Detritus age on aerobic mineralization of Salvinia auriculata Aubl.

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ABSTRACT: Detritus age on aerobic mineralization of Salvinia auriculata Aubl. Considering the essential role of the aquatic macrophytes decomposition to aquatic ecosystems, this study evaluated the oxygen consumption of Salvinia auriculata detritus with 10 and 180 days, in the presence or absence of sediment; the detritus were previously decomposed under aerobic and anaerobic conditions. The plant, water and sediment samples were colleted on Óleo Lagoon (21° 36'S and 47° 49' W; Jataí Ecologic Station; Luiz Antônio, SP, Brazil). It was set up 20 mineralization chambers (10 with and 10 without sediment), they were prepared with detritus and water from the lagoon (0.70 g detritus DW L^{-1}) and maintained in the dark, under aerobic conditions and at 20°C. The DO concentrations were measured during 177 days. The results of the accumulated consumption of oxygen were adjusted to a first order kinetic model. In general, the treatments without sediment presented higher values of maximum consumption of oxygen (CO_{max}). The incubations of the younger detritus (10 days) presented higher values of CO_{max} (mean: 213 mg g^{-1} DW) when compared with the older detritus (180 days, mean: 107 mg g^{-1} DW). The deoxygenation coefficients varied from 0.0088 day^{-1} to 0.0436 day^{-1}; it was not possible to establish a tendency between them, related to the age or presence of sediment. The results indicated that, in the Óleo Lagoon, during aerobic decomposition within the upper layers of sediment, the benthonic oxygen demand did not necessarily increase by the higher presence of microorganisms and nutrient availability. The oxygen consumption rate constants from mineralization of S. auriculata detritus were similar, regardless of the presence of sediment, but younger detritus consumed more dissolved oxygen than older detritus.

Key words: aerobic process, aquatic macrophytes, decomposition, fibers.

RESUMO: A idade do detrito na mineralização aeróbia de Salvinia auriculata Aubl. Diante da importância do processo de decomposição da fração refratária dos detritos de macrófitas aquáticas nos ecossistemas lênticos, este estudo avaliou o consumo de oxigênio de detritos refratários de Salvinia auriculata com 10 e 180 dias, na presença e na ausência de sedimento. Os detritos foram previamente decompostos em condições aeróbias e anaeróbias. Os exemplares da planta, as amostras de água e de sedimento foram coletados na lagoa do Óleo (21° 36'S e 47° 49' W; Estação Ecológica do Jataí; Luiz Antônio, SP, Brasil). Foram preparadas 20 câmaras de mineralização (10 câmaras com sedimento e 10 sem sedimento) com alíquotas de água e detritos de 10 e 180 dias (0,70 g PS L^{-1}); os frascos foram incubados no escuro, sob condições aeróbias e a 20°C. As concentrações de oxigênio dissolvido foram determinadas durante 177 dias. Os resultados dos consumos acumulados de oxigênio foram ajustados a um modelo cinético de primeira ordem. No geral, os tratamentos sem sedimento apresentaram valores mais elevados de consumo máximo de oxigênio ($CO_{máx}$). As incubações com detritos de 10 dias apresentaram valores mais altos de $CO_{máx}$ (média de 213 mg g^{-1} PS) que as com os detritos mais velhos (180 dias); média de 107 mg g^{-1} PS. Os coeficientes de desoxigenação variaram entre 0,0088 dia^{-1} e 0,0436 dia^{-1}; mas não apresentaram tendência definida em função da idade do detrito ou presença de sedimento. Esses resultados indicaram que na decomposição aeróbia que ocorre na superfície do sedimento da lagoa do Óleo, as demandas bentônicas de oxigênio não necessariamente aumentam com a maior presença dos microrganismos e disponibilidade de nutrientes. Os coeficientes de consumo de oxigênio da mineralização de S. auriculata foram similares, independente da presença do sedimento; porém, os detritos mais novos consumiram mais oxigênio.

Palavras-chave: decomposição, fibras, processo aeróbio, macrófitas aquáticas.

