INFLUENCE OF THE DECOMPOSITION OF *EICHHORNIA AZUREA* ON SELECTED ABIOTIC LIMNOLOGICAL VARIABLES OF DIFFERENT ENVIRONMENTS OF THE FLOODPLAIN OF THE HIGH PARANÁ RIVER

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ABSTRACT: Influence of the decomposition of *Eichhornia azurea* on selected abiotic limnological variables of different environments of the floodplain of the high Paraná river. Detritus of distinct populations of *Eichhornia azurea* (Swartz) Kunth from environments with limnologically different characteristics (Cortado Channel and Guaraná Lagoon, in the floodplain of the Upper Paraná River) were incubated in the laboratory in the dark for 90 days. During this period, the aquatic macrophytes were allowed to decompose in water from their original environments or in water from a different environment, in order to estimate i. the influence of decomposition products on the limnological factors of both environments; ii. whether the changes in these characteristics differed as a function of the origin of the decomposing plant material or of the water in which the decomposition was taking place and iii. to simulate flooding of the natural vegetation. Rapid leaching of phosphate compounds to the water, and reduction of the initial nitrate concentrations during the initial decomposition phases were observed. At the beginning of decomposition, there was a reduction in dissolved oxygen concentration and pH, and an increase in electrical conductivity, total alkalinity and free carbon dioxide. In the final decomposition phases the values of pH, ammonia and the concentration of dissolved oxygen increased, while the concentrations of phosphate compounds decreased a little. During decomposition, *E. azurea* liberated a large quantity of phosphorus to the water column. The changes in the limnological characteristics of the water during decomposition were affected significantly differently (ANOVAR, $p<0.05$), as much by the initial characteristics of the respective waters, as by the plants of different origin (Cortado Channel and Guaraná Lagoon). The laboratory simulation generally reflected events during and after the flood pulse in the natural environment.

Key-words: *Eichhornia azurea*; Decomposition; Nutrients; Floodplain.

RESUMO: Influencia da decomposição de *Eichhornia azurea* sobre algumas variáveis limnológicas abióticas de diferentes ambientes da planície de inundação do alto rio Paraná. Detritos de populações distintas de *Eichhornia azurea* (Swartz) Kunth, provenientes de ambientes com características limnológicas diferentes (canal Cortado e lagoa do Guaraná, na planície de inundação do alto rio Paraná), foram incubadas em laboratório, no escuro, durante 90 dias. Durante esse período, as macrófitas aquáticas foram colocadas para decompor na água proveniente do seu ambiente original ou na água do outro ambiente, com o intuito de i. estimar a influência dos produtos da decomposição sobre os fatores limnológicos de ambos os ambientes; ii. verificar se as mudanças nessas características diferem em função da origem do material vegetal em decomposição ou da água na qual a decomposição está ocorrendo e iii. simular o alagamento da vegetação natural. Foi observada uma rápida liberação de compostos fosfatados para a água e uma redução das concentrações iniciais de nitrogênio durante as fases iniciais da decomposição. No início da decomposição, houve uma redução nas concentrações de oxigênio dissolvido e no pH, e um aumento na condutividade elétrica, alcalinidade total e dióxido de carbono livre. Nas fases finais da decomposição, os valores de pH, nitrogênio amoniacal e as concentrações de oxigênio dissolvido aumentaram, enquanto as concentrações de compostos fosfatados decresceram. Durante a decomposição, *E. azurea* liberou uma grande quantidade de fósforo para a coluna de água, e as mudanças nas características limnológicas da água durante a decomposição foram significativamente afetadas (ANOVAR, $p<0.05$), tanto pelas características iniciais das respectivas águas, quanto pelas plantas de origens diferentes (canal Cortado e lagoa do Guaraná). A simulação de laboratório, de maneira geral, refletiu os eventos durante e após os pulsos de inundação no ambiente natural.

Palavras-chave: *Eichhornia azurea*; Decomposição; Nutrientes; Planície de inundação.

INTRODUCTION

Floating rooted aquatic macrophytes play an important ecological role, serving as substrates for the attached microbiota (Poi de Neiff & Neiff, 1988, 1989), shelter for many organisms (Delariva *et al.*, 1994), deposition sites for eggs, a food source (Pieterse & Murphy, 1990), in addition to supporting extensive grazing and detritus food webs (Wetzel & Ward, 1992; Wetzel, 1995). Not least, these plants function as a compartment for nutrient stocking and output, influencing the physical and chemical characteristics of the water column (Silva *et al.*, 1994).

The continuous death and decomposition of aquatic macrophytes, which tend to remain in the littoral zone, causes them to become the chief component of the detritus reservoir. Dissolved organic matter and detritus particles liberated during decomposition lead to spatial and temporal regulation of cycling (Wetzel, 1990, 1995). The effects of detritus from aquatic macrophytes on limnological characteristics must be even more accentuated in aquatic ecosystems of floodplains, where these plants are a prominent feature of the landscape.

Most studies on decomposition of aquatic macrophytes in tropical regions have focused on changes in plant biomass (Ayyappan *et al.*, 1986; Poi de Neiff & Neiff, 1988; Hammerly *et al.*, 1989; Poi de Neiff & Neiff, 1989; Neiff & Poi de Neiff, 1990; Bruquetas de Zozaya &

Neiff, 1991; Camargo, 1991). Among the few studies relating to the influence of decomposition products of aquatic macrophytes on water quality are those of Camargo *et al.* (1983), Helbing *et al.* (1986) and Gadelha *et al.* (1990).

For the present study we used leaf samples of *Eichhornia azurea* and water from two different environments: Guaraná Lagoon located in the Baía River, and Cortado Channel, of the Paraná River. Both localities are in the floodplain of the Upper Paraná River (22°43' - 22°55' S and 53°18' - 53°25' W). These two environments were chosen because they have different limnological characteristics (Thomaz *et al.*, 1991, 1992a), as well as marked differences in the morphometry of the populations of *E. azurea* (UEM.Nupelia-PADCT/CIAMB, 1993), the predominant plant in the area.

