FLOOD PULSE INFLUENCE AND ANTHROPIC IMPACT ON THE CHEMICAL COMPOSITION AND ENERGY CONTENT OF *Oryza glumaepatula* IN AN AMAZONIAN LAKE

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(With 1 figure)

ABSTRACT

The aim of this research was to study the flood pulse influence and the anthropic impact caused by bauxite tailings on the chemical composition of *O. glumaepatula* in Batata lake (PA, Brazil). Sampling was carried out in stands of *O. glumaepatula* in the low-water, filling, high-water, and drawdown periods in impacted and natural areas of Batata lake. During the low-water and drawdown periods the stands of *O. glumaepatula* were exposed, and in the filling and high-water periods the water depth was respectively 1.4 and 3.8 m. The collected material was dried at 70ºC, ground, and concentrations of total phosphorus, total nitrogen, organic carbon, and energy content were determined. The results indicate that the biomass increase, caused by the rise in water level, has a dilution effect on nitrogen and phosphorus concentrations in *O. glumaepatula*. The energy contents did not present significant differences in any of the studied periods. The results suggest that from the low water to filling period, nitrogen becomes more limiting to *O. glumaepatula* in the impacted area, whereas phosphorus becomes more limiting in the natural area. The population of *O. glumaepatula* contributes to the recovery of the impacted area of Batata lake as the detritus from this species accumulates over the sediment. This accumulation impedes future re-suspension of the bauxite tailings and increases the organic matter and nutrient concentrations in the impacted sediment.

Key words: *Oryza glumaepatula*, nutrients, Amazonia, flood pulse, and anthropic impact.

RESUMO

Influência do pulso de inundação e impacto antrópico sobre a composição química e conteúdo energético de *Oryza glumaepatula* em um lago amazônico

O objetivo desta pesquisa foi estudar as influências do pulso de inundação e do impacto antrópico causado pelo rejeito de bauxita sobre a composição química de *O. glumaepatula* no lago Batata (PA, Brasil). As amostras foram realizadas em estandes de *O. glumaepatula* nos períodos de águas baixas, enchente, águas altas e vazante nas áreas natural e impactada desse ecossistema. Nos períodos de águas baixas e vazante, a área coletada encontrava-se exposta, enquanto nos períodos de enchente e águas altas, a profundidade da coluna d'água era de 1,4 e 3,8 m, respectivamente. O material coletado foi seco a 70ºC, moído e suas concentrações de fósforo total, nitrogênio total, carbono orgânico e conteúdo energético foram mensuradas. Os resultados indicaram que o aumento da biomassa causado pela elevação do nível d'água teve efeito diluidor sobre as concentrações de nitrogênio e fósforo em *O. glumaepatula*. O conteúdo energético não variou significativamente entre as áreas e os períodos estudados. Os resultados sugerem que, à medida que o nível d'água aumenta, *O. glumaepatula* torna-se limitada por nitrogênio na área impactada e por fósforo na área natural. A população de *O. glumaepatula* contribui para a recuperação da área impactada do lago Batata em decorrência do acúmulo de detritos dessa espécie sobre o sedimento, impedindo a resuspensão do rejeito de bauxita e promovendo aumento das concentrações de matéria orgânica e nutrientes.

Palavras-chave: *Oryza glumaepatula*, nutrientes, Amazônia, pulso de inundação, impacto antrópico.

INTRODUCTION

Aquatic macrophytes play an important role in the biogeochemical cycles of Amazonian ecosystems due to their capacity to store large amounts of nutrients in comparison with sediment and water (Howard-Williams & Junk, 1977). This characteristic is even more pronounced in ecosystems with low nutrient concentrations, such as the clear and black water Amazonian ecosystems (Sioli, 1984; Setaro & Melack, 1984; Esteves *et al*., 1990). The participation of aquatic macrophytes in nutrient cycling has been verified by many authors (e.g., Granéli & Solander, 1988; Nogueira *et al*., 1996), who have demonstrated the role of this community in the absorption of nutrients from the sediment as well as their liberation in the water column.

Chemical composition analysis of aquatic macrophytes is fundamental in determining the influence of this community on water column characteristics (Nogueira *et al*., 1996; Camargo, 1991). In addition, it allows calculating nutrient amounts stored in this community (Barbieri *et al*., 1984). Wetzel (1992) has pointed out the importance of the aquatic macrophyte biomass and chemical composition in understanding the food chain and nutrient cycling in shallow aquatic ecosystems.

