# UPTAKE OF OXYGEN IN THE INITIAL STAGES OF DECOMPOSITION OF AQUATIC MACROPHYTES AND DETRITUS FROM TERRESTRIAL VEGETATION IN A TROPICAL COASTAL LAGOON.

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**RESUMO: Consumo de oxigênio dissolvido nos estádios iniciais da decomposição de macrófitas aquáticas e dos detritos da vegetação marginal de uma lagoa costeira tropical.** O objetivo dessa pesquisa foi avaliar o consumo de oxigênio dissolvido nos estágios iniciais da decomposição de quatro espécies de macrófitas aquáticas: *Typha domingensis*, *Eleocharis fistulosa*, *Nymphaea ampla* e *Potamogeton stenostachys* e dos detritos da vegetação terrestre de restinga, marginal à lagoa Cabiúnas (Macaé, RJ). O processo de decomposição das macrófitas aquáticas *N. ampla* e *P. stenostachys* apresentou as maiores taxas de consumo de oxigênio, enquanto que o processo de decomposição de *T. domingensis* e da amostra da vegetação marginal de restinga apresentou as menores taxas. As câmaras com *N. ampla* e *P. stenostachys* apresentaram os menores valores de pH e os maiores valores de condutividade elétrica. Esses resultados estão relacionados com a qualidade dos substratos (valores de percentagem de parede celular e razão C:N:P) e principalmente com a quantidade e qualidade do lixiviado liberado pelas amostras.

Palavras-chave: Macrófitas aquáticas, restinga, decomposição, lixiviado, razão CNP.

**ABSTRACT: Uptake of oxygen in the initial stages of decomposition of aquatic macrophytes and detritus from terrestrial vegetation in a tropical coastal lagoon.** The goal of this research was to evaluate the uptake of dissolved oxygen in the first stages of the decomposition of four species of aquatic macrophytes: *Typha domingensis, Eleocharis fistulosa, Nymphaea ampla* and *Potamogeton stenostachys* and of detritus from restinga terrestrial vegetation surrounding the Cabiúnas Lagoon (Macaé, RJ). The decomposition process of the aquatic macrophytes *N. ampla* and *P. stenostachys* presented the highest oxygen consumption rates, while the decomposition process of *T. domingensis* and of the sample of restinga terrestrial vegetation exhibited the smallest rates. The chambers with *N. ampla* and *P. stenostachys* showed the lowest values of pH and the highest values of electrical conductivity. These results are related to the quality of the substrate (values of cell-wall fraction and C:N:P ratio) and mainly to the amount and quality of the leachate released by the samples.

Key-words: Aquatic macrophytes, restinga vegetation, decomposition, leachate, CNP ratio.

# INTRODUCTION

Decomposition is the process in which the particulate organic matter (POM) is reduced and transformed, in simpler molecules, by the action of physical, chemical and biological factors. Among these factors, some of the most important are the leaching and the action of microorganisms. This transformation and the following uptake of the simpler molecules by the organisms is the basis of the trophic chain of many aquatic ecosystems and it is known as the detritus chain (Wetzel, 1983). Intermediate compounds, such as humic and fulvic acids and humina, can be also formed in decomposition process, especially from the supporting tissues and cellulose. The complete decomposition of these compounds is usually slow and difficult, and thus they may accumulate in aquatic ecosystems (Ljungdahl & Eriksson, 1985).

Aquatic macrophytes are considered important primary producers in aquatic continental ecosystems (Wetzel, 1992). These plants exhibit high values of biomass and interfere in many ways in the dynamics of aquatic ecosystems, including and mainly as a source of particulate and dissolved detritus (Wetzel, 1990; Bianchini Jr., 1997; Esteves, 1998). Another important source of detritus for these ecosystems is the surrounding vegetation. It contributes not only with dead leaves, which are carried by the action of the rain and the wind into aquatic ecosystems, but also with decomposed matter, which reaches the water table by percolation in the soil (Barbosa & Coutinho, 1987; Bianchini Jr., 1997).