Introduction

Most primary production within the aquatic environment is not directly consumed by herbivores. Often this biomass returns to the ecosystem as detritus and plays critical roles in functioning and sustaining of the environment (Daufresne & Loreau, 2001). Detritus can be defined as any form of non-living organic matter, including secreted, excreted or exuded products by organisms (Moore et al., 2004). The detritus are found as particulate organic matter (POM) and dissolved organic matter (DOM) and frequently represents the main source of energy in aquatic ecosystems (Ziegler & Fogel, 2003). During decomposition process, the detritus in the dissolved form tends to be processed in microbial loop while the particulate forms accumulate in the upper layers of sediment (Wetzel, 2001).

The particulate detritus are refractory compounds, i.e. compounds that are chemically stable, with low solubility and resistant to rapid microbial degradation (Wetzel, 1983). It is mainly constituted by cellulose, hemicelluloses and lignin. During decomposition, these polymers are hydrolyzed and the oligomers and monomers are metabolized in the presence or absence of molecular oxygen. In this way, the availability of electron acceptors in the environment determines the metabolic routes by which heterotrophic organisms mineralize these detritus. Each polymer is degraded by a variety of microorganisms, which produce a set of enzymes that work in synergism (Pérez at al., 2002).

The aerobic decomposition of refractory detritus has been observed in some studies (Antonio et al., 1999; Cunha-Santino & Bianchini Jr., 2002; Asaeda & Nam 2002; Bitar & Bianchini Jr., 2002; Sciessere et al., 2006), and usually presents a low dissolved oxygen consumption due to the difficulty in its degradation. Considering that, about 53% of aquatic macrophytes biomass is constituted by fibers (Henry-Silva & Camargo, 2006; Henry-Silva et al., 2001), their decomposition rates are strongly dependent on the species-specific content of structural materials (Godshalk & Wetzel, 1978). Lignin (10 to 30% of biomass) is slowly decomposed when compared with cellulose and tends to accumulate on the sediment. Once cellulose, hemicelluloses and lignin are the major components of plant biomass, the cycling of these compounds are essential to the dynamic of biogeochemical cycles.

Many studies have been done to evaluate the oxygen consumption of DOM mineralization, however, a few of them focused the POM decomposition, and how the sediment, as nutrients external sources, influences this process. In the aquatic systems, the detrital metabolism is predominant in the benthic region, where most POM is processed (Wetzel, 1983). In this context, this work aimed at evaluating the oxygen consumption of POM detritus in the presence or absence of sediment as a source of organic matter, microorganisms and nutrients (N and P).

The resource utilized on this study was Salvinia auriculata Aubl.; it is a free-floating aquatic macrophyte, annual or perennial and has small size leaves (2.5×2.0 cm^2). It is a pioneer on the succession in disturbed locals or new water bodies after a dried period; it can completely cover the surface areas in a few weeks. This specie is very common in lentic systems of Brazil and sometimes dominant in poor aquatic systems water or in rich soil wetlands (Pott & Pott, 2002).

Materials and methods

Sampling area description: The Óleo Lagoon (21° 36' S and 47° 49' W) is located in the Jataí Ecologic Station (21° 33' to 21° 37'S and 47° 45' to 47° 51'W), municipality of Luiz Antônio (São Paulo State, Brazil). This is an oxbow lagoon of the Mogi-Guaçu River, formed by the isolation of meandrous by erosion and sedimentation processes and represents a typical floodplain ecosystem. The lagoon is located at 400 m from the channel of Mogi-Guaçu River (Moschini, E. L.; personal communication). This system is classified as a seepage lagoon (Santos & Mozeto, 1992), and an oligotrophic environment during the dry season and mesotrophic during the wet season (Petracco, 2006). The Óleo Lagoon is similar to the others within the Jataí Ecologic Station; it has a low depth (Z_{mean} = 2.55 m and Z_{max} = 5.10 m) a small area (19,470 m^2), and a well-developed macrophyte community on the littoral zone (Rocha et al., 2000).