Batata lake, the site where this study was carried out, has undergone an anthropic impact of great proportions. Bauxite tailing effluent was being released directly into its waters for a 10-year period, thereby changing the environmental conditions and influencing all communities within the lake (Bozelli *et al*., 2000). Two distinct areas can be distinguished in this ecosystem: one impacted by bauxite tailings and one natural. Both areas are colonized by *Oryza glumaepatula*, a common wild rice found in Amazonian aquatic ecosystems (Morishima & Martins, 1994) and the life cycle of which is influenced by water-level variation, as is the case with many Amazonian aquatic macrophytes (e.g., *Echinochloa polystachya*, *Paspalum repens*, *Paspalum pasunculatum*, and *Luziola spruceana*) (Junk & Piedade, 1993; Piedade, 1993).

The aim of this research was to study the flood pulse influence and the anthropic impact caused by bauxite tailings on the chemical composition of *O. glumaepatula* in Batata lake.

STUDY AREA

According to the classification proposed by Sioli (1984), Batata lake is a clear-water lake located on the floodplain of the Trombetas river (1°30'S and 56°20'W), a tributary on the left bank of the Amazon river (Oriximiná, State of Pará). Like many Amazonian ecosystems, this lake is subject to a 6-to-7 meter water-level variation, which allows four different periods to be distinguished within the flood pulse: low water, filling, high water, and drawdown (Bozelli, 1992). The first of these is the period in which the water level is lower. During the filling period, the water level increases. High water signifies the period in which the water level reaches its maximum, and drawdown is the period in which the level is decreasing.

Over a ten-year period (1979-1989) Batata lake received about 50,000 m^3d^{-1} of fine-grained mineral effluents resulting from the bauxite extraction process in the region. Consequently, Batata lake presently consists of two clearly defined regions: a natural area and an area impacted by bauxite tailings. Additional information on this subject can be found in Bozelli *et al*. (2000).

The area impacted by bauxite tailings, corresponding to about 30% (630 ha) of this ecosystem, presents tailings suspended in the water column and deposited on the natural sediment. *Oryza glumaepatula*, which colonizes the igapó (swampland) region of Batata lake in both natural and impacted areas, was estimated in 1995 to have colonized about 31 ha in the natural area and 8 ha in the impacted area (Enrich-Prast, 1998).

The life cycle of *O. glumaepatula* is strongly influenced by water-level variation. The seeds of this species germinate during the low-water period, when the sediment is exposed, and it develops as a terrestrial grass until inundation due to the water-level increase. The terrestrial period of *O. glumaepatula* generally lasts about two months. However, depending on the extent of the rise and reduction of the water level, this period can increase or decrease.

After being inundated, *O. glumaepatula* individuals start to grow, accompanying the water-level increase. After some months of growth, the individuals flower, while the *O. glumaepatula* stems near the sediment begin to decompose. As a result, individuals of this species are released from the sediment and can be carried by the "current" formed by the water-level reduction in the natural area of Batata lake. As the hydrodynamics at the impacted area differs from that in the natural area, the detritus of *O. glumaepatula* is not carried by the current, and accumulates in the sediment after water-level reduction.

MATERIALS AND METHODS

Sampling was carried out in stands of *O. glumaepatula* in the low-water (December 1994), filling (March 1995), high-water (July 1995), and drawdown (September 1995) periods in both the impacted and natural areas of Batata lake. During the low-water and drawdown periods the stands of *O. glumaepatula* were exposed, and in the filling and high-water periods they were covered by a water column of 1.4 and 3.8 m of water, respectively. Sampling was performed in each area within 0.25 m^2 squares (Westlake, 1968).

The collected material was dried at 70ºC for three days until reaching constant weight and than ground. In the low-water and filling periods the detritus was disregarded, since living tissue then formed more than 80% of the collected material. In the high-water and drawdown periods, the collected biomass was constituted exclusively by detritus. In the drawdown period, detritus was found accumulated on the sediment only in the impacted area.

The total phosphorus concentrations were analyzed by the ammonium molibdate method (Fassbender, 1973), those of total nitrogen by the Kjeldhal method (Allen *et al.*, 1974), organic carbon by potassium dichromate oxidation (Embrapa, 1975), and energy content by means of a Phillipson microcalorimeter. All results, except for energy content (expressed in kJ gDW^{-1}), were expressed in percentage per gram of dry weight (% gDW^{-1}). The C:N:P and C:N ratios were calculated from the total phosphorus, total nitrogen, and organic carbon results obtained in this study.