The decomposition of the aquatic macrophytes begins in the first stages of senescence, when a weakening of the supporting tissues and a reallocation of nutrients to other parts of the plant takes place, as in the case of emergent macrophytes, in which the decomposition begins as soon as the weakened leaf bends and reaches the water (Godshalk & Wetzel, 1978b; Sculthorpe, 1985). First, a fraction of total carbon and nutrients enter in the ecosystem in the dissolved form due to a quick leaching. The decomposition follows with the mineralization of dead organic matter by periphytic organisms. The velocity of the process varies according to the composition of the plant tissues, the organisms which colonize it, the conditions of the environment and, finally, the presence of oxidizing agents, necessary to the catabolic reactions of the organic matter by the microorganisms (Nykvist, 1959; Godshalk & Wetzel, 1978abc; Opshal & Benner, 1993). In this way, measurements of dissolved oxygen concentration are often used to calculate the decomposition rate of some substances or of detritus (Twilley *et al.*, 1986; Coffin *et al.*, 1993; Brum *et al.*, 1999). Furthermore, values of pH, dissolved ions (conductivity) and $CO_2$ are also used to evaluation of the decomposition process (Godshalk & Wetzel, 1978bc).

The aim of this research was to evaluate the aerobic decomposition of four species of aquatic macrophytes from Cabiúnas lagoon: *Typha domingensis*, *Eleocharis fistulosa*, *Nymphaea ampla* and *Potamogeton stenostachys*; and the decomposition of dead leaves from the restinga surrounding vegetation. It also aims to correlate the decomposition rates with the characteristics of the samples, such as organic matter content, cell wall fraction and nutrients concentration, and with the composition of leachate

## MATERIAL AND METHODS

For this experiment we collected water from the central region of Cabiúnas lagoon, located in the Restinga de Jurubatiba National Park, in the North of Rio de Janeiro State, Brazil (22° 16'S, 41° 40'W). Cabiúnas lagoon was chosen since it presents, in the littoral region, intense colonization by aquatic macrophytes, an extensive restinga vegetation surrounding and it still has natural characteristics well preserved.

The following aquatic macrophytes were used in the experiment: *Typha domingensis*, *Eleocharis fistulosa*, *Nymphaea ampla* and *Potamogeton stenostachys*, since they are the most representatives in the studied lagoon. We also collected dead leaves of restinga arboreous vegetation (Rizzini, 1979), found closed to the margins of the lagoons. These leaves represent the entrance of particulate organic matter produced in restinga vegetation, being originated mainly from the following species: *Protium icicariba*, *Clusia hilariana*, *Eugenia aff rotundifolia*, *Myrcia lundiana*, *Rapanea parvifolia*, *Erythroxylum subsessile* and *Erythroxylum ovalifolium* (Zaluar, 1997). The samples were collected one week prior to the beginning of the experiment, dried at 40°C, grounded and kept in dry conditions (Bianchini Jr. & Toledo, 1998). We estimated in each sample the concentrations of total nitrogen and total phosphorus, according to EMBRAPA (1994); particulate organic carbon, with a Shimatzu Carbon Analyser (TOC-5000); organic matter content, through gravimetry after calcination at 550°C for 4 hours and cell wall fraction, according to the method proposed by Van Soest & Wine (1967).

The experiment was performed in decomposition chambers, set up in polyethylene flasks of 2l. Each chamber received approximately 400 mg of sample (200 mg $l^{-1}$, final concentration) and it was filled up to 2 l with lagoon water, previously filtered with GF/C 47 mm. Three chambers were used for each sample and, as a control, three chambers were set up containing just water from the lagoon. The chambers were incubated in a thermic box, in the dark, with flowing water, keeping constant the temperature during the experiment (~24 °C). After the experiment was completely set up, all chambers were aerated for 10 min, reaching oxygen saturation, and the initial measurements were done (Brum *et al.*, 1999).

Dissolved oxygen concentrations, pH, electrical conductivity and temperature were monitored for 40 days to evaluation the aerobic decomposition process. The dissolved oxygen was measured with a oxymeter TOA (model DO-11P), the pH with a pHmeter Analion (model PM - 603) and the conductivity and temperature with a YSI conductivimeter (model 30SET). The chambers were reaerated when the concentration of dissolved oxygen reached levels below 4 mg/l, to avoid anaerobic processes.