Through experiments on the decomposition of the aquatic macrophyte *Eichhornia azurea* (Swartz) Kunth, our objective was (a) to evaluate the influence of its decomposition products on some limnological characteristics and (b) to establish whether any changes in these characteristics differed according to the origin of the decomposing plant matter or of the water in which the decomposition was occurring.

MATERIAL AND METHODS

Populations and environments characteristics

The aquatic macrophytes and water were collected at Guaraná Lagoon and Cortado Channel. Guaraná is a lagoon located inside the floodplain in a region dominated by several species of grasses. Cortado Channel is a side arm of the Paraná River, and has lotic characteristics. Some limnological characteristics of these two environments and of the water used in the experiment are given in Table I. In both locations, populations of *E. azurea* are prominent (Bini, 1996) and morphometrically distinct. The Cortado Channel plants have significantly larger leaves than the ones from Guaraná Lagoon (UEM.Nupelia-PADCT/CIAMB, 1993). The petioles length, leaf area and the initial chemical composition of the detritus used in our experiments are shown in Table II. It cam be seem that the water from Guaraná Lagoon used in our experiment had lower values of pH, electrical conductivity, total alkalinity, bicarbonate and nitrate, and presented higher free carbon dioxide and total phosphorus values than Cortado Channel.

Decomposition experiment

For the decomposition experiment, we selected leaves (limb and petiole) of *E. azurea* that were dead or senescent (75 to 100% yellow or dry). The leaves were washed in running water to remove excess matter adhering to them, and then oven-dried at 70°C to constant weight. Using bunches of leaves of known dry weight (DW), we set up four treatments with three replicates each, in the following combinations:

1 - Water and plants from Guaraná Lagoon (GW-GM);
2 - Water and plants from Cortado Channel (CW-CM);
3 - Water from Guaraná Lagoon and plants from Cortado Channel (GW-CM);
4 - Water from Cortado Channel and plants from Guaraná Lagoon (CW-GM).

Table I- Minimum and maximum values of some of the main limnological factors of Guaraná Lagoon and the Paraná River (source: Thomaz, 1991), and values recorded at the beginning of the experiment.

Factor	Environment		Experiment	
	Guaraná Lagoon	Paraná River	Guaraná Lagoon	Cortado Channel
Water temperature (°C)	14.7 - 29.6	16.8-30.1	22.0	22.0
pH	5.7 - 7.0	7.1 - 7.9	6.3	7.5
Electrical conductivity (μS/cm)	16 - 67	51 - 72	19	62
Total alkalinity (mEq l^{-1})	0.10 - 0.40	0.27 - 0.54	0.14	0.46
Free carbon dioxide (mg l^{-1})	0.9 - 79.2	0.7 - 2,6	6.2	1.4
Bicarbonate (mg l^{-1})	5.9 - 24.4	16.4 - 32.8	8.4	28.3
Dissolved organic carbon (mg l^{-1})	2.10 - 19.70	1.33 - 2.03	-	-
Total phosphorus (μg l^{-1})	32.2 - 364.9	6.7 - 53.6	33.5	18.7
Total Kjeldahl nitrogen (mg l^{-1})	0.126 - 3.444	0.135 - 0.518	-	-
Nitrite (μg N-NO_2 l^{-1})	-	-	nd	nd
Nitrate (μg N-NO_3 l^{-1})	-	-	7	200
Ammonia (μg N-NH_4 l^{-1})	-	-	2.4	nd
Orthophosphate (μg P-PO_4 l^{-1})	8	5	nd	nd

nd = not detected

Table II - Mean values of morphometric (and standard deviation) and chemical constituents of *E. azurea* from Guaraná Lagoon and Cortado Channel, recorded at the beginning of the experiment (t=0).

Populations characteristics	Guaraná Lagoon	Cortado Channel
Petiole length (cm)	20.7 (3.4)	24.6 (3.4)
Limb area (cm^2)	1003 (660)	1772 (835)
Nitrogen content (% DW) *	1.430	1.546
Phosphorus content (% DW) *	0.190	0.189
Ash content (% DW) *	9.49	8.97
C:N ratio *	34.91	32.10

* = Content of leaf (limb plus petiole)

These treatments were conducted in aquaria containing 200 liters of water and 1g DW/l. After 1, 2, 3, 5, 9, 15, 30, 45, 60 and 90 days, we collected aliquots of about 1 liter of water from each aquarium, for determination of total phosphorus (TP), particulate phosphorus (PP) and dissolved nutrients (total dissolved phosphorus (TDP), dissolved reactive phosphate (DRP), nitrite, nitrate and ammonia). The water temperature in the aquaria varied between 16.5 and 26.5 °C ($\bar{x}$ = 20.92 °C).

The concentrations of TP, TDP and DRP in the water were determined by reaction with sodium molybdate (Mackereth *et al.*, 1978). The PP fraction was obtained by subtracting the concentration of total dissolved phosphorus from total phosphorus.

Determinations of nitrite and nitrate concentrations were done by Flow Injection Analysis (Zagatto *et al.*, 1981). For ammonia, the samples were treated with sodium nitroprussiate forming indophenol (Koroleff, 1983).

In each aquarium, we monitored the pH and electrical conductivity of the water with portable digital potentiometers, air and water temperature with a mercury thermometer, and dissolved oxygen by the Winkler method (Golterman *et al.*, 1978). Total alkalinity, free carbon dioxide and bicarbonate ions (Mackereth *et al.*, 1978) were determined in one aquarium of each treatment.

Because of the nature of the data, we used a repeated measurement analysis of variance (ANOVAR; von Ende, 1993) to test for differences between treatments. This analysis was chosen to take into account temporal measurements and the correlation between dates. The results for total alkalinity, free carbon dioxide and bicarbonate ions were not submitted to statistical treatment because of the lack of replicates.