Sampling and material description: The samples of S. auriculata were manually collected on the littoral region of the lagoon and subsequently, washed with tap water and oven-dried (45°C). The water samples (with similar volumes) were collected at three distinct depths (0.5, 2.5 and 5.0 m) with a Van Dorn underwater sampler; in the laboratory, these samples were integrated (mixed), filtered in 0.45 mm membrane (Millipore ester cellulose) and aerated with filtered clean air for the experimental set-up. The sediment utilized was sampled with an Eckman-Birge dredge in the littoral zone, in the area where S. auriculata predominates. In order to measure total phosphorus, nitrogen and organic matter from the sediment, the samples were submitted to the procedures suggested by Mackereth et al. (1978) and Allen et al. (1974). The water samples used in incubations had the concentration of total phosphorus and nitrogen determined by colorimetric methods (Mackereth et al., 1978).

Previous decomposition experiments: In order to obtain the S. auriculata detritus with different ages, incubations were prepared and maintained under aerobic and anaerobic conditions. Incubations were prepared with 4.0 g (DW) of S. auriculata fragments and 400.0 mL of lagoon water previously filtered in 0.45 mm membrane (Millipore ester cellulose). The flasks were maintained in the dark at 20.0°C. After 10 and 180 days, the particulate detritus were obtained by filtering the mixtures through 0.22 mm membrane (Millipore ester cellulose).

Aerobic mineralization experiments: Incubations (n = 20) were set up with distinct detritus age (10 and 180 days). The decomposition chambers were prepared in duplicate and submitted to two distinct treatments: 10 bottles were prepared with addition of fresh sediment (ca. 0.2 g DW L^{-1}) and 10 without sediment. Thus, for each treatment (with and without sediment addition) were prepared bottles with detritus with 10 days or 180 days and lagoon water in the proportion of 0.70 g detritus DW L^{-1} (Tab. I). Control bottles were also prepared with lagoon water (n = 2) and lagoon water with fresh sediment (n = 2). The bottles were kept in the dark and at 20 °C.

The concentrations of dissolved oxygen (DO) were measured during 177 days using a polarographic method (YSI DO meter, model 58; precision 0.03 mg L^{-1}). The anaerobic processes were avoided by the periodic re-aeration of incubations with filtered clean air. The deoxygenation coefficient (k_D) and the maximum amount of consumed oxygen (CO_{max}) were obtained from the fittings of the experimental results from the kinetic model usually adopted in BOD tests (Eq. 1). The fittings were carried out by non-linear regression, calculated by the iterative algorithm of Levenberg-Marquardt (Press et al., 1993). The half-life ($t_{1/2}$) of the decomposition process was calculated according to Equation 2.

$$CO = CO_{max} \times \left(1 - e^{-k_D t}\right) \quad (1),$$

$$t_{1/2} = \frac{\ln 0.5}{-k_D} \quad (2),$$

where: CO = consumed oxygen (mg g^{-1} DW), CO_{max}= maximum amount of consumed oxygen (mg g^{-1} DW); k_D = deoxygenation coefficient; t = time (day).

The oxygen consumption of the incubations was blank corrected by subtraction of CO values from the control flasks (with and without sediment). The CO temporal variations were statistically analyzed using analysis of variance (Kruskal-Wallis) followed by the Dunn´s test in order to verify significant differences among treatments (with and without sediment × detritus age: 10 or 180 days × early decomposition: aerobic or anaerobic). The level of statistical significance was 0.05, according to the test.