At the same time, a second experiment was performed to analyze the amount and the quality of the leachate release by these samples. In flasks of 200 ml capacity, 40 mg of each sample were added and the flasks were filled up with distilled and autoclaved water (200 mg $l^{-1}$, final concentration). To avoid large bacterial growth, we sampled the leachates after 2 days of incubation in the dark. We estimated the concentration in the leachate of dissolved organic carbon (DOC) with a Shimadzu TOC-5000 Carbon Analyzer, the concentration of total dissolved nitrogen by the method proposed by Mackereth *et al.* (1978) and the concentration of total dissolved phosphorus by the method proposed by Golterman *et al.* (1978).

# RESULTS AND DISCUSSION

The chambers with the aquatic macrophyte with floating leaves, *Nymphaea ampla*, exhibited, in the decomposition process, the highest values of oxygen consumption, followed by the chambers with the submersed aquatic macrophyte *Potamogeton stenostachys* and by the chambers with the emergent aquatic macrophytes *Eleocharis fistulosa* and *Typha domingensis* (Fig. 1). The sample of restinga vegetation showed a pattern of oxygen consumption similar to the emergent aquatic macrophyte *Typha domingensis.*

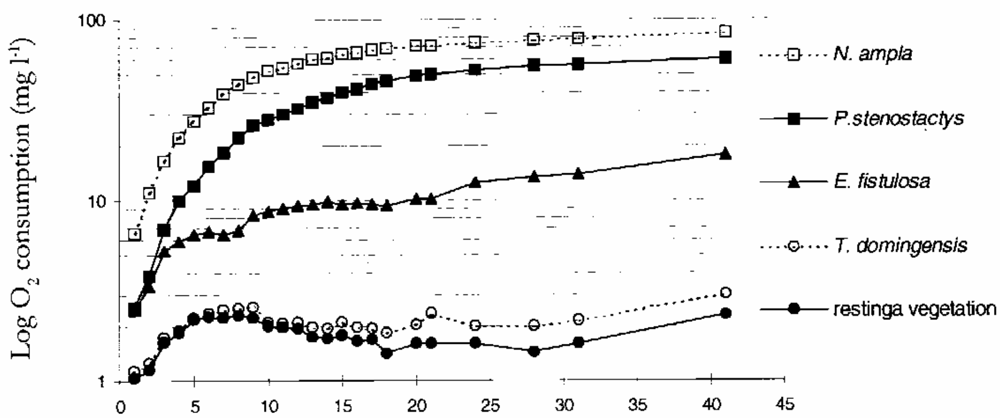


Figure 1. Oxygen consumption in the decomposition of aquatic macrophytes and sample of restinga vegetation.

The values of oxygen consumption were adjusted to a first order kinetic model, similar to the one adopted in BOD testing, to estimate the potential oxygen consumption rate, the coefficient of deoxygenation and the half-life of the decomposition process (Davies & Cromwell, 1991). The aquatic macrophyte *N. ampla* exhibited the highest potential decomposition rate (450 mg $O_2$ $g^{-1}$ DW), the highest coefficient of deoxygenation ($k = 0.112$ $day^{-1}$) and the lowest half-life (approximately 6 days), followed by *P. stenostachys* (360 mg $O_2$ $g^{-1}$ DW, $k = 0.0702$ $day^{-1}$ and half-life of 10 days) and *E. fistulosa* (60 mg $O_2$ $g^{-1}$ DW, $k = 0.0401$ $day^{-1}$ and half-life of 17 days). *T. domingensis* and the sample of restinga vegetation showed similar slow decomposition rates (32.5 and 35 mg $O_2$ $g^{-1}$ DW respectively), coefficients of deoxygenation of 0.0014 and 0.0016 $day^{-1}$ respectively, and quite high half-lives of decomposition rate (greater than 6 months). Extrapolating these results for Cabiúnas lagoon, for instance, we estimate that the detritus of *N. ampla* and *P. stenostachys* are quickly mineralized, the detritus of *E. fistulosa* have intermediate mineralization rates, while the detritus of *T. domingensis* and the dead leaves from restinga vegetation, due to their low decomposition rates, may accumulate in this environment.

