Ecological Modelling 222 (2011) 1263–1271

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Model parameterization for aerobic decomposition of plant resources drowned during man-made lakes formation

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ARTICLE INFO

Article history:
Received 30 May 2010
Received in revised form 21 January 2011
Accepted 30 January 2011
Available online 19 February 2011

Keywords:
First order kinetic model
Plant detritus
Particulate and dissolved organic carbon
Oxygen budget
Artificial reservoir

ABSTRACT

The formation of man-made reservoirs generates several impacts on water quality. In order to minimize some of these impacts mathematical models are currently used. This paper aims to discuss the issue associated with the degradation of plant resources (leaves, branches, barks and litter) that remain within the watershed of the new man-made lakes and parameterize a kinetic model related to decay of plant detritus. In these environments, the short-term variation of limnological parameters is mainly connected with biomass decay drowned during the filling operation. The kinetics of the degradation processes in reservoirs are discussed on the basis of information with related to detritus sources and the chemical properties of different types of compounds (i.e. labile and refractory fractions). Overall, the parameterization of the (first order) kinetic model showed that refractory fractions (ca. 86%) are predominant and the mineralization is a slow process, constituting the main route for decomposition and being affected by changes of environmental variables. The mineralization of labile and hydrosoluble compounds (ca. 14%) is responsible for the short-term water quality variation owing to decomposition; basically, the intensities of these changes depend on the labile/soluble compounds content of detritus and its chemical composition.

1. Introduction

Previous knowledge in constructions of reservoirs in areas covered by plants indicated that depending on the amount of biomass existent in the watersheds, the vegetation biomass drowned is a significant source of detritus; thus, adequate removal of biomass before filling the basin became one of the main environmental issues related to the formation of man-made lakes (Goodland, 1986). The decay of this detritus may cause considerable changes in the water quality, including favorable conditions for the fast development of anaerobiosis and eutrophication processes in the reservoir (Baxter and Glaude, 1980; Garzon, 1984; Ploskey, 1985; Pereira et al., 1994). The degree of eutrophication and oxygen depletion presented a temporal variation since the decay of flooded biomass (i.e. particulate – POM and dissolved organic matter – DOM) exhibit different rates. The detritus accumulating in the sediments contain mostly cellulose and lignin (Cunha-Santino and Bianchini, 2006). This may endanger the long-term health of the aquatic ecosystem, and also the water multipurpose uses and the power generation equipment (Tundisi and Matsumura-Tundisi, 2003). Due to the origin of these detritus sources, knowledge about specific stages of decomposition associated with the physical, chemical and biological processes involved are scarce in the literature.

The application of engineering techniques to the study of systems with complex interrelations implies a close cooperation between limnologists and engineers in the use of mathematical language (Straškraba, 1973; Tundisi, 1990). Previously to the reservoirs formation, the mathematical models are employed in the prospective studies that aim to measure the amounts of biomass (i.e. leaves, branches, barks and litter) that should to be removed. Basically, the deforestations of the reservoirs basins assist the legislation in order to establish the multipurpose use of the new reservoir, and also to minimize the changes of the environmental conditions to preserve the biodiversity. In addition, the simulations allow the evaluation of the financial deforestation costs in function of the project needs. An early model developed by Therien and Spiller (1981) was very adequately structured; although this model required many data that are not always available to the environmental studies related to engineering projects. More recently a simpler kinetic model was proposed, it was created

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doi:10.1016/j.ecolmodel.2011.01.019

based on results from specific experiments that simulated (under controlled conditions) the decomposition of the resources (i.e. leaves, branches, barks and litter) usually found in the watersheds (Bianchini, 1997).

The rate of decomposition depends on the environmental conditions (e.g. nutrient concentration, temperature, pH, oxi-reduction potential; Jørgensen, 1994; López et al., 1998; Mendelssohn et al., 1999; Straškraba, 1999a; López-Archilla et al., 2001; Corstanje et al., 2006; Cunha-Santino and Bianchini, 2008), the heterotrophic activity of organisms and the quality and amount of plant resources (i.e. chemical composition); Swift et al. (1979). Usually, the kinetics of decomposition is correlated with the disappearance of the substratum and the appearance of products. When the processes occur in aerobic conditions, it is further assumed that the oxygen uptake varies linearly with the formation of products such as carbon dioxide (Stumm and Morgan, 1981; Jørgensen, 1994). It is also frequently assumed that the aerobic decomposition is faster (Wetzel, 2001). Experiments related to aerobic mineralization of several types of detritus indicated that the oxygen uptake kinetics reflected qualitative aspects of debris (Bitar and Bianchini, 2002; Bianchini et al., 2006) in addition to variation in the stoichiometric values from decomposition processes (Cunha-Santino, 2003; Peret and Bianchini, 2004). The stoichiometric relation determines the extension of the biochemical transformations of organic matter (Brezonik, 1994), presenting quantitative information about reagents consumption and products formation (Characklis, 1990). Considering the importance of the decomposition of drowned leaves, branches, barks and litter to the water quality (i.e. the effects on chemical, biological and physical water characteristics) in a new reservoir and also for the understanding of the budget of greenhouse gases emissions from reservoirs, this study aimed to discuss and parameterize equations used to describe aerobic decomposition processes and also establish connections between the environmental variables and the parameters of decomposition model.

