# Community structure and temporal dynamics of cladocerans in an Amazonian lake (lake Batata, PA, Brazil) impacted by bauxite tailings.

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**ABSTRACT: Community structure and temporal dynamics of cladocerans in an Amazonian lake (Lake Batata, PA, Brazil) impacted by bauxite tailings**. We analyzed the species composition and abundance of cladocerans weekly for one year in two areas (natural and impacted) of an Amazonian lake (Lake Batata), which has received bauxite tailing for ten years (1979-89). The possible influences of this material and the marked fluctuations of the water level on the dynamics of the five most representative species (Bosmina hagmanni, Bosminopsis deitersi, Ceriodaphnia cornuta, Diaphanosoma birgei, Moina minuta) were also studied. At both sites higher richness was registered in the flood phase and a equitable distribution of species in the drawdown phase. The highest average density was recorded in the low water period (225 and 786 x $10^3$ org.$m^{-3}$ at the natural and impacted sites, respectively) and the lowest, in the high water period (71 and 198 x $10^3$ org.$m^{-3}$, respectively) probably reflecting consequences of hydrological dilution. Irregular fluctuations were registered at both sites and at several times the densities at the impacted area were higher and determined by the increase and dominance of one only species. Changes in water level were shown to be the principal factor affecting the composition and fluctuations of the cladoceran community, sometimes enhancing the positive effects of suspended material on the species.
**Key words:** Amazonian lake, impacted, cladocerans, species composition, dynamics.

**RESUMO: Estrutura da comunidade e dinâmica temporal de cladóceros de um lago amazônico (lago Batata, PA, Brasil) impactado por rejeito de bauxita.** Neste estudo foi analisada, semanalmente, durante um período anual, a composição e abundância de espécies de cladóceros de duas áreas (natural e impactada) de um lago amazônico (Lago Batata), que recebeu rejeito de bauxita durante dez anos (1979-89). A possível influência deste material e das marcantes flutuações do nível d'água sobre a dinâmica das cinco espécies de cladóceros mais representativas (Bosmina hagmanni, Bosminopsis deitersi, Ceriodaphnia cornuta, Diaphanosoma birgei, Moina minuta) foi também avaliada. Nas duas áreas, maior riqueza foi registrada no período de águas altas e uma distribuição mais uniforme de espécies no período de vazante. Densidade média mais elevada foi registrada no período de águas baixas (225 e 786 x $10^3$ org.$m^{-3}$ para as áreas natural e impactada, respectivamente) e menor no período de águas altas (71 e 198 x $10^3$ org.$m^{-3}$, respectivamente) provavelmente como reflexo da diluição. Flutuações irregulares foram registradas nas duas áreas, sendo que em vários momentos as densidades registradas na área impactada foram mais elevadas e determinadas pelo aumento e dominância de uma única espécie. Alterações no nível d'água mostraram-se como o fator determinante da composição e flutuação da comunidade de cladóceros algumas vezes ressaltando os efeitos positivos do material em suspensão sobre as espécies.
**Palavras-chave:** lago amazônico, impactado, cladóceros, composição, dinâmica.

## Introduction

The identification of factors that determine the success of a species in one habitat is among the most difficult aspects of ecology, even in environments affected by only one or a few strongly influential factors. The way as environmental factors act on behaviour, life history and morphology of the individuals is still not well known. Although there is a large number of studies on cladocerans, some aspects such as their ability to adapt, and the strategies adopted by these organisms to survive restrictions imposed by the environment have not been thoroughly investigated.

Increase of inorganic suspended material in water has been recorded for various environments, with consequences on their optical characteristics and repercussions on system productivity (Sarnelle et al., 1998; Roland & Esteves, 1998).

Several studies have investigated the effect of suspended material in structuring planktonic communities and in behavioural and reproductive aspects of some zooplanktonic species (Kirk, 1992; Cuker, 1993; Bozelli, 1996; Lind et al., 1997). Inorganic suspended particles are known to serve as substrate for colonisation by bacteria, can form aggregates, together with phytoplankton, or can concentrate, by adsorption, large amounts of protein and carbon, and this serve as an additional food source for some zooplanktonic organisms (Lind & Dávalos-Lind, 1991; Crump & Baross, 1996). Since they reduce transparency, suspended material also interferes with predator-prey relationships, in providing a visual protection for zooplankton (Zettler & Carter; 1986; Hart, 1987).