RESULTS AND DISCUSSION

During decomposition of *E. azurea*, we observed a decline in dissolved oxygen concentration during the first week and a gradual increase afterwards (Fig. 1a). The rapid consumption observed soon after the beginning of decomposition, probably is a result of the intensive activity of microorganisms, both free and adhering to the detritus, during this phase (Olah *et al.*, 1987; Thomaz, 1995). The subsequent gradual increase in concentration of dissolved oxygen must be related to diffusion of atmospheric oxygen into the water.

No significant differences in oxygen concentration were observed between treatments (p>0.05), reinforcing the idea of rapid colonization and rapid bacterial growth, independent of the origin of the macrophyte material or the water used in the experiments. Nevertheless, the rate of consumption in the first day was considerably higher in the water from the channel (Fig. 1a), indicating more accelerated initial microbial activity in this environment.

The electrical conductivity of the water, which was initially 19 μS/cm in the lagoon and 62 μS/cm in the channel, rose quickly during the first day of decomposition and more slowly thereafter (Fig. 1b). Leaching of water-soluble compounds, including ions, in the initial phases of decomposition, probably is the main cause of the initial increase in conductivity. Chief among the rapidly liberated ions are Na, K and Ca, as demonstrated by Barbieri and Esteves (1991).

Water of different origin significantly (F = 33.925, p<0.01) affected the values of electrical conductivity. There was also a significant interaction between the water and the origin of the plant material (F = 5.493, p<0.05). However, the statistical difference between the aquaria containing channel water and those with lagoon water can be attributed to the initial conductivity values, which were considerably higher in the former environment.

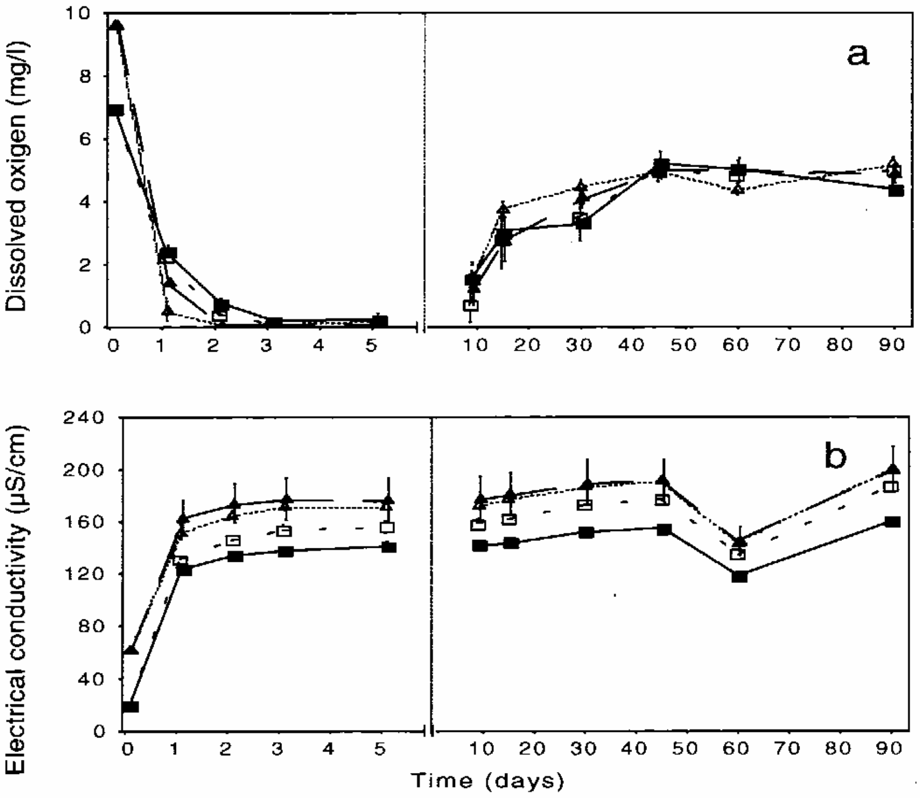

Figure 1. Values of a) dissolved oxigen concentration and b) electric conductivity during *E. azurea* decomposition (± the SD of three samples): GW-CM (white square); CW-CM (white triangle); GW-GM (black square); CW-GM (black triangle).

The values for total alkalinity and bicarbonate ions obtained during the experiment are shown in Fig. 2a and Fig. 2b, respectively. We observed a large increase in both parameters during the first week of decomposition, and then a more gradual increase to the end of the experiment. These results suggest that the biomass of decomposing aquatic macrophytes constitutes an important carbon source for "várzea" (floodplain) lagoons, as also established by Furch & Junk (1985) for Amazonian floodplain lakes. Therefore, the rise in values of electrical conductivity and alkalinity observed in "várzea" lagoons at the beginning of the flood pulse (Thomaz, 1991; Thomaz *et al.*, 1992a,c) can be attributed largely to decomposition of the flooded plant biomass.