The contribution of *O. glumaepatula* to the pool of carbon, nitrogen, phosphorus, and energy of the Batata lake ecosystem in 1995 was calculated from the biomass data of the high-water period (Enrich-Prast, 1998), which were multiplied by the above concentrations. These values were then multiplied by the extent of *O. glumaepatula* occupation in the impacted and natural areas (Enrich-Prast, 1998).

The non-parametric Mann-Whitney test was used to evaluate the significance of the results referring to the concentrations of phosphorus, nitrogen, organic carbon, and energy content of *O. glumaepatula* within the different periods and between the two studied areas. The confidence interval was 95%.

RESULTS

In general, the nitrogen and phosphorus concentrations in *O. glumaepatula* decreased as the individuals of this species grew as the water level increased in the two studied areas. Phosphorus concentrations decreased from 0.20 to 0.02% gDW^{-1} in the natural area, and from 0.17 to 0.02% gDW^{-1} in the impacted one, in the low- and high-water periods, respectively. Nitrogen concentrations decreased from 1.46% to 0.52% gDW^{-1} in the natural area, and from 1.76% to 0.42% gDW^{-1} in the impacted one, in the low and high water periods, respectively. The organic carbon concentrations, which increased with the growth of individuals of *O. glumaepatula*, presented a pattern contrary to the that of the phosphorus and nitrogen concentrations (Fig. 1). From the low- to high-water period, the carbon concentrations increased, respectively, from 45.2 to 44.6 in the natural area and from 47.8% to 48.5% gDW^{-1} in the impacted area.

In the impacted and natural areas the phosphorus and nitrogen concentrations were significantly higher (Mann-Whitney; $p < 0.05$) in the low-water period than in the filling and high-water periods. The organic carbon concentrations were significantly higher (Mann-Whitney; $p < 0.05$) in the high-water period than in the remainder of the studied periods (Fig. 1). The C:N and C:P ratios increased from the low-water to the high-water periods in both studied areas (Table 1).

In the low-water period the phosphorus concentrations in the natural area were significantly higher (Mann-Whitney; $p < 0.05$). In the filling period they were significantly higher (Mann-Whitney; $p < 0.05$) in the impacted area. In the high-water period the phosphorus concentrations presented no significant differences (Mann-Whitney; $p < 0.05$) between the two studied areas (Fig. 1).

The nitrogen concentrations were significantly higher (Mann-Whitney; $p < 0.05$) in the impacted area in the low-water period. In the filling period they were significantly higher (Mann-Whitney; $p < 0.05$) in the natural area. In the high-water period they presented no significant differences (Mann-Whitney; $p > 0.05$) between the two studied areas. The carbon concentrations did not present significant differences (Mann-Whitney; $p < 0.05$) between the impacted and natural areas in the dry and high-water periods, but were significantly higher (Mann-Whitney; $p < 0.05$) in the impacted area in the filling period (Fig. 1).

In the low-water period, the C:N ratio was higher in the natural area, but in the filling and high-water periods, this ratio was higher in the impacted area. The C:P ratio was higher in the impacted area in the low-water and high-water periods. In the filling period this ratio was higher in the natural area. The drawdown period presented lower C:N and C:P ratios than did the high-water period in the impacted area (Table 1).

The energy content of *O. glumaepatula* did not present significant differences (Mann-Whitney; $p > 0.05$) between the studied periods in either the impacted area or the natural area. It can be observed that in addition to the high standard deviations, the averages do not present a defined pattern, being similar in all studied periods (Fig. 1).

TABLE 1

C:N:P and C:N ratios of *Oryza glumaepatula* during a flood pulse in natural and impacted areas of Batata lake. ND = not determined.

	Low-water	**Filling**	**High-water**	**Drawdown**
	December/94	**March/95**	**July/ 95**	**September/95**
C:N:P natural	223:7:1	819:13:1	1757:19:1	ND
C:N:P impacted	259:10:1	667:8:1	2065:18:1	1293:13:1
C:N natural	32	63	93	ND
C:N impacted	26	83	114	99

TABLE 2

Carbon, nitrogen, phosphorus, and energy stock in the biomass of *Oryza glumaepatula* in natural and impacted areas of Batata lake in the high water period (July/1995).

