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Oxygen availability and temperature as driving forces for decomposition of aquatic macrophytes

M.D. Passerini[a,*], M.B. Cunha-Santino[a,b], I. Bianchini Jr.[a,b]

[a] Programa de Pós-Graduação em Ecologia e Recursos Naturais, Universidade Federal de São Carlos, Rodovia Washington Luiz, km 235, Caixa Postal 676, 13565-905 São Carlos, SP, Brazil
[b] Departamento de Hidrobiologia, Universidade Federal de São Carlos, Rodovia Washington Luiz, km 235, Caixa Postal 676, 13565-905 São Carlos, SP, Brazil

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ABSTRACT

The decomposition of organic matter constitutes a fundamental ecosystem process where microorganisms, affected by temperature and oxygen availability, play a fundamental role. The decomposition rates interfere in the global carbon cycle and therefore, in the potential feedback to climate change. We addressed the individual and combined effects of water temperature (15, 20, 25 and 30 °C) and oxygen availability (aerobic and anaerobic) on the decomposition of three aquatic macrophytes (*Eichhornia azurea, Eleocharis* sp. and *Salvinia auriculata*) in microcosms carried out for 120 days. A first-order kinetic model was adopted to describe the kinetics of the decomposition. The decomposition had a biphasic pattern of mass loss: labile/soluble fraction (≈15.4; 10.6 and 10.7% for *E. azurea, Eleocharis* sp. and *S. auriculata*, respectively) and refractory (≈84.2; 89.4 and 89.0% for *E. azurea, Eleocharis* sp. and *S. auriculata*, respectively). Based on the decomposition kinetics, the leaching process was faster than the degradation of refractory compounds. Comparing the effect of temperature and the availability of dissolved oxygen, the latter seems more relevant for the decomposition process of these plants. Oxygen availability accelerated the decomposition 1.25 times compared to anoxic conditions, while a temperature increase of 10 °C accelerated it by 1.35 times. However, it is important to consider that these environmental variables act synergistically in the regulation of decomposition and therefore all of them influence the decomposition rates.

1. Introduction

Due to the high production of biomass expressed by effective rates of primary production, macrophytes play an important role in nutrient cycling and organic matter, as well as energy flow (Bonanomi et al., 2014), and may represent up to 50% of the total provision of organic matter and nutrients in aquatic ecosystems (Wetzel, 2001).

After death, the detritus of aquatic plants consists of (i) refractory organic matter (e.g., lignocellulosic fibers, which represent 50–80% of the dry biomass of aquatic plants) and (ii) a protoplasmatic and soluble fraction (e.g., sugars, amino acids) (Moorhead et al., 1996; Bianchini et al., 2014). Thus, during the decomposition, these plants initially release organic compounds and dissolved nutrients contained in their protoplasmatic fraction to the water column through leaching. Leaching of aquatic macrophytes can be a major route of dissolved organic matter (DOM) formation in several aquatic systems (Lapierre and Frenette, 2009). Extrinsic factors and heterotrophic microorganisms are not involved in this stage of decomposition, however the microbial community uses the DOM turning it into particulate material via the microbial loop (Azam et al., 1983).

The refractory particulate organic matter (POMr), which is more resistant to decomposition, tends to accumulate in the sediment (Wetzel, 2001). Thus, after the rapid loss of labile and soluble compounds through leaching, microbial communities usually slowly process the remaining compounds. The more advanced stages of decomposition of POMr is closely linked to microbial enzymatic hydrolysis (Vrba et al., 2004). This process is done by the action of ectoenzymes produced by microorganisms. Environmental variables such as temperature, pH and dissolved oxygen, as well as the chemical composition of macrophytes can influence the concentration and selection of these microorganisms, controlling decomposition rates.

The individual effects of water temperature and oxygen availability on decomposers and on organic matter decomposition have

* Corresponding author. Fax: +55 3351 8310.
E-mail address: mari_duo@yahoo.com.br (M.D. Passerini).

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been frequently studied. Both water temperature and oxygen availability are important factors influencing litter decomposition, but the interactions of these factors in regulating mass loss and carbon dynamics, although developed in some studies (Liikanen et al., 2002; Kim et al., 2015), has not yet been elucidated, specially on the decomposition of aquatic macrophytes in a tropical ecosystem.

Owing to the significant carbon stocks accumulated in the soil and sediment of fresh water environments, the increase in the decomposition rate can interfere in the global carbon cycle and therefore, in potential feedback to climate changes (Bottino et al., 2013). Considering this scenario and understanding that the decomposition rate of the POMr of the macrophytes in shallow tropical ecosystems are influenced by several factors, the main objective of this study was to evaluate the combined effect of temperature and oxygen availability and its individual contribution for the degradation of aquatic plants in a tropical ecosystems. We consider both factors relevant for decomposition rates, which affect the global carbon cycle and therefore, represent a potential feedback to climate change. In this context, we evaluated the decomposition of three aquatic macrophytes of different growth forms, *Eichhornia azurea* (Swartz) Kunth (1843) (fixed floating), *Eleocharis* sp. (emergent) and *Salvinia auriculata* Aubl. (1775) (free-floating) in order to estimate the dynamics of mass loss processes in aerobic and anaerobic conditions and variable temperature as driving forces.