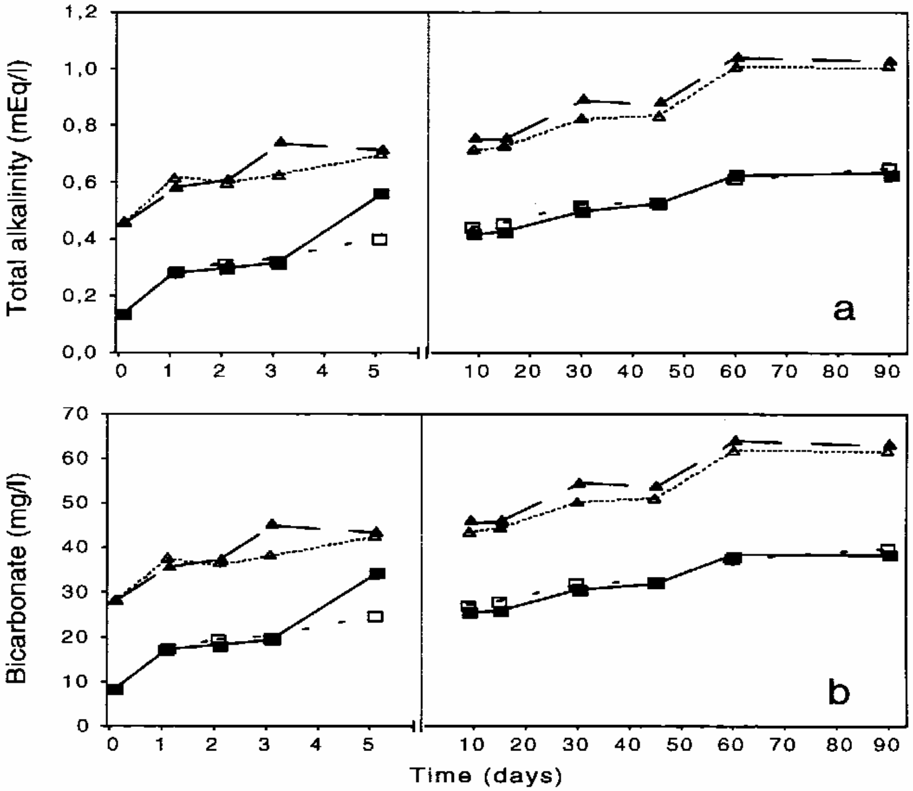

Figure 2. Values of a) total alcalinity and b) bicarbonate during *E. azurea* decomposition (± the SD of three samples): GW-CM (white square); CW-CM (white triangle); GW-GM (black square); CW-GM (black triangle).

The values of free carbon dioxide (Fig. 3a) also greatly increased during the first week of decomposition and then declined. This fact corroborates the hypothesis that there is a considerable increase in heterotrophic activity of epiphytic and free microorganisms, fostered by leaching of labile organic compounds during the initial phases of decomposition.

Regarding pH values (Fig. 3b), during the first days of decomposition we observed a decrease in the treatments containing channel water, while in the other treatments the pH remained constant. The initial decrease in pH may be associated with rapid leaching of organic acids during the initial decomposition phase (Helbing *et al.*, 1986) and to the increase in CO_2 concentrations resulting from microbial activity. After the first week, the pH values rose in all the treatments. Therefore we can state that the pH is influenced in two distinct ways: i) reduction at the beginning, to the limit of environmental buffering capacity and ii) a subsequent increase associated with leaching of Ca^{++} and HCO_3^- by the detritus.

Moreover, the results revealed that the pH of the water was affected differently by the two populations of *E. azurea* (F = 41.395, $p<0.05$). Also, the water characteristics caused significant differences in the pH dynamics, as the results obtained using the channel water were significantly different from those obtained for the lagoon water (F = 858.161, $p<0.05$). There was no significant interaction between the two factors.

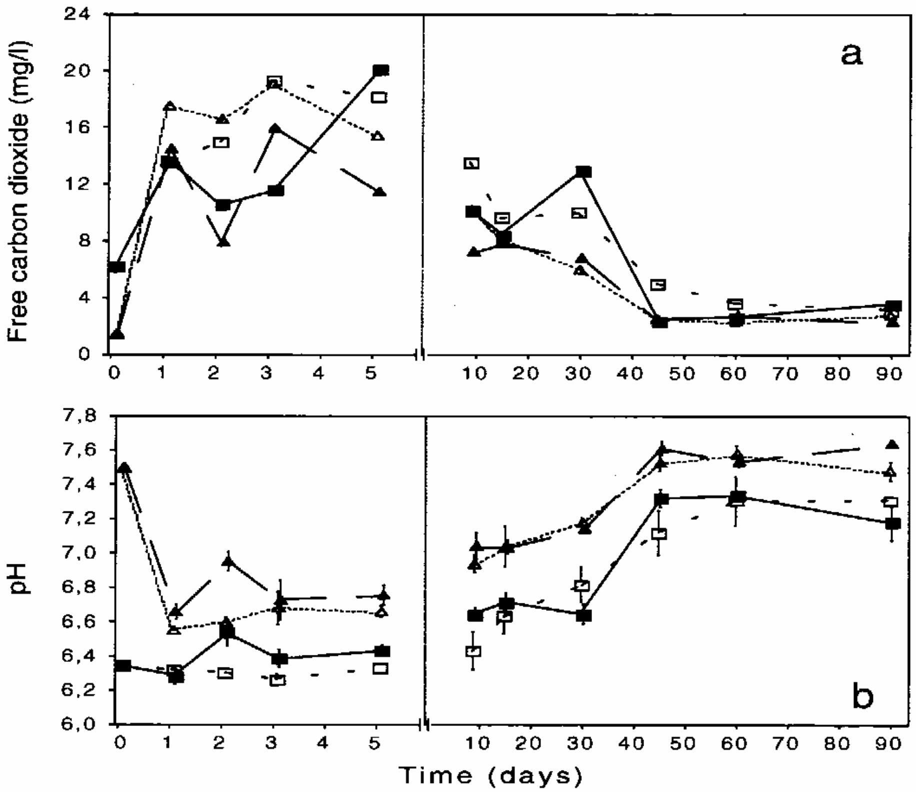

Figure 3. Values of a) free carbon dioxide and b) pH during *E. azurea* decomposition (± the SD of three samples): GW-CM (white square); CW-CM (white triangle); GW-GM (black square); CW-GM (black triangle).

The concentration of TP in the water is shown in Fig. 4a. We observed a rapid increase of approximately 600% in the concentration of TP during the first 24 hours of decomposition, and then the concentration stabilized. The increase in TDP concentration (Fig. 4b) also occurred in two stages, first a rapid increase, then a slower increase. After thirty days, there was a small decrease in the concentration of TP as well as TDP. The initial rapid increase in phosphorus in the water suggests that most of the phosphorus leached from the macrophyte material is rapidly hydrolyzed to DRP (Fig. 4c) or, together with this fraction, is transformed into PP (Fig. 4d) by adsorption on particles and assimilation by microorganisms. After 2 days of decomposition, the decrease in the particulate phosphorus fraction may be caused by the mortality and/or predation of bacteria by flagelates, which could release nutrients in dissolved form, especially DRP. In fact, a decrease of bacterial cells in batch cultures has been shown after 40 to 60 hours at 20° C (Tranvik & Sieburth, 1989).

