

The effects of mining tailings and flood pulse on zooplankton in an Amazonian floodplain environment (Batata Lake, Pará, Brazil)

Os efeitos de rejeitos de mineração e pulso de inundação sobre o zooplâncton em um ambiente amazônico de planície de inundação (Lago Batata, Pará, Brasil)

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Abstract: The flood pulse, as well as anthropogenic impacts, may shape the patterns of zooplankton communities. We evaluated the influence of bauxite tailings and water levels on zooplankton at sampling times precisely defined according to the water level. Our study area was Batata Lake, an Amazonian floodplain lake impacted by bauxite tailings. Zooplankton was sampled for seven years, four times a year, at two stations, one natural and the other impacted by bauxite tailings. Zooplankton was identified to the lowest possible taxonomic level. Differences in richness and densities between periods and stations were evaluated with a two-way ANOVA. An indicator species analysis was performed to assign species to sampling stations. Community richness was lower at low water and higher at high water, whereas densities showed the opposite result. Only one species was identified as an indicator, highlighting that the zooplankton composition in natural and impacted areas was similar. Densities were also similar at these stations, except for cladocerans, which showed higher densities at the impacted station. The use of samples taken at precisely defined flood pulse periods yielded expected but refined results, as the samples were based on a precise relationship with water levels that previous studies did not include.

Keywords: Zooplankton. Floodplain lake. Bauxite tailings. Batata Lake. Amazon. Sampling.

Resumo: O pulso de inundação, assim como impactos antropogênicos, pode moldar os padrões de comunidades zooplanctônicas. Nós avaliamos a influência do rejeito de bauxita e níveis d'água sobre o zooplâncton, em momentos de amostragem definidos de acordo com o nível d'água. Nossa área de estudo foi o lago Batata, lago de planície de inundação impactado por rejeito de bauxita. O zooplâncton foi coletado durante sete anos, quatro vezes ao ano, em duas estações, uma natural e outra impactada por rejeito de bauxita. Diferenças na riqueza e densidades entre períodos e estações foram avaliadas por uma ANOVA de dois fatores. Uma análise de espécies indicadoras foi feita para atribuir espécies às estações de coleta. A riqueza da comunidade foi menor em águas baixas e maior em águas altas, enquanto a densidade apresentou o padrão oposto. Apenas uma espécie foi identificada como indicadora, evidenciando que a composição do zooplâncton em áreas naturais e impactadas é similar. As densidades também foram semelhantes entre estas estações, exceto pelos cladóceros, com maiores densidades na estação impactada. Amostragens em momentos precisamente relacionados aos ciclos de inundação levaram a resultados esperados, porém refinados, já que as amostras foram correlacionadas ao nível d'água, fator não considerado em estudos anteriores.

Palavras-chave: Zooplâncton. Lago de planície de inundação. Rejeito de bauxita. Lago Batata. Amazônia. Amostragem.

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INTRODUCTION

Amazonian floodplains undergo changes in the volume of water that they contain during the year because of the rainfall patterns at regional or even continental scale, according to dry and wet seasons. This variation has been characterized and described as the flood pulse (Junk *et al.*, 1989). In lakes, the pulse creates a temporarily flooded area; because of the seasonal flooding of terrestrial areas, there is an allochthonous input of nutrients to the main body of the lakes (Wantzen *et al.*, 2008; Aprile & Darwich, 2013). Moreover, high-water periods contribute to the homogenization of the system and increase its predictability (Thomaz *et al.*, 2007).

Four periods of water level variation can usually be recognized during the year: flood, high water, drawdown and low water. This division is arbitrary and simplistic and may not correspond perfectly to the actual water movements and volume because it is derived from a reductionist division of the year into four periods, each consisting of three months. Bittencourt & Amadio (2007) standardized water level fluctuations in Negro River by using a 101 year-old time series of river depth data. However, frequently, the sampling schedule to obtain, for example, zooplankton samples is based on aprioristic and artificial definitions of water level periods. Another important characteristic is that, beyond this yearly variation in the volume of water, there is also a variation among years; thus, the strength of the flood pulse is usually not exactly the same in different years (e.g. Schöngart & Junk, 2007; Rudorff *et al.*, 2014). For example, the Figure 1 graphically represents the interannual flood pulse variation in Trombetas River.

Variations in the water level strongly influence the characteristics of the environment and the aquatic communities. In part, the consequences of water level variations are related to the dilutive effect of water. For instance, the richness and density of phytoplankton, as well as primary production, are lower during periods of increased water levels (Ibañez, 1998; Huszar, 2000; Raupp *et al.*, 2009). Likewise, the biomass of benthic macroinvertebrates is lower (Nessimian *et al.*, 1998), and turbidity also tends to be lower (Alcântara *et al.*, 2010).

