UPTAKE RATES OF NITROGEN AND PHOSPHORUS IN THE WATER BY *Eichhornia crassipes* AND *Salvinia auriculata*

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(With 1 figure)

ABSTRACT

The main goal of this research was to survey information about the physiology of *Eichhornia crassipes* and *Salvinia auriculata* and their capacity to remove nitrogen and phosphorus from the environment, after quantifying the concentrations of the nitrogen (NO_3–N, NH_4–N and total–N) and phosphorus (PO_4–P and total-P) compounds in the water. The macrophytes were incubated in the laboratory in plastic vials of approximately 1.5 litters containing a previously prepared solution of NH_4NO_3, NH_4Cl and KH_2PO_4. *Eichhornia crassipes* exhibited the highest rates of nutrient reduction and the concentrations of NO_3–N, NH_4–N and PO_4–P in the water influenced the uptake rates of nitrogen and phosphorus of the *E. crassipes* and *S. auriculata*. This information can help to reach adequate management strategies for aquatic macrophytes in order to reduce the eutrophication process in Imboassica lagoon.

Key words: aquatic macrophytes, *Eichhornia crassipes*, nitrogen, phosphorus and *Salvinia auriculata*.

RESUMO

Taxas de absorção de nitrogênio e fósforo na água por *Eichhornia crassipes* e *Salvinia auriculata*

Esta pesquisa teve por principal objetivo, levantar informações a respeito do funcionamento e da capacidade de remoção de nitrogênio e fósforo por *Eichhornia crassipes* e *Salvinia auriculata*, a partir da quantificação das concentrações dos compostos nitrogenados (NO_3–N, NH_4–N e N-total) e fosfatados (PO_4–P e P-total) na água. As macrófitas foram incubadas, em laboratório, em frascos plásticos de 1,5 litros, os quais continham uma solução previamente preparada com NH_4NO_3, NH_4Cl e KH_2PO_4. *Eichhornia crassipes* apresentou as maiores taxas de redução de nutrientes e as concentrações de NO_3–N, NH_4–N e PO_4–P na água influenciaram as taxas de absorção de nitrogênio e fósforo das *E. crassipes* e *S. auriculata*. Essas informações podem ser úteis para uma estratégia de manejo adequado das macrófitas aquáticas, na tentativa de reduzir o processo de eutrofização na lagoa Imboassica.

Palavras-chave: *Eichhornia crassipes*, macrófitas aquáticas, nitrogênio, fósforo e *Salvinia auriculata*.

INTRODUCTION

The first studies in dynamics, cycling and storage of nutrients established the basis for studies, in wetlands, of the transformations from effluents into various kinds of biomass (Bastian & Hammer, 1993). An effluent treatment system based on aquatic macrophytes may be defined as a natural process, where the plants play the principal role in the removal and long-term storage of residues from anthropogenic origin (Brix, 1993).

Understanding of the functioning of these "natural systems" with respect to the reduction of pollutants has greatly increased in the last years (Reddy & D'Angelo, 1997). However, the basic knowledge of these systems is not yet well-developed as large amounts of data have still to be collected. These data include studies on the long-term effects on the biota, so that successful management strategies can be developed to prevent eutrophication of fresh water bodies (Knight *et al*., 1993).

Many coastal lagoons of an exquisite beauty distinguish the northern coast of Rio de Janeiro (Brazil). These environments are important leisure grounds for the local population, as well as having large fish and shrimp fisheries. Lagoon Imboassica is located in this region and suffer various anthropogenic impacts since the mid 1980's. The lagoon began to be utilised as a dumping site for untreated domestic sewage due to the residence construction on the shoreline.

Previous studies in this lagoon indicate that the aquatic macrophyte community is of great importance in reducing the input of domestic sewage (high nitrogen and phosphorus) into the lagoon (Lopes-Ferreira, 1995). The main goal of this study was to evaluate the capacity of *E. crassipes* and *S. auriculata* to remove nitrogen and phosphorus compounds from the water and to determine which of these species has the greatest nutrient reducing ability. In addition, the influence of the initial concentrations of NO_3–N, NH_4–N and PO_4–P on the capacity of the aquatic plants to remove nitrogen and phosphorus from the water column in the lagoon was also observed.