Lake Batata, a typical floodplain lake, is situated on the right bank of the Trombetas River (1°25'-1°35' S; 56°15'-56°25' W) in Porto Trombetas (Pará State, Brazil) (Fig.I).

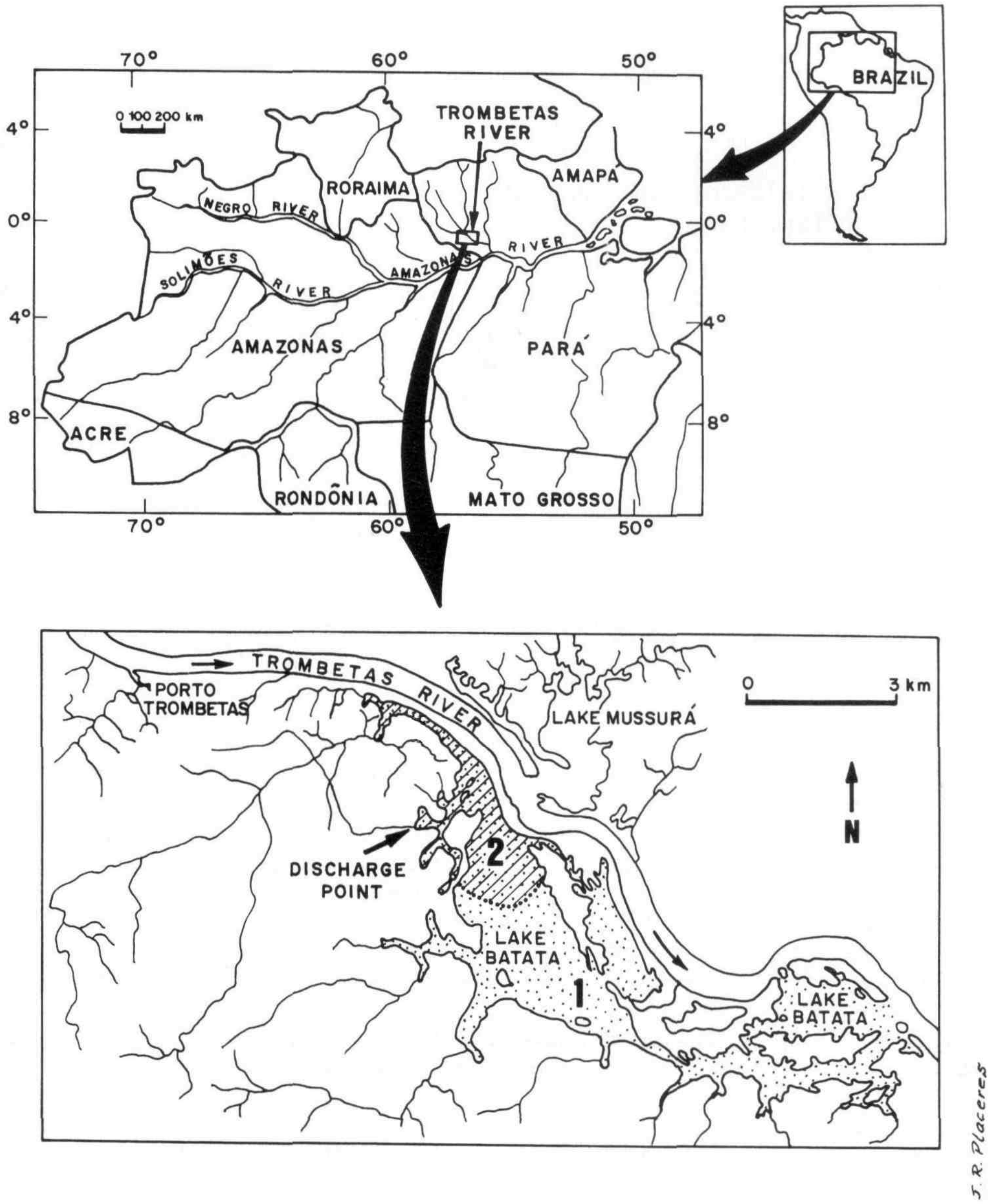


Figure 1: Map of the study area showing the location of the sampling stations: 1- natural area and 2- impacted area with bauxite tailings.