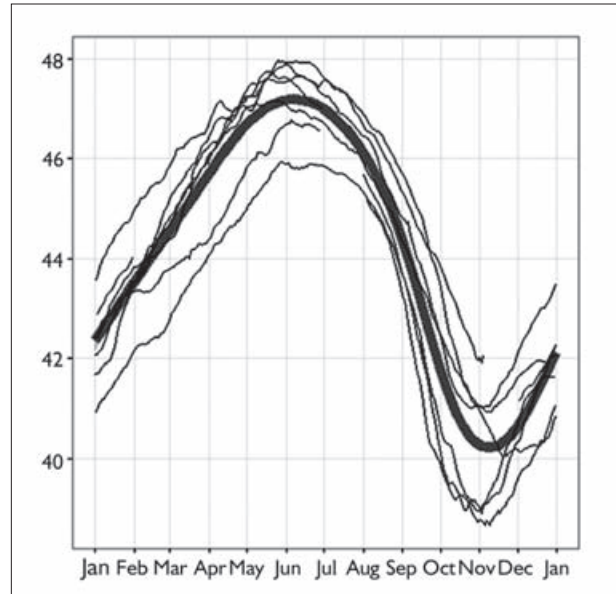


Figure 1. Trombetas River water level (in meters above sea level) from 1993 to 1999. Black single lines represent individual years; gaps in the lines are missing data. The thick grey line smoothly represents water level variation throughout the study period.

In addition to the role of water level variation, this study considered the presence of bauxite tailings from mining activity. These tailings cover part of the sediments of Batata Lake. The bauxite tailings also become resuspended in the water and may cause some disturbance to the zooplankton (Bozelli, 1996, 1998). Moreover, the tailings may increase zooplankton variability in relation to the flood pulse (Bozelli *et al.*, 2009).

Several authors have studied different aspects of zooplankton in Amazonian floodplain aquatic environments (Brandorff & de Andrade, 1978; Hardy *et al.*, 1984; Bozelli & Esteves, 1995; Pinilla *et al.*, 2007; Nova *et al.*, 2014; Torres-Bejarano *et al.*, 2014) but much remains to be discovered. In addition, zooplankton responds rapidly to disturbances and human interference. For this reason, zooplankton represents an interesting model for ecological and evolutionary studies (Lampert, 2006; Fussmann, 2010; Dahms *et al.*, 2011).

In relationship to this overview, we asked several questions about the influence of bauxite tailings and flood

pulse on the zooplankton of floodplain lakes. First, what are the specific differences between the natural and the impacted areas of Batata Lake? We propose that there are quantitative differences in the richness and densities of zooplankton but also qualitative differences in community composition. Second, how does the use of samples taken at precisely defined times during the flood pulse periods change or confirm our knowledge of zooplankton fluctuations in floodplains? We propose that the results obtained with this approach will be clearer and more accurate, making them more reliable for decision-makers and to the scientific community in general.

MATERIALS AND METHODS

STUDY AREA

This study was conducted at Batata Lake, a clear water Amazonian lake located on the right bank of the Trombetas River, in the Amazon floodplain ($1^{\circ} 25' - 1^{\circ} 35' S$ and $56^{\circ} 15' - 56^{\circ} 25' W$, Pará State, Brazil (Figure 2)). During the high water period (May-July), its depth can reach 10 m and a surface area about 30 km². During the low water period, its depth reaches less than 2 m, and its surface area is almost 18 km². This marked variation in surface area has evident consequences for the horizontal interactions between the