The liberation of phosphate from the most refractory fraction of the plant detritus will probably influence the concentration of phosphorus in the water very little, since the stabilization and slight decrease in the concentrations of TDP and DRP will occur together with the lowest values of the particulate fraction. Nevertheless, phosphate liberation seems to behavior differently in distinct species of aquatic macrophytes. Gadelha *et al.* (1990), for example also

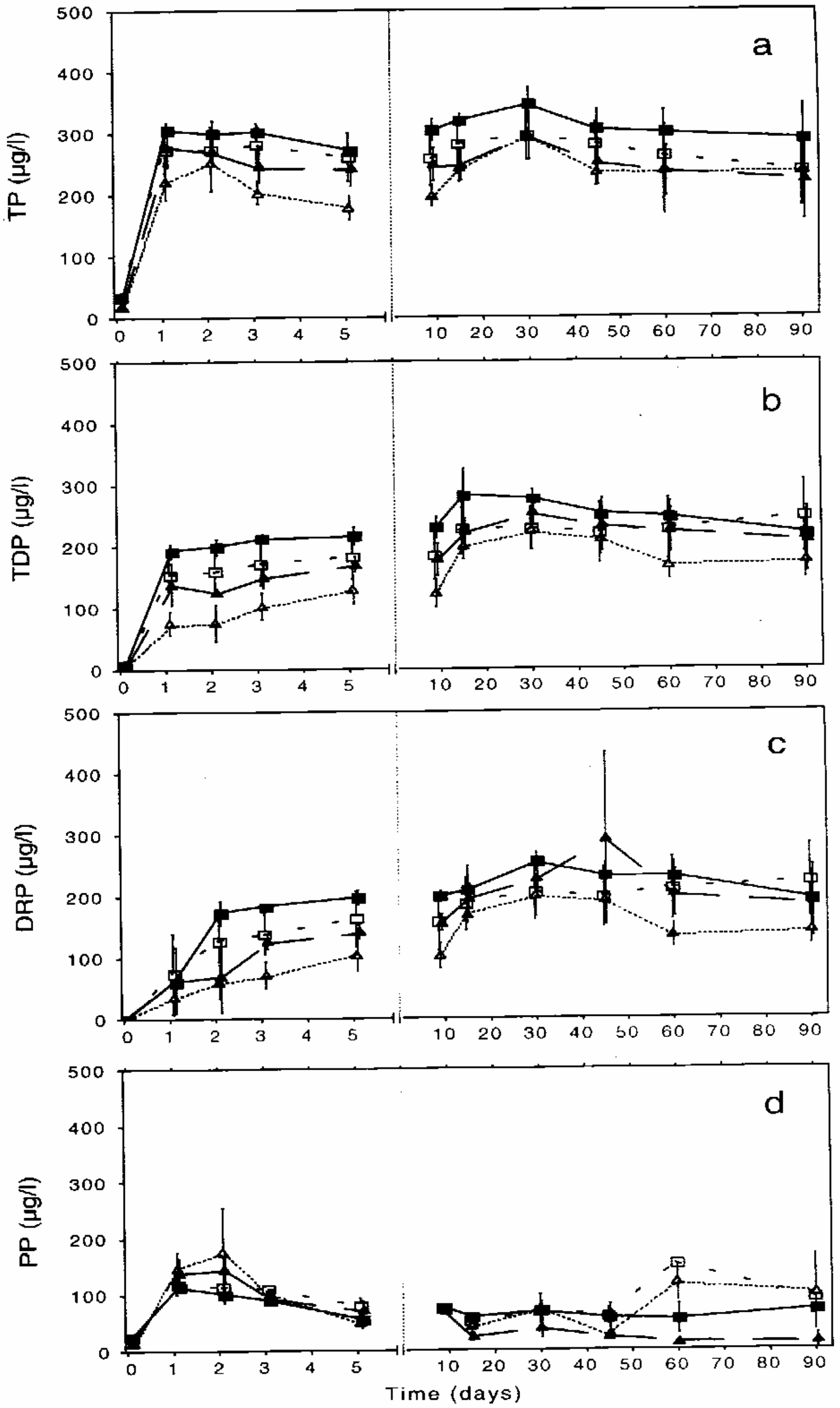

Figure 4. Concentration of a) total phosphorus; b) dissolved phosphorus; c) ortophosphate and d) particulated phosphorus during *E. azurea* decomposition (± the SD of three samples): GW-CM (white square); CW-CM (white triangle); GW-GM (black square); CW-GM (black triangle).

observed an accentuated increase in DRP concentrations in the first 20 days of decomposition of *Ludwigia natans*, followed by stabilization, while for *Salvinia auriculata* they observed a gradual increase for the first 25 days of decomposition, followed by a more rapid increase.

We found significant differences between the treatments for plants from different environments and water from different environments, for TP (F = 6.181, p<0.05 and F = 15.511, p<0.01), as well as for TDP (F = 6.981, p<0.05 and F = 7.361, p<0.05) and DRP (F = 6.165, p<0.05 and F = 6.778, p<0.05). For all these variables, the effect of the water was mainly responsible for the differences; however, the interaction between the plant and water factors was non-significant. Thus, the different phosphorus fractions are liberated more rapidly and in greater quantity from the biomass of *E. azurea* when it decomposes in water from the lagoon. The qualitative and quantitative differences in the microbial communities associated with the decomposition process are among the probable environmental factors responsible for this phenomenon.