STUDY AREA

The coastal lagoon Imboassica is located in the municipality of Macaé (22°50'S and 44°42'W), approximately 190 km north of the city of Rio de Janeiro, RJ (Fig. 1). This shallow lagoon has an area of 3.26 km^2, a mean depth around 1.1 m and a maximum of 2.2 m at the central point of the lagoon (Furtado, 1994). The littoral region is densely colonised by aquatic macrophytes, especially *Eleocharis* cf. *fistulosa* and *Typha domingensis*, which cover 38% of the total area of the lagoon (Furtado, 1994). In the area closest to the sea, there is few aquatic macrophytes. Benthic macroalgae (*Characeae*) is observed on the sediment surface in the open-water areas of the lagoon. The lagoon lost 20% of its surface area due to landfilling in the littoral zone and the floodplain around the lagoon in the mid 1980's. The construction of residences also caused an increase in the nutrient loading (especially nitrogen and phosphorus) into the lagoon, as there is no domestic sewage treatment system. Different channels into the lagoon dump this sewage, the largest of them has 2.5 m of wide and mean depth of 30 cm. The daily output into the lagoon is estimated at 65 kg of N and 7 kg of P per day (Lopes-Ferreira, 1995).

The input of these effluents has altered the sanitary conditions in the lagoon, contributing to the presence of pathogenic organisms on many occasions. Furthermore, they favour the proliferation of aquatic macrophytes, especially *Typha domingensis*, *Eichhornia crassipes* and *Salvinia auriculata*, at the mouth of the largest dumping channel. This area has been distinguished in Imboassica lagoon, considering the total and dissolved nitrogen and phosphorus in the sediment (Furtado *et al.*, 1997) and also because the composition of zooplankton community (Branco *et al*., 1998) and macroinvertebrates associated with *Thypa domingensis* (Callisto *et al*., 1996).

METHODS

Young individuals of *E. crassipes* and *S. auriculata* were manually collected in the mouth of the largest sewage channel (Fig. 1). The plants were washed in flowing water in the laboratory and incubated for 24 hours. They were exposed to sunlight in a plastic pool where the water temperature was maintained between 27 and 31°C. The light intensity was measured with a radiometer (Li-Cor LI-185B).

The macrophytes and controls (flasks without plants), were incubated in plastic vials containing 700 ml of a solution previously prepared with water from the Imboassica lagoon enriched by ammonium nitrate (NH_4NO_3), ammonium chloride (NH_4Cl) and dibasic potassium phosphate (KH_2PO_4). Three different solutions of increasing concentrations, S1 (with approximately 0.8 mg NO_3/L, 1.0 mg NH_4/l, 0.6 mg PO_4/L); S2 (4.0 mg NO_3/L, 5.0 mg NH_4/L, 3.0 mg PO_4/L) and S3 (8.0 mg NO_3/L, 10.0 mg NH_4/L, 6.0 mg PO_4/L) were tested.