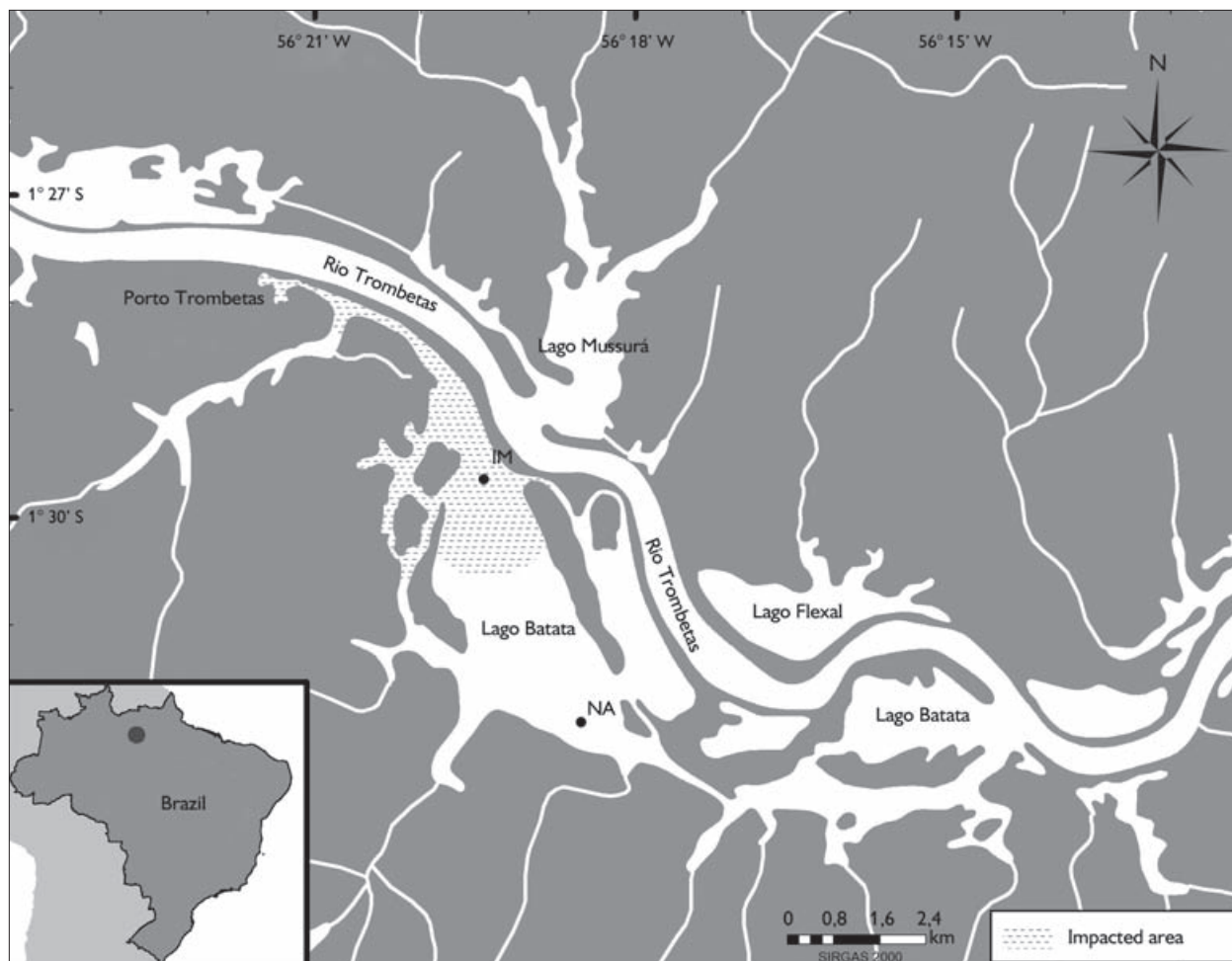


Figure 2. Lake Batata location. Dashed area equals to the impacted area. IM= Impacted station; NA = Natural station. Cartographic base: IBGE (2015).

lake and adjacent wetlands (Panosso, 2000). For example, during high water, the *igapó* forests that surround the lake are flooded, resulting in a large input of allochthonous material to the lake. Also, by flooding terrestrial environments, the flood pulse creates new habitats for aquatic organisms and stimulates fish migration between open waters and flooded *igapó* forests (Lin & Caramaschi, 2005a).

For ten years (1979-1989), Batata Lake received effluent originating from the process used to wash bauxite. This effluent, called bauxite tailings, consists of water, silt and clay particles. Its predominant components are silicates (47%), aluminum oxide (21%) and iron oxide (21%) (Lapa, 2000). The tailings caused the siltation of 30% of the area of the lake. This area is called 'impacted area'. In this area, a thick and nutrient-poor layer was formed on the natural sediment, changing its biological characteristics and the nutrient cycling of the lake (Leal *et al.*, 2003).

We sampled two stations in the lake, one in the natural (not impacted) area, and another in the impacted area (Figure 2). Both are located in the main body of Batata Lake and present similar geomorphological and hydrological characteristics (Panosso, 2000). In addition, the basic limnological variables (pH, alkalinity, electrical conductivity, dissolved oxygen, Kjeldahl nitrogen, total phosphorus and silicates) at the two stations are, on average, similar with the exception of transparency. Transparency is lower at the impacted station throughout the year but not during the high water period (Panosso & Kubrusly, 2000). This finding shows that the principal difference between these areas is the presence of bauxite tailings, which are normally deposited on the sediment and are resuspended only during periods of lower water levels. The tailings can be resuspended by the wind during periods of low water, increasing the turbidity of the water column and reducing the primary production of phytoplankton (Roland & Esteves, 1998).

SAMPLING

The zooplankton samples were collected weekly from 1993 to 1999. The samples were collected by taking

vertical hauls with a 68 μm plankton net, and then fixed in a solution of formalin and sugar, as described in Haney & Hall (1970).