The lake has a dendritic shape and total surface area between 18 and 30 km$^2$, and shows great annual fluctuations of water level. It is a well oxygenated lake, with low values of electrical conductivity (c. 8mS cm$^{-1}$ in the filling phase and 13 mS cm$^{-1}$ in the drawdown). Total alkalinity varies between 40 and 70 mEq l$^{-1}$ in the dry season and pH from 6 to 8. It is a lateral dam lake that has continuous communication with the Trombetas River. Lake Batata is a unique system among those within the inundation basin of the Amazon for having received bauxite tailings during 10 years (1979-89) and for showing correspondingly elevated mineral turbidity caused by suspension of that material.

Against these peculiarities of Lake Batata, this work aimed to compare the composition of Cladocera community in natural and bauxite impacted areas of the lake and to analyse the effects of water level fluctuation and the presence of bauxite tailings on the dynamics of the most representative planktonic cladoceran species in these two areas.

## Material and methods

Plankton samples were collected weekly from January 5$^{th}$ (week 1) to December 27$^{th}$ (week 52), 1996, from fixed stations in a natural (EN) and an impacted area (EI) (Fig.1). Zooplankton samples were collected by horizontal (qualitative analyses) and vertical (qualitative analyses) hauls using a 68mm mesh plankton net and preserved with neutral formaldehyde (4%). For quantitative analyses, 3 sub-samples (1 mL each) were counted in a Sedgwick-Rafter chamber.

Water transparency and temperature (reported as the mean value obtained at the surface and bottom) were determined weekly, using a Secchi disk and a FAC400 digital meter, (0.1° C precision) respectively. Every three months, the following additional measurements were taken from four depths determined with a Secchi disk (mean values of depths sampled are shown): pH (with a portable pH meter), chlorophyll-a (according to Nusch & Palme, 1975), and suspended material (by gravimetry).

Phytoplankton samples were collected with van Dorn bottles from the same depths of the water column. Algal counts were done under an inverted microscope by the sedimentation method in random fields (Utermöhl, 1958). Quantitative data are shown reported as mean values of the depths sampled.

Samples collected during weeks 1 to 4 and 39 to 51 were considered representative of the dry water phase; those collected between week 5 and 14 represented the filling phase while samples from weeks 15 to 28 and weeks 29 to 38 represented the high (flood) and drawdown phase, respectively.

Only those cladocerans species which contributed more than 5% to the total density in each sites (impacted and natural) were used in examining temporal fluctuations of the assemblage. Body lengths were measured, excluding shell spines, under a microscope fitted with an eyepiece micrometer and the eggs were counted. Species that consistently contributed less than 5% were grouped as "others".

Non-parametric tests of Kruskall Wallis and Mann-Whitney were made using Instatâ. Differences between the means were tested with Dunn´s test for multiple comparisons.

## Results

Lower transparency and chlorophyll-a values, and higher total suspended matter were almost always observed at impacted site. Small variations were observed in the pH. Temperatures were invariably above 27°C and phytoplankton density (ind.ml$^{-1}$) was about twice as high at the natural than the impacted site (Tab. I).

Twenty three taxa distributed among six families were identified in the cladoceran community of Lake Batata (Tab. II). Among these, only Bosmina hagmanni, Bosminopsis deitersi, Ceriodaphnia cornuta, Diaphanosoma birgei and Moina minuta contributed for more than 5% of the total cladoceran density at the two sites sampled. Although Diaphanosoma polyspina was frequently present it was abundant only during a few weeks of the drawdown phase. The remaining species, such as Bosminopsis brandorffi and Moina rostrata, occurred sporadically only during the high water phase.