	Natural	**Impacted**	
Colonized area (ha)	31	8	
Total biomass (g DW m^{-2})	467	868	
C (% C.gDW^{-1})	47.8	48.5	
N (% N.gDW^{-1})	0.52	0.42	
P (% P.gDW^{-1})	0.027	0.023	
Energy content (kJ.gDW^{-1})	18.3	18.5	
C, N, P, and energy stocked in *O. glumaepatula* in Batata lake in high water period			
	Natural	**Impacted**	**Total**
Carbon (t)	69.2	33.7	102.9
Nitrogen (kg)	752.8	293.7	1046.5
Phosphorus (kg)	39.4	16.3	55.7
Energy (kJ × 10^9)	2.64	1.28	3.92

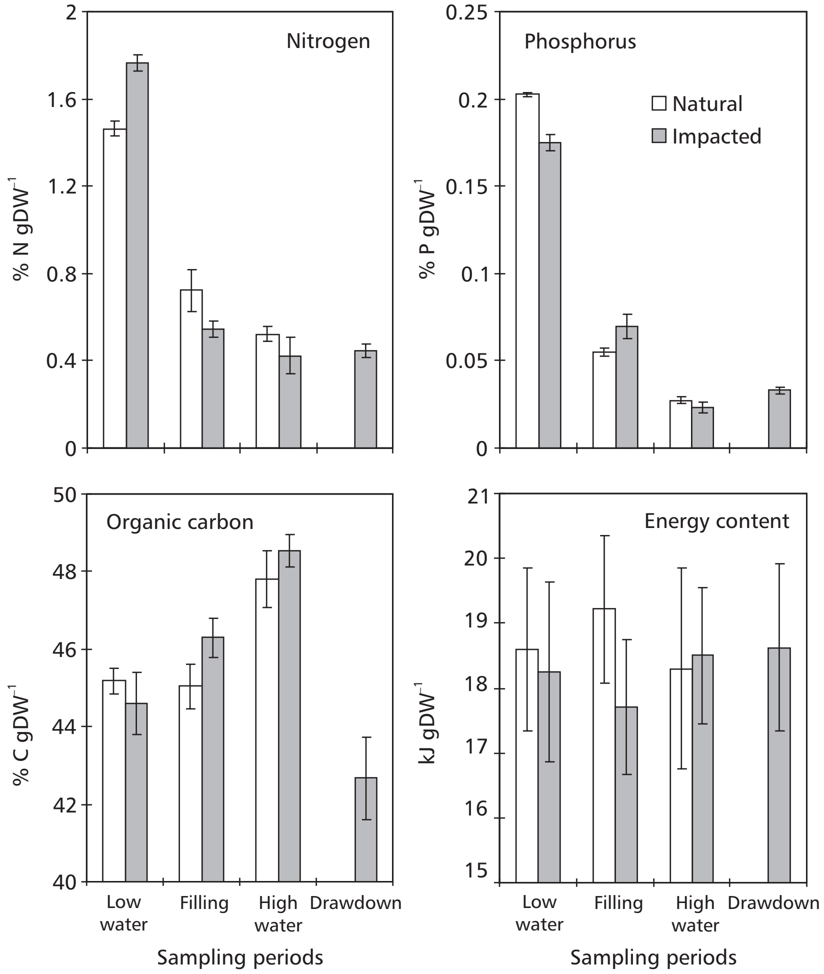

Fig. 1 — Nitrogen, phosphorus, organic carbon, and energy content of *Oryza glumaepatula* during a flood pulse period in natural and impacted areas of Batata lake (PA).

The nutrient amount stored in *O. glumaepatula* in July 1995 was 102.9 t of carbon, 1,046 kg of nitrogen, 55.7 kg of phosphorus, and 3.92×10^9 kJ of energy (Table 2).

DISCUSSION

The biomass increase, caused by the water-level rise, results in dilution of the nitrogen and phosphorus concentrations in the *O. glumaepatula* individuals. Rubim (1995), who observed the same pattern in *O. glumaepatula* and *O. grandiglumis* in the Negro and Solimões rivers, suggested that the higher nutrient concentrations in individuals of these species in the low-water period occurred due to high nutrient availability in the sediment. Furtado & Esteves (1996) observed that young individuals of *Typha domingensis* presented higher concentrations of nitrogen and phosphorus than did the adults. Boyd (1969), Esteves (1979), and Piedade *et al.* (1992) also have observed this effect in other species. According to Boyd (1969), the content of these nutrients tends to decrease with the maturity of the plant structures.

The carbon concentration increase in *O. glumaepatula*, observed in the low-water to filling periods in the two studied areas, can be attributed in this species to stem development, which is stimulated by the water-level rise. This is the structure mainly responsible for sustaining *O. glumaepatula* following flooding (Rubim, 1995). According to Brum *et al*. (in press), carbon concentrations in the stems of *O. glumaepatula* are higher than those in the remaining structures. In studying the chemical composition of various *Echinochloa polystachya* structures at Jurumirim dam (São Paulo State), Pompeo (1996) observed that, of all the structures of this species, the stems presented the highest carbon concentrations due to their high fiber content.