From the samples collected by the weekly sampling program, only one sample from each sampling station was analyzed during each water level period (4 samples per station per year). To select the samples to be analyzed, we used the water level curves for Trombetas River. Thus, each year, the high water and low water samples were defined as the samples taken during the weeks in which the lake reached its maximum and minimum depths, respectively. The flood and drawdown depths were defined as the depth that was halfway between the high and low water level. In this manner, we chose the sample that corresponded exactly to the water level of the particular period, reducing the "noise" associated with samples that would be selected based on an artificial division of the year. In such cases, a sample representing a low water period could be confused with a sample representing a flood period if the pulse shifted slightly during that year.

We identified zooplankters to the lowest possible taxonomic unit. For each sample, three aliquots of zooplankton subsamples were counted in either a Sedgewick-Rafter cell under an Olympus BX50 microscope (for rotifers, cladocerans and nauplii) or in open chambers under an Olympus SZ-40 stereomicroscope (for copepods). Only rotifers of the superorder Monogononta were counted, because fixed bdelloid rotifers cannot be appropriately identified. Nauplii were differentiated into cyclopoids and calanoids. The entire sample was inspected to include rare species.

STATISTICS

We performed two-way ANOVAs (Gotelli & Ellison, 2011) to compare the effects of the stations and of the periods of the flood pulse on the richness and density of organisms. Data densities (ind/m^3) were transformed by $\ln(\text{dens} + 1)$ to meet the ANOVA assumptions. We performed a Holm-Sidak post-test (Holm, 1979) to evaluate the

differences in zooplankton richness and density between the periods if the ANOVA showed significant differences. We used indicator species analysis (IndVal) (Dufrêne & Legendre, 1997) to assign indicator species for each sampling station. ANOVA and Holm-Sidak post-test were performed in SigmaPlot (Systat Software, San Jose, CA), and IndVal was performed utilizing indicpecies package (De Cáceres & Legendre, 2009) in R software (R Core Team, 2013).

RESULTS

We found a total of 56 species of rotifers, 23 species of cladocerans and 6 species of copepods during the seven years of the study. The complete species list, with the frequencies of the zooplankton species, is shown in Tables 1 (rotifers) and 2 (microcrustaceans).

Only nine rotifer species were found in one-half or more of the samples, and only two of these (*Brachionus zahniseri gessneri* (Hauer, 1956) and *Keratella americana* Carlin, 1943) were found in 75% or more of the samples. Six species of cladocerans appeared in more than 75% of the samples, and these species were considered common. These species were *Bosmina hagmanni* Stingelin, 1904, *Bosminopsis deitersi* Richard, 1895, *Ceriodaphnia cornuta* Sars, 1885, *Diaphanosoma birgei* Kořínek, 1981, *Diaphanosoma polypina* Korovchinsky, 1982 and *Moina minuta* Hansen, 1899. Only one species of copepod, the cyclopoid *Oithona amazonica* Buckhardt, 1913, was found in more than 75% of the samples. Actually, this species was present in all samples during the study period. Thus, this species was very common, whereas all other copepod species were not common in Batata Lake.

Table 1. Rotifer species from Batata Lake. A: Percentage of samples in which each species was present; B: Maximum density found for the species during the time interval of this study (ind/m³). (Continue)

Rotifera	A	B
<i>Anuraeopsis fissa</i> Gosse, 1851	1.79	5302
<i>Ascomorpha ecaudis</i> Perty, 1850	3.57	68
<i>Ascomorpha saltans</i> Bartsch, 1870	1.79	812
<i>Asplanchna sieboldi</i> (Leydig, 1854)	16.07	757
<i>Brachionus bidentata</i> Anderson, 1889	1.79	902
<i>Brachionus dolabratus</i> Harring, 1914	16.07	1299
<i>Brachionus falcatus</i> Zacharias, 1898	8.93	1412
<i>Brachionus gillardi</i> Hauer, 1966	5.36	31578
<i>Brachionus mirus</i> Daday, 1905	32.14	37221
<i>Brachionus quadridentatus</i> Hermann, 1783	1.79	33
<i>Brachionus zahniseri</i> Ahlstrom, 1934	57.14	9087
<i>Brachionus zahniseri gessneri</i> (Hauer, 1956)	91.07	371212
<i>Collotheca</i> sp.	46.43	45888
<i>Conochilus</i> sp.	41.07	6818
<i>Dissotrocha</i> sp.	1.79	145
<i>Filinia longiseta</i> (Ehrenberg, 1834)	37.5	23484
<i>Filinia saltator</i> (Gosse, 1886)	12.5	7792
<i>Filinia terminalis</i> (Plate, 1886)	55.36	5413
<i>Gastropus stylifer</i> (Imhof, 1891)	1.79	244

Table 1.