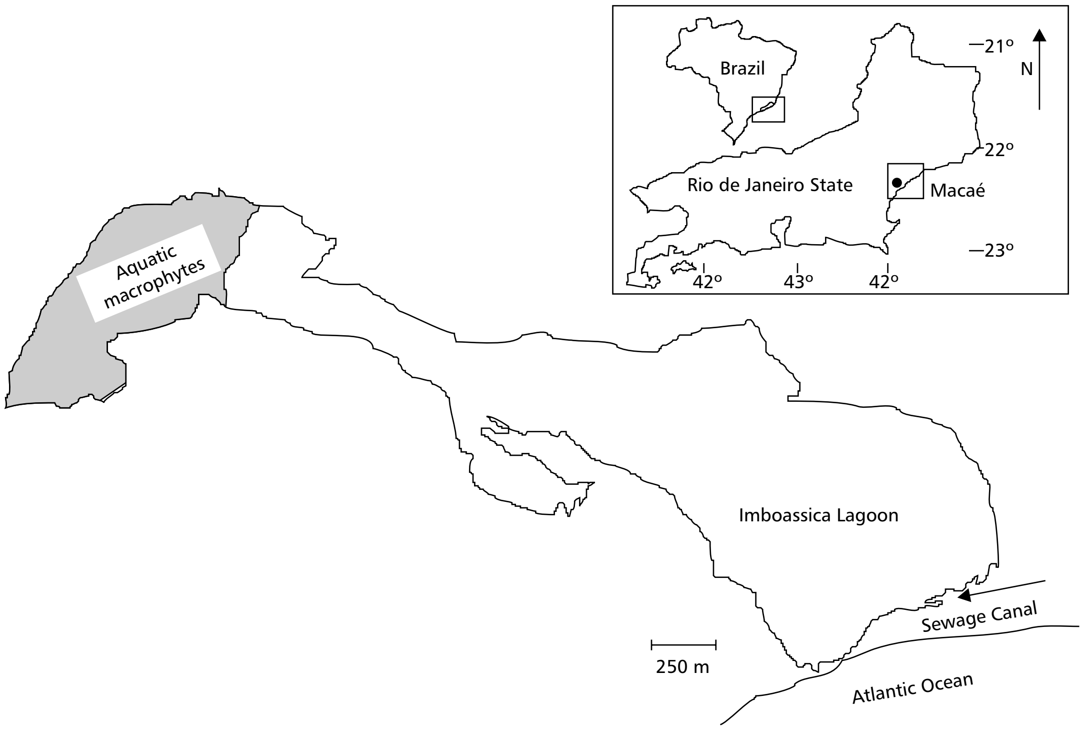

Fig. 1 — Imboassica Lagoon in the State of Rio de Janeiro, Brazil.

A young individual of *Eichhornia crassipes*, having an average of 3 leaves with their sizes close to 4 x 7 cm, was incubated in each flask. Another series of flasks received an individual of *Salvinia auriculata,* each one with approximately 6 rosettes of 1.0 cm (diameter). Before and after the incubation period, the temperature, salinity and electrical conductivity of the water were measured (digital thermo-salinometer-conductivimeter, LabComp SCT), as well as the concentrations of nitrogen and phosphorus. At the end of the experiment the plants were removed from the flasks and dried at 70°C in order to obtain dry weight.

After a filtration using filters GF 52/C (Schlücher & Schüll), the chlorophyll-*a* concentrations were obtained according to Nusch & Palme (1975). Total nitrogen and nitrate (µg/L) were determined according to Mackereth *et al*. (1978) and the ammonium (µg/L) according to Grasshoff (1976). Total and reactive soluble phosphorus (µg/L) were determined as suggested by Golterman *et al*. (1978). Dissolved oxygen concentrations were measured using Winkler method (Golterman *et al*., 1978).

The analysis of variance (ANOVA) was applied to verify the significance different among the uptake rates (*E. crassipes* and *S. auriculata*) and the treatments (S1, S2 and S3 enrichment). Pearson's Linear Correlation between chlorophyll-*a* values and nutrient concentrations were also obtained.

RESULTS

Dissolved oxygen in the water presented high values (> 80% sat) in all of the flasks after 24 hours of incubation (Table 1). In all the flasks containing *S. auriculata,* the values were above 100% saturation. In the flasks with *E. crassipes,* there was an oxygen consumption after 24 hours of incubation. In the flasks concerning the S1 and S2 treatments, there was an increase in the chlorophyll-*a* values, while in the flasks of S3 treatment a small reduction related to the initial concentration (To) was detected.

TABLE 1

Nitrogen, phosphorus, dissolved oxygen and chlorophyll-*a* of the water in *E. crassipes* (E), *S auriculata* (S) and control (C) samples, incubated in three different enrichment solutions (S1, 2 and 3) and average percentage of reduction (% red) in the nutrient concentrations after 24 hours.

Sample		TN (µg/L)	NO_3–N (µg/L)	NH_4–N (µg/L)	TP (µg/L)	PO_4–P (µg/L)	D.O (%sat)	Chlor. (µg/L)
S1 Enrichment								
To		2,016.0	827.0	1,046.5	658.3	638.7	97.7	2.7
C	Mean	1,957.2	792.2	827.4	634.8	580.9	103.2	9.3
	SD	14.5	11.7	29.5	5.7	16.9	1.0	0.4
	Mean	783.7	8.28	19.4	83.3	6.9	85.1	11.9
E	SD	159.6	1.1	3.0	23.9	3.7	1.0	3.6
	%red	61.1	99.0	98.1	87.3	98.9		
	Mean	1,219.7	314.0	31.7	437.0	203.3	111.1	9.6
S	SD	146.6	117.0	4.5	34.0	60.6	5.0	7.0
	%red	39.5	62.0	97.0	33.6	68.2		
S2 Enrichment								
To		5,040.0	3,883.3	4,938.0	3,036.8	2,977.5	98.0	1.3
C	Mean	4,914.0	4,323.6	4,316.6	3,006.2	2,905.8	103.1	15.1
	SD	50.4	87.3	33.6	5.1	18.6	1.0	0.9.
	Mean	788.8	457.2	29.5	78.3	17.3	89.3	12.3
E	SD	102.2	180.4	22.5	18.8	18.1	3.6	6.0
	%red	84.3	88.2	99.4	97.4	99.4		
	Mean	3,170.2	3,701.1	2,820.6	2,685.1	2,496.6	106.0	20.5
S	SD	314.9	45.0	285.5	79.5	45.6	1.7	4.3
	%red	37.1	4.7	42.9	11.6	16.1		
S3 Enrichment								
To		9,727.2	7,782.2	9,509.6	6,200.7	6,179.5	96.8	6.2
C	Mean	9,676.8	7,577.0	8,825.0	6,184.2	6,138.4	105.3	2.8
	SD	25.2	56.3	68.2	5.5	11.7	2.1	0.7
	Mean	6,872.0	6,334.2	6,175.3	5,008.1	4,555.7	83.2	3.6
E	SD	272.5	330.8	691.3	143.0	321.1	7.2	1.8
	%red	29.3	18.6	35.1	19.2	26.3		
	Mean	8,583.1	7,525.0	8,219.0	6,084.3	5,917.2	113.6	4.0
S	SD	99.5	61.1	104.8	30.4	60.1	3.1	1.6
	%red	11.8	3.3	13.6	1.9	4.2		