However, the greater assimilation of inorganic phosphorus by the microbiota in the channel water may be an additional factor explaining the lower concentrations of TDP in this environment. This process appears to be most accentuated during the first 24 hours of decomposition, and is suggested by the increase in the PP fraction (Fig. 4d) in the channel water. During this same period, the concentrations of nitrate in the channel water decreased from 200 mg/l to values lower than 5 mg/l (Fig. 5a). We can postulate that the decomposition of the aquatic macrophyte biomass contributed a considerable load of TDP to the channel water, and at the same time caused consumption of nitrate, or denitrification. Thus, the N:P ratio of the channel water, initially 537:1, was 6:1 after 24 hours of decomposition. After this period, the values of nitrate were below detection limits. This process frequently occurs during the flood pulses, when waters of the Paraná River invade the "várzea" lagoons, which contain large amounts of decomposing biomass. In these circumstances, an immediate decrease in concentrations of inorganic nitrogen from the river, as well as significant changes in the N:P ratio have been observed (Carignam & Neiff, 1992; Paes da Silva & Thomaz, 1997).

The concentrations of nitrate, nitrite and ammonia are shown in Fig. 5a, Fig. 5b and Fig. 5c. Rapid exhaustion of the nitrate initially present in the channel water must have been caused as much by nitrate ammonification, as by assimilation of this form of nitrogen, as mentioned previously. These data are in agreement with those obtained by Carignan & Neiff (1992), who recorded a high nitrogen demand during decomposition of *E. crassipes*. However, considering that ammonification depends on a reducing environment, this process must occur in the floodplain aquatic environments during the flood pulses, being little likely in the main channel of the Paraná River. On the other hand, assimilation of inorganic nitrogen by the microbiota associated with decomposition must be considerable, in view of the fact that these microorganisms need an external nitrogen source to decompose low-quality detritus. In the first week of decomposition, for example, the C:N ratios of *E. azurea* detritus varied from 29 to 40 (see Table II and Pagioro & Thomaz, 1999).

Part of the nitrogen of the aquatic macrophytes was liberated to the water in the form of ammonia (Fig. 5c). A small increase of the ammonia concentrations was found during the first week of decomposition. This was probably because of the leaching and the activity of anaerobic microorganisms, given the low oxygen concentrations during this period. Similar results were obtained by Camargo *et al.* (1983) studying the decomposition of *Nymphoides indica* and *Pontederia cordata*. Between days 15 and 60 a small decrease in the ammonia concentration was observed. It can be partially attributed to nitrification, given that an increase in the nitrate concentrations was observed simultaneously.

Nitrite (Fig. 5b) was detected at low concentrations only after the reduction in ammonia concentration, due it is an unstable form, intermediate between ammonia and nitrate. In areas in Brazil subject to flooding by the Mogi-Guaçu River, the observed nitrate and nitrite concentrations are low (< 5 mg/l), while ammonia dominates the concentrations of dissolved inorganic nitrogen, especially when dissolved oxygen concentrations are low (Howard-Williams *et al.*, 1989). Additionally,

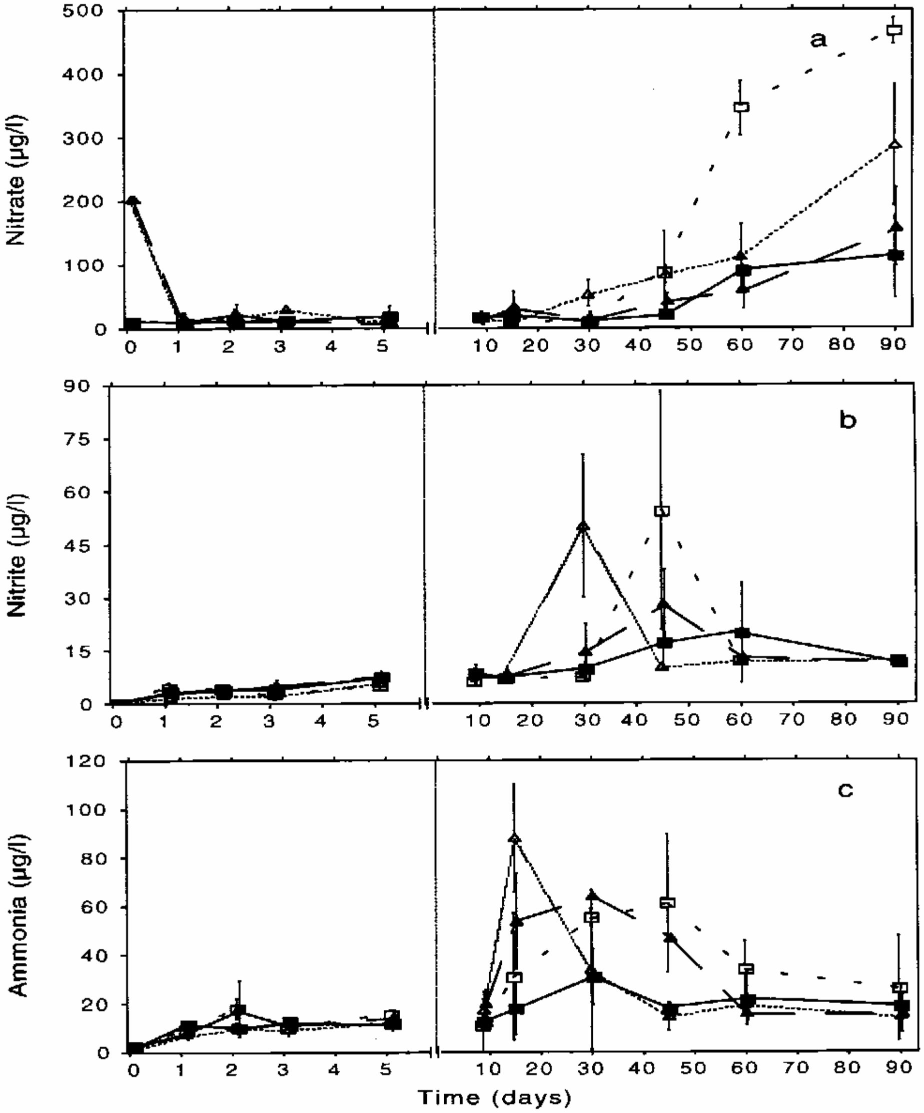

Figure 5. Concentration of a) nitrate; b) nitrite and c) amoniacal nitrogen during *E. azurea* decomposition (± the SD of three samples): GW-CM (white square); CW-CM (white triangle); GW-GM (black square); CW-GM (black triangle).

these investigators considered that the sediment is the main source of ammonia for aquatic environments. Our results indicate that organic detritus derived from aquatic macrophytes is also an important source of nitrogen.