(Conclusion)

Rotifera	A	B
<i>Hexarthra mira</i> (Hudson, 1871)	60.71	11247
<i>Kellicottia bostoniensis</i> (Rousselet, 1908)	1.79	16
<i>Keratella americana</i> Carlin, 1943	83.93	188568
<i>Keratella cochlearis</i> (Gosse, 1851)	10.71	1740
<i>Lecane bulla</i> (Gosse, 1851)	1.79	57
<i>Lecane cornuta</i> (Müller, 1786)	5.36	45
<i>Lecane curvicornis</i> (Murray, 1913)	10.71	914
<i>Lecane deridderae</i> Koste, 1972	1.79	97
<i>Lecane hamata</i> (Stokes, 1896)	1.79	26
<i>Lecane leontina</i> (Turner, 1892)	8.93	167
<i>Lecane ludwigii</i> (Eckstein, 1883)	10.71	85
<i>Lecane melini</i> Thomasson, 1953	30.36	759
<i>Lecane pertica</i> Harring & Myers, 1926	5.36	144
<i>Lecane prolecta</i> Hauer, 1956	42.86	67668
<i>Lecane quadridentata</i> (Ehrenberg, 1830)	3.57	67
<i>Lecane remanei</i> Hauer, 1964	7.14	361
<i>Lecane rudescui</i> Hauer, 1965	1.79	28
<i>Macrochaetus collinsi</i> (Gosse, 1867)	5.36	902
<i>Macrochaetus longisetus</i> Sudzuki, 1991	1.79	72
<i>Macrochaetus sericus</i> (Thorpe, 1893)	3.57	394
<i>Macrochaetus</i> sp.	5.36	1083
<i>Plationus patulus</i> (Müller, 1786)	10.71	1066
<i>Platylabus quadricornis</i> (Ehrenberg, 1832)	3.57	1515
<i>Ploesoma truncatum</i> (Levander, 1894)	44.64	5504
<i>Polyarthra dolichoptera</i> Idelson, 1925	50	38796
<i>Polyarthra vulgaris</i> Carlin, 1943	23.21	350
<i>Ptygura libera</i> Myers, 1934	50	8661
<i>Sinantherina</i> sp.	25	25520
<i>Synchaeta</i> sp.	26.79	22195
<i>Stephanoceros fimbriatus</i> (Goldfusz, 1820)	21.43	3158
<i>Testudinella patina</i> (Hermann, 1783)	1.79	33
<i>Trichocerca bicristata</i> (Gosse, 1887)	44.64	3082
<i>Trichocerca cylindrica</i> (Imhof, 1891)	51.79	1330
<i>Trichocerca pusilla</i> (Jennings, 1903)	64.29	13920
<i>Trichocerca similis similis</i> (Wierzejski, 1893)	28.57	6316
<i>Trichocerca similis grandis</i> Hauer, 1965	16.07	677
<i>Trichotria tetractis</i> (Ehrenberg, 1830)	1.79	28

Table 2. Microcrustacean (cladoceran and copepod) species from the Batata Lake. A: Percentage of samples in which each species was present; B: Maximum density found for the species during the time interval of this study (ind/m³).

Cladocera	A	B
<i>Alona intermedia</i> Sars, 1862	1.79	100
<i>Alona ossiani</i> Sinev, 1998	1.79	30
<i>Alona verrucosa</i> Sars, 1901	7.14	1237
<i>Alona</i> sp.	1.79	20
<i>Alonella dadayi</i> Birge, 1910	7.14	394
<i>Alonella</i> sp.	5.36	451
<i>Bosmina hagemanni</i> Stingelin, 1904	100	57370
<i>Bosminopsis deitersi</i> Richard, 1895	91.07	132088
<i>Ceriodaphnia cornuta</i> Sars, 1885	82.14	23819
<i>Chydorus eurynotus</i> Sars, 1901	1.79	45
<i>Chydorus nitidulus</i> (Sars, 1901)	1.79	72
<i>Chydorus pubescens</i> Sars, 1901	7.14	72
<i>Chydorus</i> sp.	1.79	28
<i>Diaphanosoma birgei</i> Kořínek, 1981	82.14	162403
<i>Diaphanosoma brevireme</i> Sars, 1901	1.79	1523
<i>Diaphanosoma fluviatile</i> Hansen, 1899	3.57	152
<i>Diaphanosoma polypina</i> Korovchinsky, 1982	76.79	47948
<i>Disparalona</i> sp.	1.79	394
<i>Holopedium amazonicum</i> Stingelin, 1904	8.93	564
<i>Ilyocryptus spinifer</i> Herrick, 1882	3.57	3158
<i>Macrothrix</i> sp.	7.14	1201
<i>Moina minuta</i> Hansen, 1899	89.29	23007
<i>Nicsmirnovius</i> sp.	1.79	45
Copepoda	A	B
Calanoida Nauplii	98.21	177483
Ciclopoida Nauplii	100	218342
Calanoida Copepodids	100	42379
Ciclopoida Copepodids	100	45670
Harpacticoida Copepodids	8.93	60
Harpacticoida	25	113
<i>Aspinus acicularis</i> Brandorff, 1973	80.36	3609
<i>Mesocyclops longisetus</i> Thiébaud, 1912	3.57	15
<i>Notodiaptomus coniferoides</i> (Wright, 1935)	76.79	9970
<i>Oithona amazonica</i> Buckhardt, 1913	100	19213
<i>Rhacodiaptomus bestii</i> Santos-Silva and Robertson, 1993	7.14	30
<i>Rhacodiaptomus retroflexus</i> Brandorff, 1973	37.5	180