SD = Standard Deviation; To = Initial concentration.

In all of the treatments, higher percentages of nutrient reduction in *E. crassipes* compared to *S. auriculata* flasks were observed (Table 1) after 24 hours of incubation.

In the S1 and S2 treatments, the individuals of *E. crassipes* exhibited high percentages of reduction (around 90%) of the nutrients (except for TN). High percentage of ammonium reduction (97%) in S1 treatment was observed in the flasks with *S. auriculata*. The great enrichment of the initial concentrations of nutrients in the water (S3 treatment) was not followed by a corresponding increase in the percentage of absorption in both species.

No significant correlation between the chlorophyll-*a* and nutrient values was found in the enriched flasks (S1, S2 and S3 treatments) containing the macrophytes (Table 2).

By the other hand, the ANOVA analyses (Table 3) showed that: a) the nutrient uptake in the three treatments in the water containing *E. crassipes* was significantly different that from *S. auriculata*; b) there are significant difference, in both macrophytes, comparing the treatments (S1, S2 and S3 treatments) and the initial concentration of nutrients on the rates of nutrient reduction; c) the controls flasks always had decreasing concentrations of nutrients that were significantly different from the flasks with plants.

TABLE 2

Linear Correlation of Pearson between chlorophyll-*a* and nitrogen and phosphorus obtained in the flasks containing *Eichhornia crassipes* and *Salvinia auriculata* and enriched by three different solutions (S1, 2 and 3).

Treatments	S1		S2		S3	
Macrophytes	*E. crassipes*	*S. auriculata*	*E. crassipes*	*S. auriculata*	*E. crassipes*	*S. auriculata*
TN	0.13	0.48	–0.23	0.09	0.34	0.46
NO_3–N	–0.05	–0.25	–0.24	0.43	–0.11	–0.08
NH_4–N	–0.24	–0.37	–0.32	0.34	0.08	0.57
TP	0.02	0.27	–0.02	–0.47	0.07	–0.11
PO_4 -P	0.04	–0.20	–0.51	0.13	–0.31	–0.16

TABLE 3

Results of variance analysis (ANOVA) between the samples of *E. crassipes* (E), *S. auriculata* (S) and control (C); and between the treatments enriched by three different solutions (S1, 2 and 3).

Factor	TN	NH_4–N	NO_3–N	TP	PO_4–P
Samples	H	H	H	H	H
E X C	23.69*	21.10*	25.34*	20.03*	25.65*
S X C	29.96*	19.93*	25.72*	30.78*	81.86*
S X E	26.74*	55.56*	28.38*	50.57*	55.12*
Treatment					
E. crassipes	796.2*	239.0*	391.2*	2,147*	395.9*
S. auriculata	54.09*	98.11*	46.39*	49.58*	42.57*

* $p < 0.05$

DISCUSSION

According to Cary & Weerts (1983b, 1984), Reddy & Debusk (1987) and Fisher & Reddy (1987), temperature has a direct influence on the absorption capacity and on the productivity of *Eichhornia crassipes* and *Salvinia auriculata*. The water temperature measured in the different treatments corresponds to the optimum to the production of these two aquatic plants. By other hand, the low dissolved oxygen and chlorophyll-*a* concentrations in the water indicate that no growth of phytoplanktonic community and neither O_2 consumption by microrganisms were observed, and that the decreases in the nutrient concentrations were linked to the presence of the aquatic macrophytes.