Results

The kinetics of oxygen consumption during the aerobic mineralization of S. auriculata detritus is presented in Fig. 1 and 2. The $180^{(+)}$Y treatment (Tab. I) was significantly different from $10^{(+)}$N ($p < 0{,}01$), $10^{(+)}$Y ($p < 0{,}001$), $10^{(+)}$Y ($p < 0{,}01$) $10^{(-)}$Y ($p < 0{,}01$). The $10^{(-)}$N treatment also presented a significant difference from $180^{(-)}$Y ($p < 0{,}001$). In the treatments without sediment, the maximum amount of oxygen consumption (CO_{max}; Eq. 1) varied from 134 mg g^{-1} DW ($180^{(-)}$ N) to 281 mg g^{-1} DW ($10^{(-)}$N; Tab. II). Overall, the incubations with 180 days detritus presented CO_{max} values 1.6 times lower than that with 10 days detritus. Among the incubations with sediment, the higher CO_{max} value was observed in the $10^{(+)}$Y treatment (201 mg g^{-1} DW); and the lower in the $180^{(+)}$Y; on average the younger detritus approximately consumed 3 times more oxygen than the 180 days detritus.

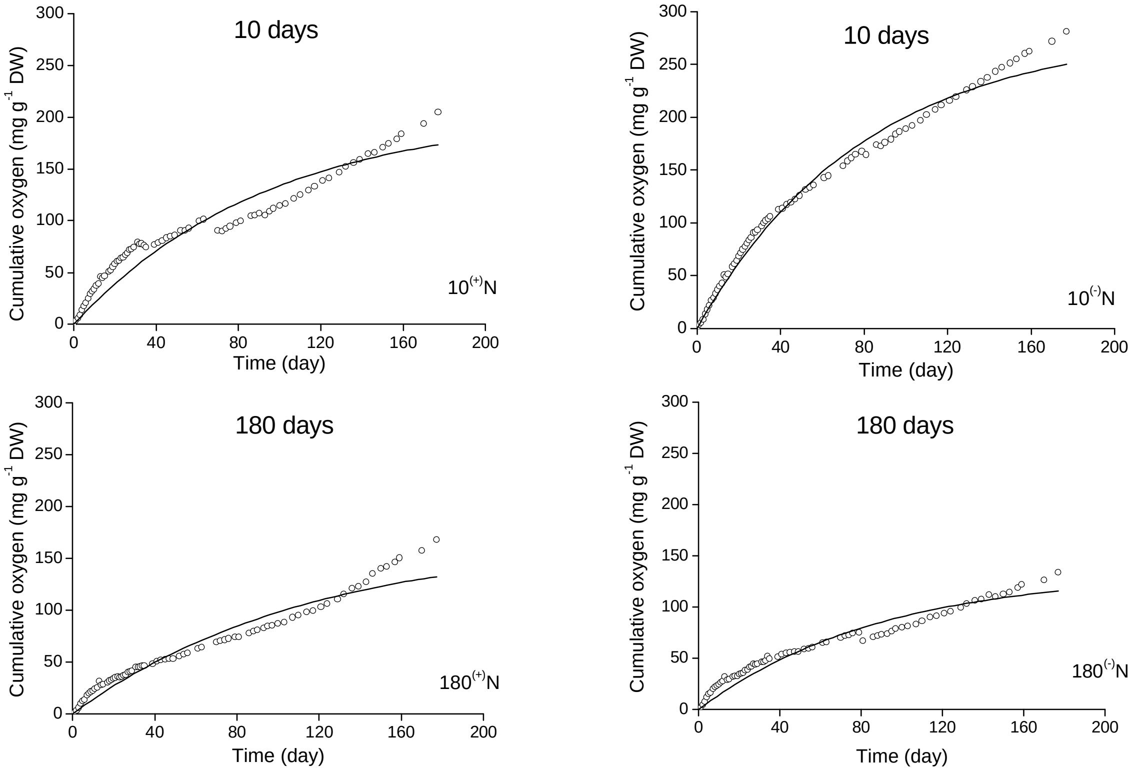

Figure 1: Oxygen consumption (without sediment addition) from aerobic mineralization of 10 and 180 days detritus from previous aerobic (+) and anaerobic (-) decomposition of Salvinia auriculata.

