in the lentic sites, which can be related to both the higher heterogeneity in some lowland ponds (Ragonha et al., 2014a; Bilia et al., 2015) and the fact such environments have received a greater sampling effort throughout the time mainly about some representative groups, like Ostracoda. These results agree with survey studies in ponds around the world (Williams et al., 2003; Biggs et al., 2005), which have highlighted that such habitats have higher taxa richness than rivers, reinforcing the importance of wetland areas for biodiversity conservation (Gibbs, 1995; Gibbs, 2000; Dudgeon et al., 2006). In relation to substrate type, the sediment had a larger number of taxa, followed by aquatic macrophytes and artificial substrates. This is a result of the massive sampling effort on sediments, which include both the long-term ecological research performed in the upper Paraná River floodplain and research on rich groups such as Chironomidae and Oligochaeta, which are usually identified at the genus or species level.

Despite its status as a conservation area, the upper Paraná River floodplain has been heavily affected by human influences such as dam construction and species introduction (Agostinho et al., 2004a, 2008). Studies aiming to verify the damage to the construction of dams began mainly in 1999, before the construction of the dam of Porto Primavera (in 1999), in which the macroinvertebrate community was represented by 126 taxa, of which 44 were Chironomidae (Agostinho et al., 2009). Together with the construction of dams, non-native species can be of great concern because they promote a series of negative impacts on the native community (e.g. competition, predation, and parasitism) and are considered one of the main causes of biodiversity loss (Vitousek et al., 1997; Parker et al., 1999; Didham et al., 2005). Since the beginning of studies in the upper Paraná River floodplain, three species of mollusks were confirmed to be non-native invasive for the macroinvertebrate community, that is, *Corbicula fluminea* (Müller, 1774), which has been recorded since the 90's (Takeda et al., 2004), *Melanoides tuberculate* (Müller, 1774), recorded in 2000 (PELD, 2000), and *Limnoperna fortune* (Dunker, 1857), recorded in 2002 (Takeda et al., 2004). However, the number of non-native species can be underestimated in the upper Paraná River floodplain, owing to the scarcity of knowledge about the invertebrate community in this area.

The number of macroinvertebrate taxa we found (517 taxa) can be considered lower than those found in the other wetlands, although the sampling effort and the taxonomic resolution have been different among the studies. For example, in an extensive review of freshwater macroinvertebrates carried out by Curtis et al. (1998) in the wetlands of Namibia, they found 778 species, and similar to our results, the authors reported many shortcomings in terms of information on several groups. However, the number of taxa we found can be considered higher than that in the seven-year survey carried out by Scarsbrook et al. (2000) in New Zealand's wetlands. These authors found 122 taxa, the majority of which were insects (Diptera, Trichoptera, Ephemeroptera, and Coleoptera). In addition, if we consider the data compilation of Junk et al. (2006), in which they compared the biodiversity of wetlands throughout the world (Pealtand = 48 taxa; Tonle Sap = 167; Everglade = 590 taxa; Sundarban = 886 taxa; and Kakadu = 900 taxa), we can see that the upper Paraná River floodplain has more than half of the richness found in Sundarban and Kakadu wetlands, and the estimated taxa richness is closer to the richness found in Sundarban and Kakadu wetlands. This scenario highlights the representativeness of Neotropical wetlands with respect to taxonomic richness.

Many taxa recorded in the upper Paraná River floodplain are endemic, which increases their importance for biodiversity conservation. For example, in South America, more than 80% of all species of ostracods are endemic to this continent and zoogeographical region (Martens et al., 2008), and several new species and genera have been described in the upper Paraná River floodplain (Higuti et al., 2009; Higuti & Martens, 2012; Higuti et al., 2013; Higuti & Martens, 2014). A similar contribution has been found for Oligochaeta, with 91 species endemics to the Neotropical region, which corresponds to 51% of the Oligochaeta species described (Martin et al., 2008). On the other hand, the last information about the amount of endemic Chironomidae species in the Neotropical region was given by Ashe et al. (1987) who reported 15 genera as being endemic from this area. Moreover, most of the Chironomidae identification from the upper Paraná River floodplain goes down to the genera or morphospecies only. Therefore, despite the high diversity found for Chironomidae, most records are imprecise estimates of the real Chironomidae

species richness (Roque et al., 2007). These findings indicate that studies in the upper Paraná River floodplain continue to contribute to fulfilling the Linnean shortfall (Hortal et al., 2015).

The increasing accumulation curves show a tendency for new findings for future research. In addition, the estimator curve (bootstrap) and the observed curve were closely related, but as they were not asymptotic, it indicates that the biodiversity of this area seems to be underestimated. Thus, we suggest that sampling biodiversity could be an important activity for incessant research in the upper Paraná River floodplain. It is expected that the sampling effort should be increased several times until an asymptote is obtained, mainly in the tropics, where the presence of rare species and the diversity of species is high (Gotelli et al., 2011). In addition, once species accumulation curves describe the relationship between the expected richness and the sampling effort, they are useful for making comparisons among different sites or communities (Colwell & Coddington, 1994).

In this study we could find some major problems which could be easily solved. For example, we call attention to the need to provide species lists (even in supplementary documents) accompanied by geographical coordinates, in primary research papers, which can allow the identification of any change in the occurrence or distribution of species over time and can help to perform review papers with more accurate information. In addition, nonstandard sampling efforts over the years and the few taxonomic descriptions about the group were also concerning. Such problems have been corrected as much knowledge about macroinvertebrates ecology and taxonomy have been grown across the years. We emphasise the importance of the upper Paraná River floodplain in the maintenance of endemic species and its potential for new discoveries, once this ecosystem is recognised by its mosaic of habitats, encompassing a great biological diversity, which reinforces the importance of wetland areas for biodiversity conservation. Finally, once most of the studies reported results related to long-term ecological research (PELD/CNPq, Sítio PIAP), we argue for the continuity of long-term studies in wetlands as a powerful tool to assess biodiversity, which can provide useful data for the creation of conservation strategies that enhance the maintenance of biodiversity in wetland areas.

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