Because the biomass of *O. glumaepatula* consisted exclusively of detritus in the high-water period, the carbon concentrations exceeded those found in the filling period. When the collection of *O. glumaepatula* was carried out in the high-water period, its detritus had probably been decomposing for some time. When the decomposition process begins, non-structural soluble compounds rich in nutrients such as nitrogen and phosphorus are liberated.

The nitrogen and phosphorus concentrations of *O. glumaepatula* presented different patterns for the impacted and natural areas. In the natural area, the nitrogen concentrations showed a more conspicuous reduction from the low-water to the filling period. On the other hand, the phosphorus concentrations presented a more conspicuous reduction from the low-water to the filling period in the impacted area. The same pattern was observed in a study on spatial variation in nutrient concentrations in stands of *O. glumaepatula* in the natural and impacted areas of Batata lake (Enrich-Prast *et al*., 2002). These results suggest that from the low-water to the filling period nitrogen becomes more limiting to *O. glumaepatula* in the impacted area, whereas phosphorus becomes more limiting in the natural area.

Energy contents showed no significant differences in any of the studied periods. According to Boyd & Goodyear (1971), a small variation in energy contents is mainly caused by fluctuation in the protein, lipid, and carbohydrate contents in the aquatic macrophyte biomass. Nogueira & Esteves (1990) observed an energy content reduction in the senescent period and in the detritus of *Nymphaea ampla*, and associated this result with the liberation of energy-rich compounds during the decomposition process. On the other hand, Furtado & Esteves (1996) found no energy loss in detritus of *Typha domingensis* in Imboassica lagoon, a coastal lake in northern Rio de Janeiro State. In studying the energy content of various aquatic macrophytes of tropical and temperate regions, Thomaz & Esteves (1986) found values near those found in this study.

The C:N:P and C:N ratios in *O. glumaepatula* in both areas also indicated that in the low-water period the phosphorus and nitrogen concentrations were less limiting than in the filling and high-water periods. This was attributed to stem development, since these structures are rich in carbon compounds. Between the two areas studied, the variation in C:P ratios did not show a clear pattern. However, the N:P ratio demonstrates that in the filling and high-water periods, phosphorus can be singled out as the more limiting element in the impacted area than it is in the natural area, a result also presented by Enrich-Prast *et al*. (2002).

An average C:N:P ratio of 435:20:1 has been proposed for all kinds of aquatic macrophytes (Duarte, 1990). However, a bibliographic review done by Pompeo (1996) of the C:N:P ratios in various species of aquatic macrophytes prompted him to suggest, despite the high variation found, a ratio of 274:11:1 for immersed aquatic macrophytes. This ratio represents an average of different species of aquatic macrophytes subjected to different environmental conditions that, despite all restrictions, serves as a parameter in making comparisons in aquatic macrophyte studies. It was so used in this study, since *O. glumaepatula* is an immersed aquatic macrophyte. In the filling, high-water and drawdown periods of both studied areas, the C:P and C:N ratios were higher than the averages obtained by Pompeo (1996), suggesting that nitrogen and phosphorus become more limiting to the growth of *O. glumaepatula* as this species develops.

The evaluation of nutrient and energy stock in aquatic macrophyte biomass is of great relevance in understanding of the role of this community in the metabolism of continental aquatic ecosystems (Esteves, 1979, 1998; Furtado & Esteves, 1996; Nogueira *et al*., 1996).

The nutrient and energy stock in the population of *O. glumaepatula* in Batata lake was greater in the natural area because this species occupied a larger region of Batata lake. It should be taken into account that the values obtained in this study apply only to 1995 and are relative to both the maximum biomass produced and the area occupied by *O. glumaepatula*. The area occupied by this species varies annually and is determined by the minimum level of the water column in each hydrological period. The more the water level decreases, the greater the exposed area and, consequently, the greater the area colonized by *O. glumaepatula.*

Because of accumulated detritus produced by the population of *O. glumaepatula* and spread over the sediment at the end of the flood pulse, this species contributes to the recovery of the impacted area of Batata lake. In the permanently flooded area, mainly in the periods in which the water level is low, the re-suspension of the bauxite tailings in the sediment causes a decrease in light radiation and, consequently, a decrease in the phytoplankton primary production rates (Roland, 2000). The accumulated detritus of *O. glumaepatula* promotes the formation of a layer of organic material that impedes re-suspension of the bauxite tailings. It also promotes an increase in nutrient concentrations in the sediment of the impacted area.

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