Despite the similarity in species richness at both sites during the filling and high water phases (February to July), a slightly higher species richness was observed at the impacted sites mainly due the occurrence of representatives of the

Table I: Physical and chemical characteristics of the water and densities of phytoplankton at the natural (EN) and impacted (EI) areas of Lake Batata during the four hydrological phases of 1996.

| | Transp. (m) | Chlor.-a (mgl-1) | Susp. Mat. (mgl-1) | pH | Temp °C | Phytopl. (ind.ml-1) |
|---|---|---|---|---|---|---|
| **EN** | | | | | | |
| Filling | 1.6 | 1.73 | 4.27 | 6.57 | 28.6 | 2127 |
| High water | 1.2 | 1.62 | 6.97 | 6.16 | 28.7 | 2210 |
| Drawdown | 1.1 | 6.54 | 6.73 | 6.38 | 30.7 | 3200 |
| Low water | 0.7 | 15.03 | 11.60 | 6.92 | 30.05 | 7668 |
| **EI** | | | | | | |
| Filling | 1.0 | 3.03 | 8.23 | 6.35 | 28.95 | 724 |
| High water | 1.2 | 1.26 | 6.07 | 6.16 | 27.9 | 1072 |
| Drawdown | 0.6 | 4.81 | 8.00 | 6.60 | 32.1 | 1716 |
| Low water | 0.2 | 1.50 | 23.00 | 5.31 | 30.95 | 1387 |

Table II: Species of Cladocera identified at natural (EN) and impacted (EI) areas of Lake Batata during 1996 (+ = presence; - = absence).

| Month | J | | F | | M | | A | | M | | J | | J | | A | | S | | O | | N | | D | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weeks | 1-4 | | 5-8 | | 9-13 | | 14-17 | | 18-22 | | 23-25 | | 26-29 | | 30-34 | | 35-38 | | 39-42 | | 43-47 | | 48-52 | |
| | | | filling | | | | | high water | | | | | | drawdown | | | | | dry water | | | | | |
| **Species** | **EN** | **EI** | **EN** | **EI** | **EN** | **EI** | **EN** | **EI** | **EN** | **EI** | **EN** | **EI** | **EN** | **EI** | **EN** | **EI** | **EN** | **EI** | **EN** | **EI** | **EN** | **EI** | **EN** | **EI** |
| **Chydoridae** | | | | | | | | | | | | | | | | | | | | | | | | |
| Acroperus harpae | - | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Disparalona leptorhyncha | - | - | - | - | - | - | + | + | + | + | - | + | - | + | - | - | - | - | - | - | + | - | - | - |
| Alona retangula | + | + | - | + | - | - | + | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Alona spp. | + | + | - | + | + | + | - | + | + | + | + | + | + | + | + | - | - | - | - | + | - | - | - | + |
| Alona verrucosa | + | + | - | - | - | - | - | - | + | + | + | + | + | + | - | - | - | - | - | - | - | - | - | - |
| Alonella dadayi | - | - | + | - | - | - | - | - | + | + | + | + | + | + | - | - | - | - | - | - | - | + | - | - |
| Alonella spp. | - | + | - | + | - | - | - | - | - | + | - | + | - | - | + | - | - | - | - | - | - | - | - | - |
| Ephemeroporus barroisi | - | - | - | + | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Chydorus spp. | + | + | + | + | + | + | + | + | + | + | - | - | - | - | - | - | - | - | + | + | + | + | - | - |
| **Bosminidae** | | | | | | | | | | | | | | | | | | | | | | | | |
| Bosmina hagmanni | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| Bosminopsis brandorffi | - | - | - | - | - | - | - | - | + | + | + | + | + | + | + | - | - | - | - | - | - | - | - | - |
| Bosminopsis deitersi | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| **Daphniidae** | | | | | | | | | | | | | | | | | | | | | | | | |
| Ceriodaphnia cornuta | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| Daphnia gessneri | - | - | + | - | + | - | - | + | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **Sididae** | | | | | | | | | | | | | | | | | | | | | | | | |
| Diaphanosoma birgei | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| Diaphanosoma polyspina | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| Diaphanosoma sp. | - | - | - | - | + | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - |
| Holopedium amazonicum | + | - | + | + | + | + | + | + | - | - | - | - | - | + | - | - | + | + | - | + | - | - | + | + |
| **Ilyocryptidae** | | | | | | | | | | | | | | | | | | | | | | | | |
| Ilyocryptus spinifer | + | + | - | + | - | + | - | + | + | + | + | - | - | - | - | - | - | - | - | - | - | - | - | + |
| **Macrothricidae** | | | | | | | | | | | | | | | | | | | | | | | | |
| Macrothrix spp. | + | + | + | + | - | + | - | + | + | + | - | - | - | - | - | - | - | - | - | - | + | - | - | + |
| **Moinidae** | | | | | | | | | | | | | | | | | | | | | | | | |
| Moina minuta | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| Moina reticulata | - | - | - | + | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Moina rostrata | - | - | - | - | - | - | + | + | + | - | + | - | + | - | - | - | - | - | - | - | - | - | - | - |
| **Total de Taxa** | 13 | 13 | 11 | 15 | 11 | 13 | 11 | 14 | 16 | 18 | 12 | 12 | 11 | 12 | 9 | 6 | 7 | 7 | 7 | 9 | 9 | 9 | 7 | 10 |