The differences in the decomposition rates of these samples, verified by the oxygen consumption values, the coefficient of deoxygenation and the half-life of decomposition process, are related to the composition of the tissues of the samples and especially to the amount and composition of the leachate released. According to Esteves (1998), submersed aquatic macrophytes, such as *P. stenostachys*, and of floating leaves, such as *N. ampla*, present a great reduction in their supporting tissues, since they are sustained by the medium itself (water), and by aerenchyma tissue. On other hand, emergent aquatic macrophytes, such as *E. fistulosa* and *T. domingensis*, and the terrestrial vegetation have well developed supporting tissues, as may be observed by their great values of organic matter content and cell wall fraction when compared to the submersed and floating-leaved aquatic macrophytes (Tab. I). The decomposition of the cell wall and other supporting tissues (such as colenchyma and eschlerenchyma) is slow, due to the complex structure of the molecules and to their tertiary arrangements, that hamper the action of microorganisms (Ljungdahl & Eriksson, 1985). Furthermore, the decomposition of these tissues is usually incomplete, resulting in soluble intermediate compounds known as humic substances. These substances, composed by large and complex carbon chains, are of difficult degradation, like the original tissues, and may accumulate in aquatic environments,

Table I- Content of organic matter (OM), cell wall fraction, carbon, nitrogen and phosphorus, and C:N:P ration of the aquatic macrophytes and of the sample of restinga vegetation.

| | OM (%) | Cell Wall (%) | Carbon (%) | Nitrogen (%) | Phosphorus (%) | C : N : P |
|---|---|---|---|---|---|---|
| *N. ampla* | 41.65 | 46.76 | 36.72 | 2.40 | 0.18 | 205 : 13 : 1 |
| *P. stenostachys* | 39.32 | 48.59 | 36.17 | 2.16 | 0.16 | 233 : 14 : 1 |
| *E. fistulosa* | 42.63 | 73.52 | 39.47 | 0.98 | 0.08 | 515 : 37 : 1 |
| *T. domingensis* | 44.52 | 62.48 | 43.72 | 0.74 | 0.04 | 1016 : 17 : 1 |
| restinga vegetation | 44.17 | 53.80 | 43.16 | 0.99 | 0.05 | 959 : 22 : 1 |

bestowing a brown coloration to the water. Then, the significantly higher decomposition rates of *N. ampla* and *P. stenostachys* may be related to their lower percentage of supporting tissues, such as cell wall, in their leaves.

However, in short range experiments it is analyze mainly the process of decomposition of the leachate released by the plants (exponential phase of the oxygen consumption curve), in lieu of decomposition of the particulate detritus (Cunha & Bianchini Jr., 1998; Brum *et al.*, 1999). In the second experiment it was observed that the leaching rate in flasks with *N. ampla*

Table II- Concentration of dissolved organic carbon, total dissolved nitrogen and total dissolved phosphorus, and C:N:P ratio of the leachates from the aquatic macrophytes and from the sample of restinga vegetation.

| | Carbon (mg $l^{-1}$) | Nitrogen (mg $l^{-1}$) | Phosphorus (mg $l^{-1}$) | C : N : P |
|---|---|---|---|---|
| *N. ampla* | 38,55 | 1,62 | 0,46 | 84 : 4 : 1 |
| *P. stenostachys* | 18,40 | 0,77 | 0,22 | 82 : 4 : 1 |
| *E. fistulosa* | 10,20 | 0,48 | 0,05 | 192 : 9 : 1 |
| *T. domingensis* | 10,52 | 0,45 | 0,05 | 210 : 9 : 1 |
| Restinga vegetation | 11,56 | 0,38 | 0,04 | 321 : 10 : 1 |

was 2-times greater than in the flasks with *P. stenostachys* that, on the other hand, released approximately 2-times more leachate than the other macrophytes and the restinga vegetation sample (Tab. II). The leachate is usually the most labile fraction of organic matter, originating mainly from the protoplasmic fraction of the cell (Godshalk & Wetzel, 1978a). This labile fraction, by promoting an increase in the bacterial activity, leads to a greater oxygen consumption. Therefore, the greater decomposition rate of *N. ampla*, followed by *P. stenostachys*, may be related to the greater concentrations of leachate released by these aquatic macrophytes, which are quickly assimilated by the microbial community.