Significant differences were observed only in relation to nitrate, and the macrophytes origin ($F = 91.638, p<0.01$), the water origin ($F = 8.480, p<0.05$) and the interaction between the two ($F = 18.862, p<0.01$) were responsible for these differences. After 90 days of decomposition, the plants from Cortado channel were responsible for the highest concentrations of this nutrient in the water. This could be associated with the higher nitrogen concentrations that occurred in the biomass at this locality during the entire experiment (Pagioro, 1996).

CONCLUSIONS

During the decomposition process, a large quantity of nutrients is liberated by the aquatic macrophytes. This release is affected differently by water characteristics as well as by plant origin. Thus the waterbodies of the floodplain are influenced differently by aquatic macrophyte decomposition. After releasing, probably the labile fraction is rapidly assimilated and transformed into particulate organic matter, exhausting the dissolved oxygen. The mass mortality of or predation on the bacteria, which probably constitute the main community forming particulate organic matter, will liberate nutrients, especially nitrogen in the form of ammonia, which will gradually be oxidized to nitrate by aerobic bacteria. This reveals the important role of detritus as a nutrient source for the water column, which then cycles through the grazer food chain and higher trophic levels.

The laboratory simulation generally reflected the events occurring during and after the flood pulse in the natural environments (Guaraná Lagoon and the Paraná River), that is, the reductions in dissolved oxygen and pH, and the increases in electrical conductivity, total alkalinity, bicarbonate, free carbon dioxide, nitrogen and phosphorus during the high water period (Thomaz *et al.*, 1992a,b; Pagioro *et al.*, 1994). Thus, such changes, observed mainly in lentic environments, can be attributed to decomposition of the vegetation of the shoreline and "várzea", which causes rapid transport of labile compounds from the plants to the water, and subsequent gradual leaching of nutrients from the more refractory fractions. It is important to emphasize that in the experiment, the use of compounds derived from plant decomposition was only by heterotrophic organisms, although in the natural environment, photoautotrophic organisms will also benefit from these nutrients.

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REFERENCES

Ayyappan, S.; Oláh, J.; Taghavan, S.L.; Sinha, V.R.P. & Purushothaman, C.S. 1986. Macrophyte decomposition in two tropical lakes. Arch. Hydrobiol., 106(2):219-231.

Barbieri, R. & Esteves, F.A. 1991. The chemical composition of some aquatic macrophyte species and implications for the metabolism of a tropical lacustrine ecosystem - Lobo Reservoir, São Paulo, Brazil. Hydrobiologia, 213:133-140.

Bini, L. M., 1996. Influência do pulso de inundação nos valores de fitomassa de três espécies de macrófitas aquáticas na planície de inundação do alto rio Paraná. Arq. Biol. Tecnol., 39(3):715-721.

Bruquetas de Zozaya, I.Y. & Neiff, J.J. 1991. Decomposition and colonization by invertebrates of *Typha latifolia* L. litter in Chaco cattail swamp (Argentina). Aquat. Bot., 40:185-193.

Camargo, A.F.M. 1991. Dinâmica do nitrogênio e do fosfato em uma lagoa marginal do rio Mogi Guaçú (lagoa do Mato, SP). São Carlos, UFSCar, 204 p. (Tese).

Camargo, A.F.M.; Ishii, I.H. & Esteves, F.A. 1983. Liberação de compostos orgânicos e inorgânicos para a coluna d'água durante o processo de decomposição de duas espécies de macrófitas aquáticas tropicais. An. Sem. Reg. Ecol., III:87-99.

Caringnam, R. & Neiff, J.J. 1992. Nutrient dynamics in the floodplain ponds of the Paraná River (Argentina) dominated by the water hyacinth *Eichhornia crassipes*. Biogeochemistry, 17:85-121.

Delariva, R.L.; Agostinho, A.A.; Nakatani, K. & Baumgartner, G. 1994. Ichthyofauna associated to aquatic macrophytes in the upper Parana river floodplain. Revista Unimar, 16 (Suplemento 3):41-60.

Furch, K. & Junk, W.J. 1985. Dissolved carbon in a floodplain lake of the Amazon and in the river channel. Mitt. Geol.-Paläont. Inst. Univer. Hamburg, 58:285-298.

Gadelha, C.L.M.; Watanabe, T. & Passerat-De-Silans, A.M. 1990. Liberação de nutrientes inorgânicos durante o processo de decomposição de *Ludwigia natans* (Ell.) (Dicotyledoneae: Onagraceae) e de *Salvinia auriculata* (Aubl.) (Pteridophyta: Salviniaceae). Acta Limnol. Brasil., 3(2):633-652.

Golterman, H.L.; Clymos, R.S. & Ohmstad, M.A.M. 1978. Methods for Physical and Chemical Analysis of Freshwaters. Blackwel Scientific Publication, Oxford. 214p.

Hammerly, J.; Leguizanon, M.; Maine, M.A.; Schiver, D. & Pizarro, M.J. 1989. Decomposition rate of plant material in the Parana Medio River (Argentina). Hydrobiologia, 183:179-184.

Helbing, U.W.; Esteves, F.A.; Tilzer, M.M. & Stabel, H.H. 1986. Influência dos produtos de decomposição da macrófita aquática *Nymphoides indica* (L.) O. Kuntze, na composição química da água da represa do Lobo (Broa) - São Paulo. Acta Limnol. Brasil., 1: 611-637.

Howard-Williams, C.; Esteves, F.A.; Santos, J.E. & Downes, M.T. 1989. Short term nitrogen dynamics in a small Brazilian wetland (Lago Infernão, São Paulo). Trop. Ecol., 5:323-335.