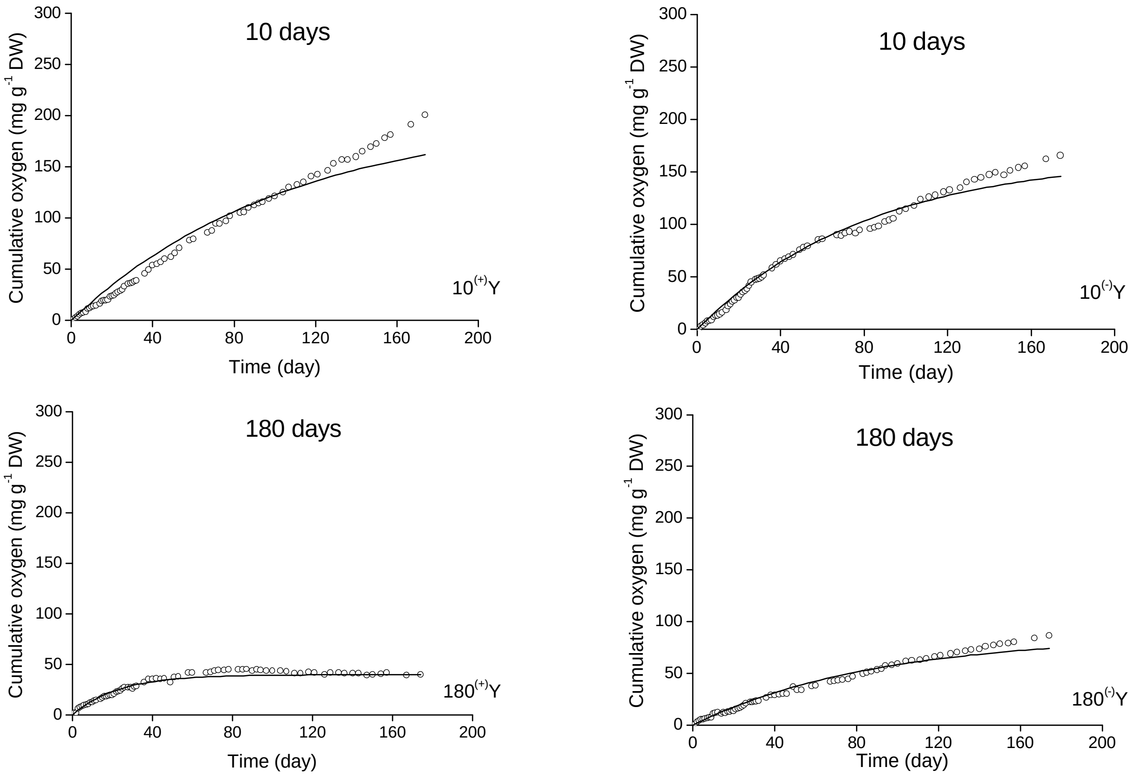

Figure 2: Oxygen consumption (with sediment addition) from aerobic mineralization of 10 and 180 days detritus from previous aerobic (+) and anaerobic (-) decomposition of Salvinia auriculata.

In general, the treatments without sediment presented higher CO_{max} values when compared to those treatments with sediment amended. The sediment added to the chambers presented 16 mg g^{-1} DW of total phosphorus, 23 mg g^{-1} DW of total nitrogen and 230 mg g^{-1} DW of organic content. The nutrient concentrations of lagoon water used in the incubations were: 566.7 mg L^{-1} of total nitrogen and 7.9 mg L^{-1} of total phosphorous.

The mineralization of 10 days detritus of all treatments presented higher values (mean: 213 mg g^{-1} DW) when compared to the 180 days detritus (mean: 107 mg g^{-1} DW). The determination coefficient values derived from the fittings varied from 0.90 to 0.98, indicating that the kinetic model used was robust.

Based on the kinetic fittings of the results of the mathematical model, it was possible to observe that the deoxygenation rate constants (k_D) (Tab. II) varied from 0.0088 day^{-1} ($180^{(+)}$N) to 0.0436 day^{-1} ($180^{(+)}$Y). With exception of $180^{(+)}$Y, that presented a k_D value with a different magnitude order, the other treatments presented similar k_D. Therefore the half-life varied from 55 to 79 days with exception of the $180^{(+)}$Y treatment that presented a half-life of 16 days.