Chydoridae and Macrothricidae, none of which were numerically significant. Species richness was lower during drawdown and low water (August to December) than during the filling and high water phases.

Planktonic cladocerans densities were lower during the high water stage of the hydrograph period at both sites, but higher during the filling and drawdown phases at the natural site, and at the impacted site during drawdown and dry phases (Fig. 2). Significant density differences between the filling and flood phases (p=0.0300, Mann-Whitney) and flood and drawdown phases (p=0.0057, Mann-Whitney) were observed only at the natural station.

Between sites densities differed significantly during the same hydrographic period only during the drawdown phase (p=0.004, Mann-Whitney).

Over the full study period, average density was significantly higher at the impacted station (5,569.7 org.m$^{-3}$; SD=13,960.5) than at the natural site (2,467.4 org.m$^{-3}$; SD=4,557.1).

The temporal dynamics of the cladoceran communities were similar, apart from marked differences at the impacted station, especially during low water, reflected in single species predominances of Diaphanosoma birgei in weeks 42 and 45 and of Bosminopsis deitersi in weeks 4 and 5 (Fig. 2).

Considering the relative contribution of all cladoceran species (Fig. 3), it is possible to identify two species that,

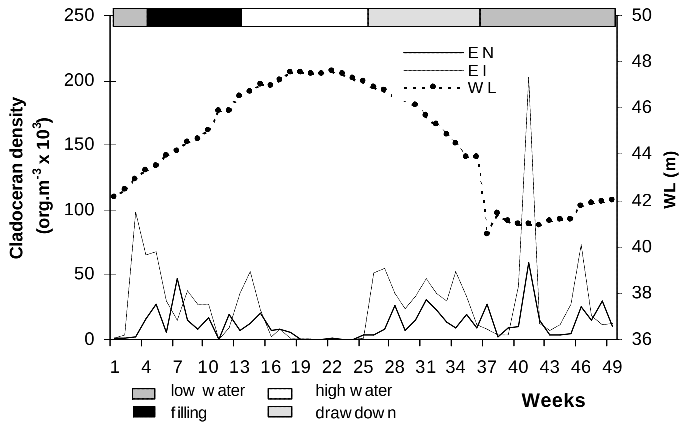


Figure 2: Density fluctuations of cladocerans at natural (EN) and impacted (EI) areas of Lake Batata, and the water level (WL) of Trombetas River during 1996.