Table 3 shows the results of two-way ANOVAs for the richness of the zooplankton and for the logarithms of the densities. The richness did not differ significantly between the two stations. However, differences were found between the periods (Figure 3). The richness during the high water period was higher than in all other periods (Holm-Sidak test).

Only in the group of cladocerans there were significant differences between the natural and impacted areas of the lake, with higher densities in the impacted area. All groups showed significant differences in density between periods. For the total zooplankton, all interperiod comparisons were significant with the exception of flood and drawdown (Figures 4-7).

One species was identified as an indicator species for the impacted station: the copepod *Rhacodiaptomus retroflexus* Brandorff, 1973 ($P=0.01$). This species was present in 50% of samples from the impacted station. According to the analysis, if a random sample shows one individual of *R. retroflexus*, then exist an 83% probability that this sample belonged to the impacted station. No indicator species were found exclusively for the natural station.

DISCUSSION

Rotifera was the richest zooplankton group, followed by cladocerans and copepods. Bozelli (2000), studying the zooplankton of Batata Lake, found 98 species of rotifers, 10 of cladocerans and 7 of copepods. The greater richness of rotifers cited by Bozelli (2000) was most likely caused by the higher spatial variation of his study, which covered seven sampling stations. Moreover, as no chydorids were identified by Bozelli (2000), the richness of cladocerans may have been underestimated. Despite these differences in richness, the principal species recorded, e.g. *Oithona amazonica*, were the same in both studies and in other studies of the zooplankton community of the Batata Lake (Bozelli, 1992; Carneiro *et al.*, 2003).

Despite the differences between stations, particularly regarding bauxite tailings present on sediments and suspended in the water, the richness of the natural station

Table 3. Two-way ANOVA results. Significant p values are underlined.

Data	Source of variation	F-ratio	P-value
Richness	Sampling area	0.016	0.9
	Period	7.428	<u><0.001</u>
	Interactions	0.980	0.41
Zooplankton density ($\ln x + 1$)	Sampling area	2.702	0.107
	Period	17.768	<u><0.001</u>
	Interactions	0.523	0.668
Rotifer density ($\ln x + 1$)	Sampling area	0.404	0.528
	Period	13.989	<u><0.001</u>
	Interactions	0.236	0.871
Cladocera density ($\ln x + 1$)	Sampling area	4.978	<u>0.030</u>
	Period	3.197	<u>0.032</u>
	Interactions	0.531	0.663
Copepod density ($\ln x + 1$)	Sampling area	3.112	0.084
	Period	23.342	<u><0.001</u>
	Interactions	1.208	0.317

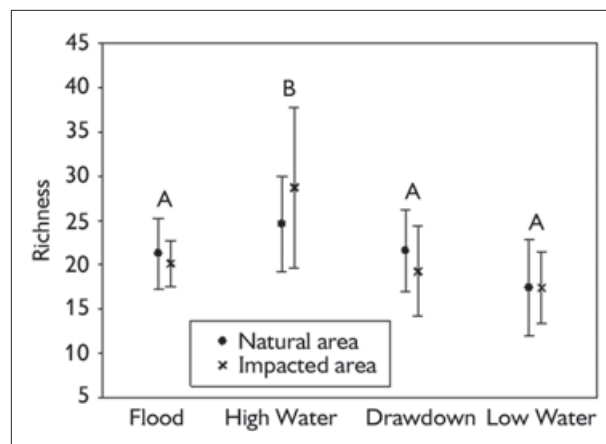


Figure 3. Mean and standard deviation of the total zooplankton richness. Richness in high water was significantly different from the richness in all other periods. Different letters represent significant differences among periods.