Koroleff, K. 1983. Determination of ammonia. In: Grasshoff, E. & Kremling, S., (eds.) Methods of Seawater Analysis. Verlag Chemie, Weinhein, 150 pp.

Mackereth, F.Y.H.; Heron, J.G. & Talling, J. 1978. Water analysis some revised methods for limnologists. Frehwater Biol. Assoc., 36:1-120.

Neiff, J.J. & Poi De Neiff, A. 1990. Litterfall, leaf decomposition and litter colonization of *Tessaria integrifolia* (Compositae) in the Parana river floodplain. Hydrobiologia, 203:45-52.

Oláh, J.; Sinha, V.R.P.; Ayyappan, S.; Purushothaman, C.S. & Radheyshyam, S. 1987. Detritus associated respiration during macrophyte decomposition. Arch. Hydrobiol., 111(2):309-315.

Paes Da Silva, L. & Thomaz, S.M. 1997. Diel variation of some limnological parameters and metabolism of a lagoon of the high Paraná river floodplain, MS. An. Sem. Reg. Ecol., VII: 169-189.

Pagioro, T.A. 1996. Decomposição de duas populações distintas de *Eichhornia azurea (*Swartz) Kunth da planície de inundação do alto rio Paraná. Maringá, UEM. 37p. (Dissertation)

Pagioro, T.A.; Roberto, M.C. & Lansac-Tôha, F.A. 1994. Caracterização limnológica de uma lagoa (lagoa Figueira) da planície de inundação do alto rio Paraná. Revista Unimar, 16(3):203-215.

Pagioro, T.A. & Thomaz, S.M. 1999. Decomposition of *Eichhornia azurea* from limnologically different environments of the Upper Paraná River floodplain. Hydrobiologia, 411: 45-51.

Pieterse, A.H. & Murphy, K. 1990. Aquatic Weeds: The Ecology and Management of Nuisance Aquatic Vegetation. Oxford University Press., Oxford. 593pp.

Poi De Neiff, A. & Neiff, J.J. 1988. Decomposition of *Eichhornia crassipes* Solms in a pond of Parana river valley and colonization by invertebrates. Trop. Ecol., 29(2):79-85.

Poi De Neiff, A. & Neiff, J.J. 1989. Dry weight loss and colonization by invertebrates of *Eichhornia crassipes* litter under aerobic conditions. Trop. Ecol., 30(2):175-182.

Silva, C.J.; Nogueira, F. & Esteves, F.A. 1994. Composição química das principais espécies de macrófitas aquáticas do lago Recreio Pantanal Matogrossense (MT). Rev. Bras. Biol., 54(4):617-622.

Thomaz, S.M. 1991. Influência do regime hidrológico (pulsos) sobre algumas variásveis limnológicas de diferentes ambientes aquáticos da planície de inundação do alto rio Paraná, MS, Brasil. São Carlos, UFSCar. 294p. (Dissertation).

Thomaz, S.M. 1995. Biovolume, Densidade, Biomassa e Produção Secundária da Comunidade de Bactérias Perifíticas Associada aos Detritos de Typha domingensis (Pers.) na Lagoa Imboacica, Rio de Janeiro. São Carlos, UFSCar, 117p. (Tese).

Thomaz, S.M.; Roberto, M.C.; Lansac-Tôha, F.A.; Esteves, F.A. & Lima, A.F. 1991. Dinâmica temporal dos principais fatores limnológicos do rio Baía - planície de inundação do alto rio Paraná-MS, Brasil. Rev. Unimar, 13(2):299-312.

Thomaz, S.M.; Lansac-Tôha, F.A.; Roberto, M.C.; Esteves, F.A. & Lima, A.F. 1992a. Seasonal variation of some limnological factors of lagoa do Guaraná, a várzea lake of the High Rio Paraná, State of Mato Grosso do Sul, Brazil. Rev. Hidrobiol. Trop., *25*(4):267-354.

Thomaz, S.M.; Roberto, M.C.; Lansac-Tôha, F.A.; Lima, A.F. & Esteves, F.A. 1992b. Características limnológicas de uma estação de amostragem do alto rio Paraná e outras do baixo rio Ivinheima (PR, MS, Brasil). Acta Limnol. Brasil., 4:32-51.

Thomaz, S.M.; Roberto, M.C.; Esteves, F.A.; Lansac-Tôha, F.A. & Lima, A.F. 1992c. Influência do regime hidrológico do rio Paraná sobre os valores de transparência, oxigênio dissolvido e clorofila-*a* de três lagoas de sua várzea. Revista Unimar, 14(Suplemento):167-176.

Tranvik, L.J. & Sieburth, J.McN. 1989. Effects of floculated humic matter on free and attached pelagic microorganisms. Limnol. Oceanogr., 34 (4): 688-699.

UEM.Nupelia-PADCT/CIAMB. 1993. Estudos ambientais da planície de inundação do alto rio Paraná no trecho compreendido entre a foz do rio Paranapanema e o reservatório de Itaipu. Maringá, PR., 612p.

Von Ende, C. 1993. Repeated-measures analysis: grouth and other time-dependent measures. In: Scheiner & Gurevitch (eds.) Design and Analysis of Ecological Experiments. Chapman & Hall Inc., New York, 113 p.

Wetzel, R.G. 1990. Detritus, macrophytes and nutrient cycling in lakes. Mem. Ist. Ital. Idrobiol. Dott. Marco di Marchi, 47:233-249.

Wetzel, R.G. 1995. Death, detritus, and energy flow in aquatic ecosytems. Freshwater Biol., 33:83-89.

Wetzel, R.G. & Ward, A.K. 1992. Primary production. In: Calow, P. & Petts, G.E. (eds.) River Handbook. Blackwell Scientific Publs., Oxford, 354 p.

Zagatto, E.A.G.; Jacintho, A.O.; Reis, B.F.; Krug, F.J.; Bergamin, H.; Pessenda, L.C.R.; Mortatti, J. & Giné, M.F. 1981. Manual de análises de plantas empregando sistemas de injeção em fluxo. Universidade de São Paulo, Piracicaba-SP, 45p.