2. Material and methods

2.1. Study area

Beija-Flor Reservoir is located inside the Jatai Ecological Station (J.E.S.) (21°33′and 21°37′ S; 47°45′and 47°51′ W), São Paulo State—Brazil, and it was formed in 1965 by damming the Beija-Flor Stream (tributary of the Mogi-Guaçu River, located on the Paraná sedimentary Basin). The reservoir is shallow, with 1.8 m of average depth, and has an area of 17.54 ha (Pires et al., 2000). According to Köppen (1923), the regionís climate is Aw (tropical savanna), a climate characterized by strong seasonality of rainfall and stability of the average daily temperature. The altitude of J.E.S. varies from 515 to 835 m asl. The community of aquatic macrophytes in the littoral zone of the reservoir is composed of several species (i.e., *Pontederia* sp., *Eleocharis* sp., *E. azurea, S. auriculata, Nymphaea* sp., *Cabomba* sp. and *Utricularia* sp.). During 2011, dissolved oxygen concentration and temperature were measured in the reservoir, both at the surface and the bottom and at three points (multiple probe YSI – 556 MPS – Yellow Spring). Dissolved oxygen concentrations were higher from June to August and in January, reaching average values of 7.76 and 6.87 mgL^{-1} at the surface, and were similar at the bottom. The lowest dissolved oxygen concentrations were observed from February to April, ranging from 4.5 to 5.4 mgL^{-1} on the surface and 2.96 to 4.3 mgL^{-1} near the bottom. For water temperature, February and March were the months with the highest values, 27.81 and 27.7 °C respectively. June and July were the months with the lowest temperatures, reaching 17.33 and 18.83 °C respectively.

2.2. Sampling procedures and analyses

The water samples were collected in the subsurface layer (≈10 cm) and near the sediment (about 15 cm) of the reservoir using a Van Dorn bottle (vol = 5 L) and these samples were mixed. The water sample in the bottom layer was collected according to the depth of each sampling point ($n = 3$). This procedure ensures an integrate and homogeneous chemical and microbiological water sample considering the entire water column, once according to Tundisi et al. (2010), the composition in the surface and in the bottom of the water column vary both, biotic and abiotic variables. In the laboratory, the water samples were filtered through cellulose ester membranes (pore = 0.45 μm—Millipore) to remove remaining suspended particles.

Mature individuals of *Eleocharis* sp., *S. auriculata* and *E. azurea* were collected manually and randomly in different regions of the reservoir and at different times. After collection, macrophytes were washed in running water in order to remove adhered material (e.g., inorganic material, small organisms, biofilm). The macrophytes were dried at 50 °C until constant mass. This methodology was adopted to ensure the same initial plant mass for all incubations, as well as the data precision for kinetic fittings.

The initial carbon content of the macrophyte fragments was determined by the combustion method (SSM – 5000A – Shimadzu). The carbon content was considered to be constant. The incubations were prepared with ca. 10 g (dry mass basis) of plant fragments and 1 L of reservoir water previously filtered. A microbial inoculum containing sediment and unfiltered water from the reservoir was prepared (200 mg sediment in 1 L of reservoir water). 10 mL of the inoculum was added to each incubation chamber to include the original microbial community composition. The incubations were maintained in the dark under controled temperatures: 15 °C (±1.2), 20 °C (±1.5), 25 °C (±0.5) and 30 °C (±0.5). The temperatures were defined according to in situ measures. For each temperature, 40 incubations were prepared: 20 under aerobic conditions (maintained by continuous bubbling with filtered air) and 20 under anaerobic conditions (these bottles were only opened in the respective sampling days, preventing any gaseous exchange with the external environment). In order to estimate the time required for the occurrence of the anaerobic condition in the incubations, the following data were used: (i) the dissolved oxygen saturation concentration at each temperature and the local atmospheric pressure (i.e., [DO] sat = 9.10, 8.21, 7.46 and 6.83 $mg\,L^{-1}$ at 15, 20, 25 and 30 °C, respectively, altitude: 850 m); (ii) the maximum oxygen consumption (OCmax) and the deoxygenation rate constants due to aerobic decomposition of macrophytes (i.e., OCmax *E. azurea* = 206 mg O g^{-1} dry mass and kd = 0.045 day^{-1}; OCmax *Eleocharis* sp. = 292 mg O g^{-1} dry mass and kd = 0.027 day^{-1}; OCmax *S. auriculata* = 244 mg O g^{-1} dry mass and kd = 0.040 day^{-1} (Bianchini et al., 2011). Based on these data, it was possible to calculate that anaerobiosis in incubations was established between ca. 1 h and 40 min. and 2 h and 40 min. after adding the plant.

Every sampling day (day 1, 3, 5, 10, 15, 20, 30, 60, 90 and 120), the content of two chambers of each macrophyte species in each temperature was pre-fractionated into dissolved and particulate fractions through a nylon mesh (pore = 400 μm) and then filtered on cellulose ester membranes (pore = 0.45 μm—Millipore) to remove remaining suspended particles. The particulate fraction was dried at 50 °C until constant weight, and its final mass was determined by gravimetry. In the dissolved fraction, the following was determined: (i) pH values using the potentiometric method (Qualxtron, model 8010); and (ii) electrical conductivity (EC) values using the potentiometric method (Digimed, model DM3).

2.3. Statistical analyses

The temporal variations of the remaining POC were adjusted to a biphasic decay model (Eq. (1)); (Jenkinson, 1977) using the iterative algorithm Levemberg–Marquardt (Press et al., 1993):

$$POC = POCls \times e^{-kls \times t} + POCr \times e^{-kr \times t} \quad (1)$$

where POCls = initial content of labile/soluble particulate organic carbon (%); POCr = initial content of particulate organic carbon refractory (%); kls = $k_1 + k_2$; the coefficient of overall mass loss (= coefficient of mineralisation labile (k_1) + coefficient of leached soluble (k_2) (day^{-1})), kr = decomposition coefficient of refractory mass; t = time (day).