Recent researches have shown that the ratio between the concentrations of carbon, nitrogen and phosphorus (C:N:P) is one of the main factors determining the growth of free floating and attached bacteria (Enriquez *et al.* 1993, Chrzanowski & Kyle, 1996; Cimbleris & Kalff, in press), these being regarded as the main players in the decomposition process (Fenchel & Jørgensen, 1977). It is also known that the phosphorus is the most limiting nutrient to bacterial growth in continental aquatic environments (Toolan *et al* 1991, Coveney & Wetzel, 1992), including in Cabiúnas lagoon (Farjalla, 1998). In this case, as the C:N:P is lower, or in a simpler way, as the concentration of phosphorus is higher, the resource (or substrate) is better for bacterial growth.

The aquatic macrophyte *N. ampla* exhibited the lowest C:N:P ratio and the greatest concentration of phosphorus in its tissues, closely followed by *P. stenostachys* (Tab. I). A similar pattern emerges when we compare the leachates of these samples (Tab. II). In this case, the leachate of *P. stenostachys* exhibited lowest C:N:P, but the highest concentration of phosphorus was found in the leachate of *N. ampla*. The leachate of *E. fistulosa* presented an intermediate situation and *T. domingensis* and the restinga vegetation sample exhibited the highest C:N:P

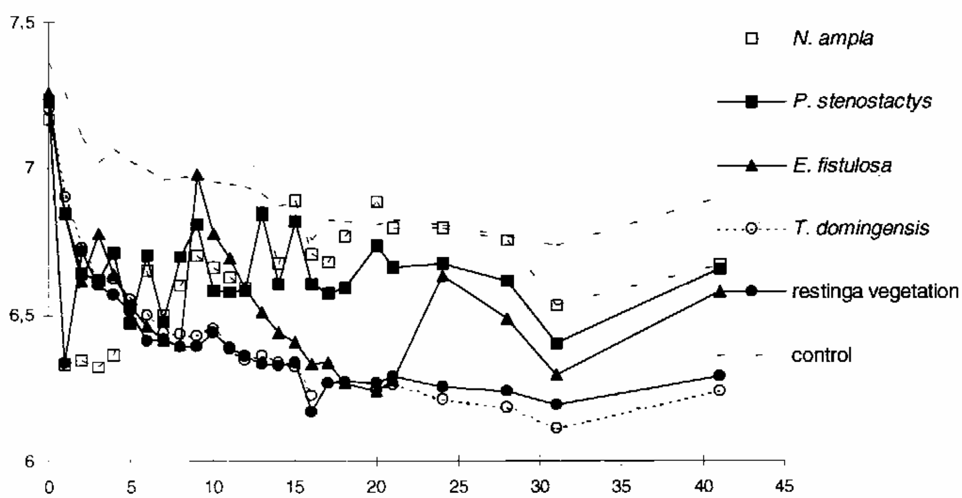


Figure 2. Changes on pH during the decomposition of aquatic macrophytes and the sample of restinga vegetation

ratios and the lowest concentrations of phosphorus. Therefore we suggest that the differences observed in decomposition rates among these samples may be also related to the C:N:P ratios and the concentrations of phosphorus of the detritus and leachates.

In the course of the experiment, we observed a reduction in the pH values in all samples as well as in the control (Fig. 2). This acidification was especially enhanced in the chambers with detritus of *N. ampla* and *P. stenostachys*, while, in the chambers with detritus of *E. fistulosa*, *T. domingensis* and the sample of restinga vegetation, this acidification was lower and more gradual. This results may be attributed to the formation of $CO_2$ in the process of mineralization of the detritus and leachates, as well as to the release of acids compounds. In the graphs of pH related to *N. ampla*, *P. stenostachys* and *E. fistulosa*, some peaks with high values of pH are followed by quick drops. Probably, these high values of pH are related to the release of $CO_2$ produced in the decomposition process to the atmosphere, in the aeration of some chambers. Due to the quick consumption of oxygen, the chambers with detritus of *N. ampla* and *P. stenostachys* were frequently aerated, while the chambers with *E. fistulosa* were aerated in some occasions. There was no need of aerating the chambers with *T. domingensis* and with samples of restinga vegetation.