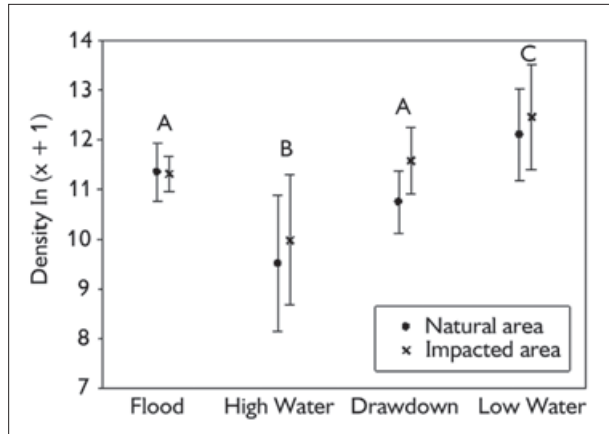


Figure 4. Mean and standard deviation of the total zooplankton densities (ind/m³). All comparisons inter-periods were significant, except between flood and drawdown. Different letters represent significant differences among periods.

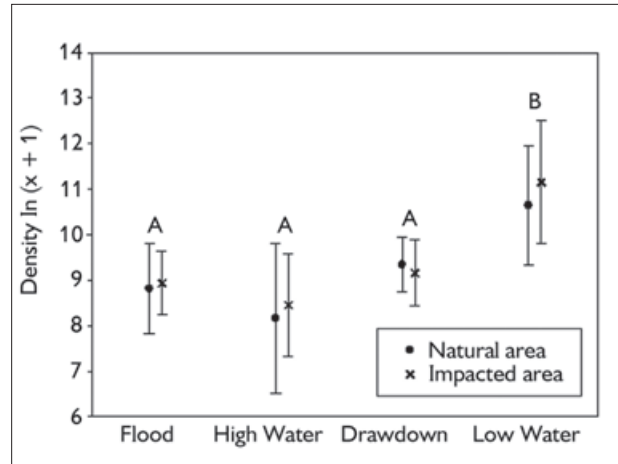


Figure 5. Mean and standard variation of rotifer densities (ind/m³). Low water was significantly higher than all other periods. Different letters represent significant differences among periods.

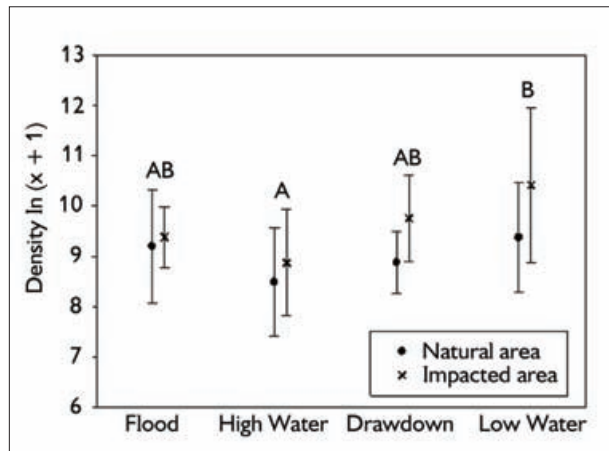


Figure 6. Mean and standard variation of cladoceran densities (ind/m³). Low water had higher densities than high water. No other comparisons between periods were significantly different. Note that densities in impacted area were greater than in the natural area. Different letters represent significant differences among periods.

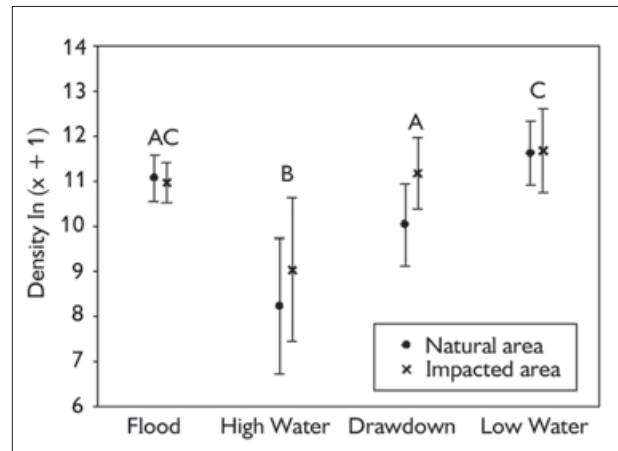


Figure 7. Mean and standard variation of copepod densities (ind/m³). High water densities were significantly smaller than all other periods, and low water densities were higher than those of drawdown. Different letters represent significant differences among periods.

was not significantly different from that of the impacted station. The stations are permanently connected and may exchange species throughout the year (although the strength of such connections varies according to the flood pulse (Bozelli *et al.*, 2015)). In addition, the harmfulness of bauxite tailings is not constant throughout the year. For instance, the turbidity at the impacted station during high water periods was not different from that at the natural

station (Panosso & Kubrusly, 2000). During the low water period, however, the tailings and sediments suspended in the water column cause a decrease in primary production (Roland & Esteves, 1998) and interfere with the cladoceran filtration apparatus (Bozelli, 1998, 2000).