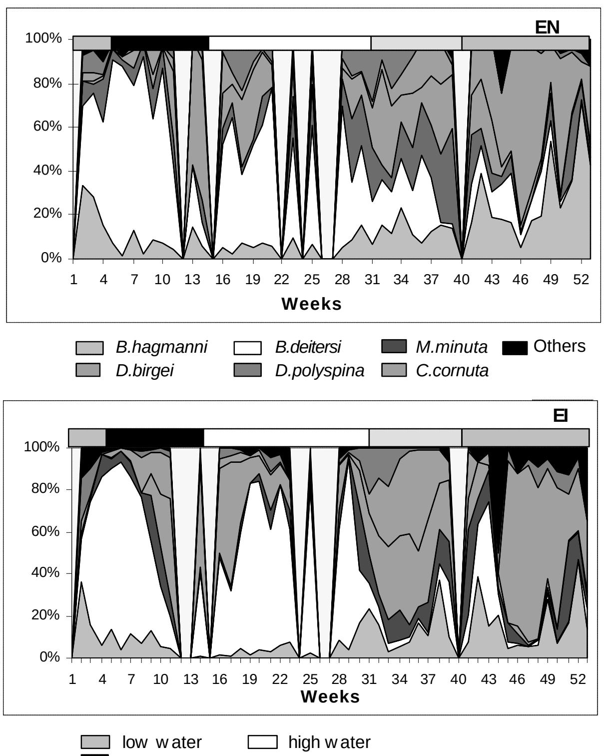


Figure 3: Relative abundance of Cladocera at natural (EN) and impacted (EI) areas of Lake Batata during 1996.

together, represented more than 60% of the total density at each site during each phase of the hydrological cycle: B. deitersi and C. cornuta in the filling and flood phases at both sites; D. birgei and B. hagmanni at the natural site and D. birgei and B. deitersi at the impacted one in the dry phase site. During the drawdown phase, species distribution was more uniform; this period can be considered as a "recovery period" for the species considered.

## Discussion

Despite the presence of bauxite tailings, the cladoceran community composition was similar in the two sampling stations, at least in respect of the commoner and more persistent species. Apart from a switch in dominance between Diaphanosoma polyspina and Diaphanosoma birgei, the cladoceran community did not differ from that observed in 1992 (Bozelli, 1994).

The five most abundant and frequent cladoceran species (Bosmina hagmanni, Bosminopsis deitersi, Ceriodaphnia cornuta, Moina minuta and Diaphanosoma birgei) are widely dominant and regular components of aquatic environments in Brazil. Ceriodaphnia cornuta, Diaphanosoma birgei and Moina minuta have also been reported as dominant in environments subject to water level fluctuations in Venezuela (Saunders & Lewis, 1989; Hamilton et al., 1990).

Moina reticulata was recorded for the first time in Lake Batata at the impacted site during this study. Its occurrence in low densities only during the filling and high water phases suggests that this species either was brought into L. Batata from other waters or that it lives in Lake Batata in sub-optimal conditions. Increases in species richness during the high water phase, by allochthonous contribution or habitat expansion have been reported by several authors (Bozelli, 1994; Campos et al., 1996). Allochthonous contribution perhaps accounts for the presence in Lake Batata of higher occurrences of representatives of the non-planktonic Chydoridae and Macrothricidae families during the filling and high water phases.

Holopedium amazonicum occurred in Lake Batata only during the filling period. This representative of a family rarely found in the tropics occasionally occurs abundantly in the Cladocera community of Amazon aquatic environments (Robertson & Hardy, 1984).

The periodic fluctuations of the water level in Lake Batata, although generally predictable, are also dynamic due to their inter-annual variation in amplitude and duration, and correspondingly induce subsequent reorganisation of the communities, favouring or eliminating species, ultimately resulting in the between-year differences.

Some authors consider that nutrients carried with the rain enrich the waters favouring phytoplankton and consequently zooplankton, which could respond with increased densities. However, at Lake Batata conversely lower densities were obtained during the flood phase and higher during the dry phase. This seems to be a common pattern for environments subject to strong water level fluctuations (Vasquez & Rey, 1989; Bozelli, 1994; Lima et al., 1998). Loss of organisms and food dilution may explain the decline during flood phase. In Lake Batata this phase is marked by an approximately 5m increase in water depth, and corresponding reductions in primary production, causing accentuated alterations in phytoplankton biomass and densities, and bacterial productivity (Huszar & Reynolds, 1997; Anésio et al., 1997). In addition, the Trombetas River water is poor in nutrients and does not provide a flood-pulse of nutrients for Lake Batata. Alterations in current velocity can affect the residence time and also reproductive activity of species in the waters; these factors, accompanying nutrient dilution during this hydrographic phase appears to be the main responsible factors for the results observed.