E. crassipes showed an increasing percentage of nutrient absorption when the initial concentrations of NH_4–N, NO_3–N and PO_4–P changed from the S1 to S2 treatments, but *S. auriculata* became less effective in the absorption of nutrients. In the flasks of S3 treatment, the high concentrations of the nutrients in water resulted for both species in a large reduction in the percentage of nutrient absorption, because the saturation capacity on the nutrient uptake of the plants was attained.

Reddy *et al.* (1989) observed that *E. crassipes* responds positively to additions of nitrogen up to 5.5 mg/L and when the concentrations were higher, the plant growth didn't increase in a same magnitude. Reddy *et al.* (1990) emphasised also that a phosphorus concentration higher than 1.06 mg/L didn't rise the growth rates of *E. crassipes*. For *Salvinia molesta*, Cary & Weerts (1983a) reported that concentrations higher than 20 mg/L of nitrogen in the water did not result in an increase on the productivity. This plant species do not showed an increase in biomass when the phosphorus concentrations in the water were higher than 2 mg/L (Cary & Weerts, 1984).

Studies showed also a luxury uptake of nitrogen and phosphorus, for *Eichhornia* and *Salvinia*. However, high concentrations of nutrients may reduce the absorption and growth rates of the plants. In our research, a same case concerning *E. crassipes* and *S. auriculata* was observed, when the high concentrations of nitrogen and phosphorus in the water (9,700 and 6,000 µg/L, respectively) were not reflected by an increase on the nutrient absorption percentages.

Another factor that may influence the absorption capacity is the N:P ratio in the water. Reddy & Tucker (1983) reported that the best rates of nitrogen and phosphorus absorption were observed when the N:P ratio in the water is around 2.3 and 5, when the highest production of *E. crassipes* biomass was recorded. Sato & Kondo (1981) referred that the greatest productivity of *E. crassipes*, occurs when the N:P ratio in the water was close to 3.6. In our study, the N:P ratios were around of 3.0 in the S1 treatment, but in the S2 and S3 treatments the N:P ratios were very low (around 1.5). In these two treatments, the low N:P ratios had probably a negative influence in the nutrient uptakes, indicated by nitrogen limitation in the water.

The percentages of nutrient reduction and the absorption rates of *E. crassipes* show a great range of variation. For the concentrations of total nitrogen, values included between 416 to 2,316 $mgN/m^2/d$ for the absorption rates and a percentage of reduction between 50% to 96% were found (Debusk & Reddy, 1987; Tripathi *et al.*, 1991; Sharma & Oshodi, 1991; Zakova *et al.*, 1994). Regarding phosphorus, the values ranged from 50 to 542 $mgP/m^2/d$ for the absorption rates and, the percentages of reduction varied from 36% to 90%, according to the environmental conditions to which *E. crassipes* is exposed (Debusk & Reddy, 1987; Tripathi *et al.*, 1991; Sharma & Oshodi, 1991; Zakova *et al.*, 1994).

For the genus *Salvinia,* total nitrogen concentrations around 300 $mgN/m^2/d$ for absorption rates and a percentage reduction around 40% and 60% were reported (Room, 1986). Likewise, for phosphorus, values around 100 $mgP/m^2/d$ for absorption rates and a percentage of reduction between 35% and 50%, were found (Room, 1986).

Concerning the experiment, using water and plants from Imboassica lagoon, the maximum values of the absorption rate (estimated from the reduction of each nutrient related to the surface of the flask used in the experiment) of nitrogen and phosphorus were 538 $mgN/m^2/d$ and 374 $mgP/m^2/d$ for *E. crassipes* and 237 $mgN/m^2/d$ and 45 $mgP/m^2/d$, for *S. auriculata*. Regarding the percentages of reduction, the maximum values are 85% and 97%, for N and P respectively in the samples with *E. crassipes,* and corresponded to 40% and 33%, for N and P respectively in the samples with *S. auriculata*. These results confirm that *E. crassipes* is more efficient in the removal of nutrients (when expressed in terms of surface area) than *S. auriculata*.

In tropical areas, *E. crassipes* exhibited the highest efficiency in the absorption of nitrogen and phosphorus than *S. auriculata*, and a high concentration of these elements reduced the absorption rate of N and P in the water by both species. This information, can help to reach adequate management strategies for aquatic macrophytes in order to reduce the eutrophication process in Imboassica lagoon.

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