In all chambers we verified, in the first days, an increase in the electrical conductivity values, followed by a quick decrease and a later stabilization of these values (Fig. 3). The leaching process releases to the water, almost immediately, a great amount of electrolytes (Nykvist, 1959). This process was more intense in the chambers with detritus of *N. ampla* and *P. stenostachys*. However, as the decomposition process goes on, these electrolytes are used in the bacterial metabolism (Fenchel & Jørgensen, 1977), resulting in a decrease in their concentrations and, finally, in a stabilization between the production and uptake of these electrolytes. As the dissociation of the carbonic acid is an important factor in the increase of

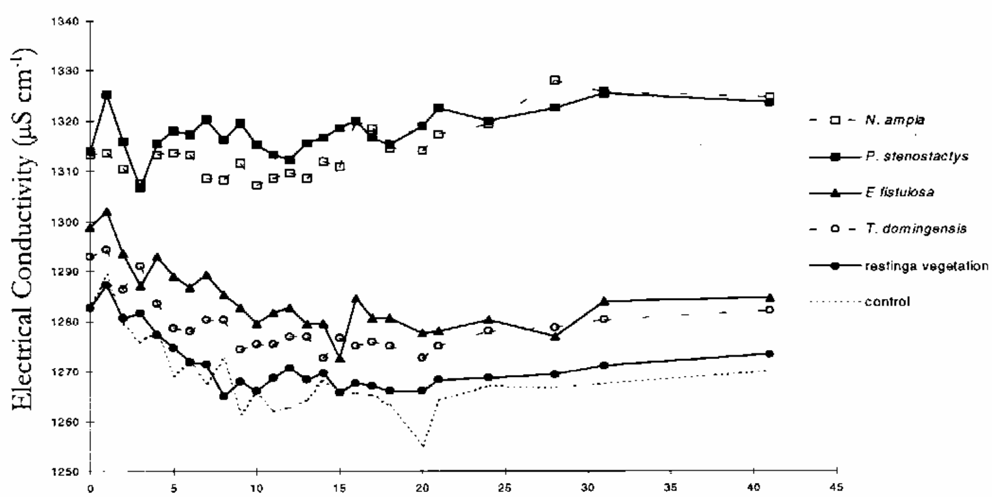


Figure 3. Changes of electrical conductivity during the decomposition of aquatic macrophytes and the sample of restinga vegetation.

the electrical conductivity, it is important to mention that, due to the successive aerations in the chambers with detritus of *N. ampla* and *P. stenostachys* and the consequent release of $CO_2$, the variation in the conductivity values, as well as in the pH values, may have been overestimated.

The temperature varied only between 21.7 °C and 26.4 °C during the experiment. However, as the temperature is a major factor in the solubility of oxygen, we may explain some values of oxygen concentration, especially in the chambers with *T. domingensis* and sample of restinga vegetation. Therefore, the data of deoxygenating rate and half-life of decomposition process related to the decomposition of *T. domingensis* and sample of restinga vegetation may be overestimated.

We conclude that the quality of the detritus, especially regarding their cell wall fraction and C:N:P ratio, influence the decomposition process. However, in short range experiments, the decomposition process is more related to the decomposition of the leachate released by the sample, particularly to the amount of leachate released and its concentration of nitrogen and phosphorus. In this context, *N. ampla* is, among the studied aquatic macrophytes and restinga vegetation, the one with the fastest decomposition rates, followed by *P. stenostachys* and *E. fistulosa*. On the other hand, *T. domingensis* and the leaves of the surrounding restinga vegetation that arrives at the lagoon are only slowly decomposed.

## ACKNOWLEDGMENTS

This work was supported by grants of the Brazilian Research Council (CNPq) to the authors. In addition, we would like to thank PETROBRAS, for the additional financial support, and Paulo Roberto Brum for assistance in the translation to English.

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