Table I: Description of treatments based on addition of sediment, detritus age and previously decomposition.

Detritus age (day)	Previously decomposition	Sediment addition	Symbol
10	Aerobic	No	$10^{(+)}$N
180	Aerobic	No	$180^{(+)}$N
10	Anaerobic	No	$10^{(-)}$N
180	Anaerobic	No	$180^{(-)}$N
10	Aerobic	Yes	$10^{(+)}$Y
180	Aerobic	Yes	$180^{(+)}$Y
10	Anaerobic	Yes	$10^{(-)}$Y
180	Anaerobic	Yes	$180^{(-)}$Y

Table II: Parameterization of aerobic mineralization of Salvinia auriculata according to age of detritus and previously decomposition treatment.

Detritus age (day)	k_D (day^{-1})	Error	CO_{max} (mg g^{-1} DW)	r^2	$t_{1/2}$ (day)
			Without sediment addition		
$10^{(+)}$	0.0106	0.0003	204	0.90	65
$180^{(+)}$	0.0088	0.0002	168	0.94	79
$10^{(-)}$	0.0125	0.0002	281	0.98	55
$180^{(-)}$	0.0112	0.0003	134	0.94	62
			With sediment addition		
$10^{(+)}$	0.0094	0.0002	201	0.96	74
$180^{(+)}$	0.0436	0.0017	40	0.95	16
$10^{(-)}$	0.0122	0.0002	165	0.98	57
$180^{(-)}$	0.0113	0.0002	86	0.98	61

Discussion

According to the studies related with biogeochemical cycling in the aquatic systems (Asaeda, 2002; Entry, 2000; Wetzel, 1983; Nowlin, 2005), the refractory fraction of aquatic macrophytes detritus are mainly decomposed at the sediment surface, where changes in the availability of oxygen and nutrients can occur. According to the plant specie the decomposition can also occur at the water column. In this context, studies involving the effect of aquatic chemical variables at the decomposition are essential to describe the dynamic of the carbon cycle, in particular to the tropical oxbow lakes.

The results obtained in this study showed significant difference between detritus age; the younger detritus (10 days) values of CO_{max} were higher when compared with the older detritus (180 days) in all treatments. The younger detritus did not present a readily available hydrosoluble fraction such as observed in integral detritus mineralization that presented a labile fraction (Farjalla et al., 1999). In fact, many studies showed that 7 days is sufficient for the conclusion of leaching process (Otsuki & Wetzel, 1974; Fallon & Pfaender, 1976; Canhoto & Graça, 1996; Wrubleski et al., 1997; Pope et al., 1999; Brum & Esteves, 2001; Albariño & Balseiro, 2002; Schlickeisen et al., 2003). The non-previously degraded detritus tend to generate higher DO (dissolved oxygen) demand than the detritus submitted to previous decomposition (Sciessere et al., 2006). The 10 days old detritus showed an intermediate degradation fraction (e.g. waxes, pectin, oils); on the other hand, the 180 days old detritus was probably formed only by fibers (i.e. refractory compounds) such as lignin, cellulose and hemicelluloses, hence showing a slow degradation caused by the intricate structural complexity of these compounds and to the complex enzymatic pool required for their effective breakdown (Ahmed et al., 2001). A study on different age of rhizomes decomposition showed that for younger detritus (< 1 year old) the mass losses were enhanced twice than those with 1 to 4 years old rhizomes (Asaeda & Nam, 2002)

The decomposition coefficient of macrophytes are extremely dependent on their refractory fraction (Godshalk & Wetzel, 1978); however, in this experiment it was not possible to establish any deoxygenation coefficient tendency between detritus ages; the detritus under same treatment presented similar k_D values, except for $180^{(+)}$Y that presented a higher value (0.0436 day^{-1}) when compared with the other treatments. According to Bianchini Jr. (2003) the k_D from mineralization of labile fractions are higher than those of refractory fractions, the leaching and oxidation processes of labile fractions are faster than the mineralization of refractory fractions. However, in this study, other factors such as the condition of previous decomposition (i.e. aerobic or anaerobic) and the presence or absence of sediment must have influenced the k_D values.