2. Materials and methods

2.1. Sampling procedures and experimental design of decomposition kinetics experiments

Samples of water were collected in the Ribeira de Iguape River (22J 698.581 UTM 7.272.182) and plant resources (leaves, branches, barks and litter) were obtained in their watershed at municipal district of Adrianópolis, Paraná State, Brazil. In laboratory, these resources were washed with tap water to remove the adhered coarse material. After being washed the plant material was oven-dried (40 °C) and cut; the fragments (size ca. 1.5 cm) of leaves, branches (diameter < 1.0 cm), barks and litter were homogenized. The carbon contents of particulate resources were quantified using a Carlo Erba Model EA1108 Elemental Analyzer. In the laboratory 68 decomposition chambers were prepared and were incubated under aerobic conditions with continuous filtered air bubbling. In each chamber 4.0 g (on dry weight basis; DW) of plant fragments were added to 400.0 mL of river water (pH = 8.09; dissolved oxygen = 9.50 mg L^{-1}; total carbon = 3.26 mg L^{-1}; total phosphorus = 66.6 μg L^{-1}; NO_3^- = 55.6 μg L^{-1}; NH_4^+ = 12.6 μg L^{-1}) that was previously filtered (pore size membrane = 0.45 μm, Millipore). The chambers were maintained in the dark at 25.4 ± 1.0 °C (n = 16).

Periodically (0.5, 0.98, 1.83, 2.83, 4, 5, 6, 8, 9, 15, 20, 30, 45 and 60th day), the material of chambers with each resource was fractionated into particulate organic matter (POM) and dissolved (DOM) by pre-filtration and centrifugation (1 h; 978 × g). POM samples were oven-dried (45 °C) until constant weight, and their final masses were determined by gravimetric method. The carbon contents of particulate detritus (POC) were quantified by Elemental Analyzer (EA 1108) and the dissolved organic carbon (DOC) concentrations were measured by controlled combustion (TOC Analyzer Shimadzu model 5000A). The total inorganic carbon (TIC) derived from organic matter mineralization was calculated by the difference between their initial contents in the resources (leaves, branches, barks and litter) and the remaining organic carbon determined on the sampling days (POC + DOC).

2.2. Sampling procedures and experimental design of oxygen consumption experiments

Decomposition chambers (n = 21) were prepared to monitor the oxygen consumption inherent in the aerobic decomposition processes. These incubations were prepared by the addition of plant resources fragments in samples of water. As substrate there were selected branches from 3 distinct sites: (i) Salto Iporanga Reservoir (age of 16 years; 23J 0223.331 UTM 7.332.089); (ii) Piraju Reservoir (age of 3.7 years; 22K 0665.839 UTM 7.438.694); (iii) Atlantic Rain Forest (23S 0743.015 UTM 7.523.814). The branches derived from reservoirs were located in the aerial parts of semi-submersed remaining logs. The branches of the forest were collected directly on the trees. All the samples of branches presented a diameter <1.0 cm. In addition, in the forest were collected samples of tree leaves and litter. The water samples were collected from Salto Iporanga and Piraju reservoirs and to the incubations with forest materials (branches, leaves and litter) the water samples were prepared from previously filtered (pore size membrane: 0.45 μm Millipore) aqueous soil extract. To remove the background DO consumption (i.e. blank corrected), for each type of incubation 2 blank bottles (with only water sample) were prepared.

In order to measure the oxygen uptake in aerobic mineralization, the resources fragments (average initial masses: 312–892 mg L^{-1} DW) was placed in triplicate in acid-washed 1-L flasks with samples of water, according to the experimental procedures proposed by Bianchini et al. (2006). The incubations were maintained under aerobic conditions in the dark at 20.0 ± 0.5 °C (n = 28). To maintain the solutions under aerobic conditions, they were oxygenated (in the initial of experiment) during 1 h, to keep dissolved oxygen near saturation. After oxygenation, the dissolved oxygen (DO) was measured with a DOmeter (Yellow Spring Instruments model 58). During sampling days whenever the DO concentrations reached 2.0 mg L^{-1}, the solutions were oxygenated again; this procedure was adopted to ensure aerobic condition. The oxygen consumption was estimated during 50 (forest resources) to 159 (branches from reservoirs) days.

2.3. Decomposition kinetics of the detritus

Due to detritus heterogeneity (i.e. chemical composition), the biomass decomposition can be represented as a sum of several exponential functions, according to the model proposed by Lousier and Parkinson (1976) about litter decay. Eqs. (1)–(6) describe the mineralization processes, where the chemical heterogeneity of the detritus is considered. In this 1st order kinetic model the mineralization is assumed to occur thought three pathways (Bianchini, 1997). In the first, the labile compounds are oxidized quickly, simultaneously to leaching. The second way comprises the consecutive processes of leaching and catabolism of the dissolved fractions of organic carbon (DOC). In the third route, the oxidation of the refractory particulate organic carbon (RPOC) is responsible for the mass loss.