Only one species was found to be an indicator, and it only had this status at the impacted station. This result implies that community composition, in addition to

richness, was highly similar between stations. In general, both stations had the same dominant species. Accordingly, these species were not noted as indicators. Additionally, rare species, even if they appeared only at one station, were not noted as indicators either (Dufrêne & Legendre, 1997; De Cáceres & Legendre, 2009).

Except for cladocerans, densities were also the same between stations. Cladoceran densities were significantly higher at the impacted station. The impact by bauxite tailings, by causing siltation and decreasing depth, may have increased cladoceran densities. Additionally, bauxite tailings, by increasing water turbidity, can decrease the local population density of visually oriented fish (Lin & Caramaschi, 2005b), thereby decreasing predation rates on cladocerans (Carvalho, 1984). However, these tailings may have negative consequences unrelated to densities. The tailings interfere with cladoceran feeding, decreasing the rates of filtration (Bozelli, 1998, 2000). Thus, in the impacted area, cladoceran body size is smaller and, due to the ingestion of tailings particles and their accumulation in the valves, the average weight is higher (Maia-Barbosa & Bozelli, 2005).

Both species richness and densities differed among periods. However, opposite patterns were found. Richness was higher in the high water period and lower in the low water period. In contrast, densities were higher in the low water period and lower in the high water period. Water level variation has a dilutive effect on the zooplankton community, so that densities tend to be lower during periods of high water (Bozelli, 2000; Carneiro *et al.*, 2003). Furthermore, phytoplanktonic primary productivity is higher during low water periods (Roland, 2000), and the availability of food resources for zooplankton is also larger.

Zooplankton densities had a clear pattern of variation among periods. All interperiod comparisons were statistically different, with the exception of flood and drawdown (Figure 4). Flood and drawdown may differ in relation to hydrology (Junk, 1997), nutrient dynamics (Reckendorfer *et al.*, 2013) and even in biological communities (Nova *et al.*, 2014) but in this study we found that intermediate level in itself played a

major role in zooplankton densities. Differences in densities of the zooplanktonic groups (Figures 5-7) also showed some difference among periods, in accordance to the general density pattern. However the difference among all four periods were not as clear as the differences found for the whole community. Different factors may act upon different groups and species (Nielsen & Watson, 2008; Zhao *et al.*, 2008; Villabona-González *et al.*, 2011) and the sum of individual taxonomic groups makes up the pattern found for all zooplankton.

During high water periods, there is a higher diversity of habitats, and richness was higher because of occasional species, such as cladocerans of the family Chydoridae. This family normally inhabits the littoral region of lakes, living on macrophytes, plant detritus and sediments (Williams, 1982; Campbell & Clark, 1983; DiFonzo & Campbell, 1988). During flood and high water periods, river currents can increase the exchange of organisms among different habitats of the ecosystem. As a result, littoral and benthic species can be found in the pelagic region (Thomaz *et al.*, 2007; Lansac-Tôha *et al.*, 2009). During low water periods, the lake is more homogeneous (Brito *et al.*, 2014), causing zooplankton richness to decrease.

In this study, our definition of flood pulse periods according to the water level of the Trombetas River has produced more accurate and reliable results. However, the patterns of richness and density was consistent with previous studies. We emphasize that seasonal events, such as the flood pulse, vary among years (Simões *et al.*, 2012; Huang *et al.*, 2014; Espínola *et al.*, 2014). This variation has consequences on intensity and also on the timing of floods and droughts. We suggest that this variation should be recognized when sampling is designed, as the results would be more precise. However, traditional sampling schedules may still be used if such sampling designs are not possible.

Despite the presence of the bauxite tailings, there was little difference between the natural and the impacted stations. The effect of tailings, not constant throughout the year, has also been mitigated by restoration efforts (Bozelli *et al.*, 2000; Dias *et al.*, 2012). Moreover, when statistically

significant differences were found, they showed that cladoceran densities were higher at the impacted station. In addition to richness and densities, composition was also similar, as only one species was noted as an indicator. We conclude that despite certain harmful effects of bauxite tailings, the zooplankton community was similar at the natural and impacted stations in Batata Lake. Moreover, the use of specifically defined flood pulse periods confirmed the typical pattern of zooplankton variation that occurs in Amazonian floodplain lakes. However, we emphasize that the natural seasonality of the water level and its variations should not be disregarded when samples and experiments are designed for use in floodplains.

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