We could observe that the detritus mineralized in the presence of sediment presented the lowest values of CO_{max}. Basically, the sediments of freshwater systems consist of four components: (i) organic matter in various stages of decomposition; (ii) particulate mineral matter; (iii) an inorganic component of biogenic origin and (iv) microorganisms; in some lakes the sediment may represent a more important source of nutrients than inputs from external sources (Wetzel, 1983; Nowlin et al., 2005). Due to the high organic matter content found on the sediment of Óleo lagoon and its nutrient addition (2,3% and 1,6% of N and P, respectively), it was expected a higher oxygen consumption in treatments with sediment, due to an increment of microorganism respiration rates caused by the increase of microorganism biomass, once freshwater sediments generally presented ca. three times more microorganisms when compared to the water column (Fischer & Pusch, 2001). The bacterial production, abundance, and cell size is also higher on the sediment community if compared with the pelagic and epiphyte bacterial community (Fischer & Pusch, 2001). In addition, the littoral zone covered with a well-developed macrophyte community may present a higher bacterial numbers in the sediment surface than in the profundal sediments from limnetic zones (Wetzel, 1983).

Del Giorgio & Cole (1998) developed the idea that catabolism and anabolism are not well coupled process and this disconnection could provides to bacteria the metabolic flexibility necessary to compete with the vicissitude of diverse environmental conditions. Thus, the low CO_{max} in treatments with sediment may have occurred by three reasons: (i) the microorganism community invested on catabolism (e.g. growing) instead of anabolism (e.g. respiration); (ii) the high number of microorganisms in treatments (enhanced by the sediment added) have generated competition in the bacterial community, leading to selection of species and consequently causing a lower respiration rate or (iii) and the most probably, is that the N addition by sediment suppressed the POM decomposition. A decrease in decomposition was also observed by Entry (2000) that found an inhibition of cellulose and lignin decomposition in black and redwater forest wetland soils enriched with N. Nitrogen addition to recalcitrant organic materials (such as lignin) showed low decomposition rates (Fogg, 1988). The NO_3 and NH_4 addition suppressed lignin degradation in a terrestrial decomposition and stimulated holocellulose decomposition on leaves (Osono & Takeda, 2001). In the present study, the nutrient addition by the presence of sediment did not necessarily increase the k_D; Villar et al. (2001) and Xie et al. (2004) affirmed that the addition of nutrients can, even inhibit those rates.

In the treatments with no sediment addition, the only source of organic matter and nutrients was the refractory detritus; in this way, the microorganism community probably opted for catabolism as suggested by Del Giorgio & Cole (1998). On the same way that the comparison among all detritus age, the presence or absence of sediment does not appear to influence the k_D.

Overall, the deoxygenation rate constants presented a difference between previously decomposed detritus under aerobic or anaerobic conditions; the early processed in anaerobic conditions presented higher deoxygenation rates when compared with aerobic detritus; except for $180^{(+)}$Y. This could be related with the cellulose system of anaerobic micro-organisms that is clearly different from aerobic fungi and bacteria (Pérez et al., 2002). Thus, those differences may have reflected on the previous disorganization of fibers (e.g. cellulose) facilitating the microbial attack on the aerobic decomposition in the present study and, as a consequence, led to higher k_D values.

According to the experimental procedures adopted, our results indicate that during aerobic decomposition within the upper layers of the sediment of Óleo Lagoon, the benthic oxygen demand is not necessarily increased by the presence of microorganisms and nutrients continuously liberated from sediment. The cycling rates of S. auriculata detritus are quite the same regardless of the presence of sediment, but younger detritus consumed more dissolved oxygen than older detritus.

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