The additional factor that cannot be ignored in Lake Batata is the presence of bauxite tailings which interfere with the phyto- and zooplanktonic communities and also with the water properties. The presence of suspended inorganic matter can affect zooplankton directly, by interfering in filtration processes and indirectly by affecting phytoplankton community (e.g. decreasing primary productivity and increasing sedimentation of organisms). However, the high zooplankton densities observed at the impacted site suggest some adaptation of the occurring species to the constant presence of tailings and/or substitution of primary food source. Reproductive adaptations (fecundity, size of first reproduction, production of resting eggs, etc.), morphological and behavioural adjustments (harder to be observed in natural conditions) need to be evaluated.

Changes in abundance of the major Cladocera species were very similar at both sites, indicating that the presence of the tailing cannot be a major determinant of the dynamics of these populations. Tailings are no doubt a complicating factor that can act in a sporadic but rapid way to differentially favour or reduce the density of some species, depending on their adaptability. However, the trophic requirements and interactions between the species need to be considered.

Trying to correlate the information provided by Huszar & Reynolds (1997) about the phytoplankton community structure of Batata Lake with the composition and life history of the zooplankton we observed that during the flood phase, the natural area can be seen as an ultra-oligotrophic system, in the beginning of succession, i.e., with low density and phytoplanktonic biomass, dominated by small-sized (‹20mm) and r-strategist algae. In spite of the marked reduction of all cladoceran species, Ceriodaphnia cornuta and Bosminopsis deitersi still persisted during this period. According to Romanovsky (1985), species showing small size, slow growth, low fecundity and short longevity, which he classed as "patients" or "stress-tolerators", can dominate the initial stages of the community development, mainly by their ability to resist low food concentrations. In keeping with this, the above mentioned species are the smallest (mean body lengths of 272 and 226mm respectively) and show the lowest fecundity (average 1.32 and 1.29 eggs/female respectively). The drawdown phase is a more productive period, which leads to a recovery of phytoplankton biomass and diversity. During this period aggregates formed by organic detritus and small algae adhered to the mud have been observed, while planktonic cladocerans taxa are more equitably distributed (Fig. 3), probably because of a higher food availability. Moina minuta, a ruderal species, appears in its maximum densities in this period. Regardless of the high biotic potential, this species is a weak competitor, needs high food concentrations and is found in productive or severely disturbed environments (Romanovsky, 1985). Bozelli (1998) has observed that, in laboratory experiments, the ingestion rates and carbon incorporation of Moina minuta, were considerably higher in the presence of bauxite tailings and food at high concentrations.

In the dry phase there is an increase of phytoplankton, with community representatives predominated at times by species of larger size, and generally characteristic of eutrophic environments. System instability increases with the reduction in the water depth and corresponding increase in wind-induced vertical circulation. Bosmina hagmanni and Diaphanosoma birgei which are dominant during this period are larger species (mean body lengths 292 and 469mm respectively) possibly able to utilise the larger algal species present.

Bosmina hagmanni is capable of active food selection, shows high food plasticity and is able to utilise larger-sized filamentous and cyanophyte algae (Demott & Kerfoot, 1982; Sommer 1989). Some species of the genus Diaphanosoma are considered by Demott (in Sommer, 1989) as tolerant to the interference of filamentous algae (common in Lake Batata's plankton during this period) and efficient in ingesting bacteria (Hessen, 1990). These species are considered summer species, and are both associated with high temperatures. Bozelli (1996) also recorded a positive correlation for Bosmina hagmanni with bacteria numbers. The poor waters of Trombetas River, which run over the lake during flood, promote not only a dilution of phytoplanktonic biomass but also its loss by drainage. Again, the environment shows a reduction in the phytoplanktonic biomass and low diversity (Huszar & Reynolds, 1997). Stress tolerators then dominate again.

In conclusion, our results suggest that the inundation pulse, associated with characteristics of high turbidity determine the structuring of the zooplankton community at Lake Batata. In spite of the possible deleterious effects of tailings on the organisms, they conversely appear to contribute in two ways to the maintenance of high zooplankton densities in impacted areas. First, by the offer of a non-conventional food source, albeit known to have important nutritious value in some cases; and second by the higher protection against visual predators. Although the fish population in the impacted area is not large (Halboth, 1995), the number of individuals increases seasonally at this time of year, and tailings will certainly function to limit the predation of zooplankton.

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