Journal of Environmental Management 165 (2016) 31–52

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Modeling phytoplankton community in reservoirs. A comparison between taxonomic and functional groups-based models

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ARTICLE INFO

Article history:
Received 6 August 2014
Received in revised form
21 July 2015
Accepted 20 August 2015
Available online 23 September 2015

Keywords:
Phytoplankton community
Dynamic parameter estimation
Water quality mathematical model
Phytoplankton functional groups

ABSTRACT

In this paper we address the formulation of two mechanistic water quality models that differ in the way the phytoplankton community is described. We carry out parameter estimation subject to differential-algebraic constraints and validation for each model and comparison between models performance. The first approach aggregates phytoplankton species based on their phylogenetic characteristics (Taxonomic group model) and the second one, on their morpho-functional properties following Reynolds' classification (Functional group model). The latter approach takes into account tolerance and sensitivity to environmental conditions. The constrained parameter estimation problems are formulated within an equation oriented framework, with a maximum likelihood objective function. The study site is Paso de las Piedras Reservoir (Argentina), which supplies water for consumption for 450,000 population. Numerical results show that phytoplankton morpho-functional groups more closely represent each species growth requirements within the group. Each model performance is quantitatively assessed by three diagnostic measures. Parameter estimation results for seasonal dynamics of the phytoplankton community and main biogeochemical variables for a one-year time horizon are presented and compared for both models, showing the functional group model enhanced performance. Finally, we explore increasing nutrient loading scenarios and predict their effect on phytoplankton dynamics throughout a one-year time horizon.

1. Introduction

Ecological and environmental factors continuously interact so that the planktonic habitat never reaches the equilibrium for which only one species would be favored (Scheffer et al., 2003; Wyatt, 2013). External factors such as fluctuations in the environment, periodic forcing and spatial heterogeneity, as well as self-organizing mechanisms seem to be the cause of non-equilibrium dynamics allowing coexistence of many species (Roy and Chattopadhyay, 2007). Grime (1979) explained the co-existence of phytoplankton species through the CSR (Competitor-Stress tolerator-Ruderals) theory. This theory is based on the idea that spatial and temporal environmental heterogeneity creates a complex mosaic of microhabitats allowing a broad suite of strategies to co-exist. In aquatic ecosystems, such as lakes and reservoirs, phytoplankton communities are highly diverse and hundreds of phytoplankton species coexist. However, a usual approach in lake models is to represent phytoplankton biomass through a single variable that describes the major seasonal pattern of total phytoplankton (Hongping and Yong, 2003; Zhang et al., 2004; Ito et al., 2010; del Barrio Fernandez et al., 2012). Also, the use of taxonomic criteria to assign plankton species to a group that, in turn, is included as an output variable has been widely applied in lake modeling (e.g. Riley and Stefan, 1988; Sagehashi et al., 2000; Bowen and Hieronymus, 2003; Romero et al., 2004; Arhonditsis and Brett, 2005a; Mooij et al., 2007; Rigosi et al., 2011). Some authors model blooming species of cyanobacteria such as *Oscillatoria agardhii* (Montealegre et al., 1995), *Planktothrix rubescens* (Omlin et al., 2001a) and *Microcystis aeruginosa* (Bonnet and Poulin, 2002)

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http://dx.doi.org/10.1016/j.jenvman.2015.08.027

separately from the rest of the phytoplankton community. On the other hand, a few authors have proposed phytoplankton classification based on different properties (Reynolds et al., 2002; Friedrichs et al., 2007; Salmaso and Padisák, 2007; Mieleitner and Reichert, 2008; Kruk et al., 2010; Segura et al., 2013). Reynolds' approach (Reynolds et al., 2002; Padisak et al., 2009) aggregates phytoplankton species into 38 functional groups based on their morphology, survival strategies and environmental tolerance and sensitivity. This classification has been recently applied to a wide range of aquatic environments such as deep lakes (Salmaso and Padisak, 2007), temperate lakes (Huszar and Caraco, 1998), eutrophic lakes (Padisák and Reynolds, 1998; Fonseca and Bicudo, 2008) tropical coastal lagoons (Alves-de-Souza et al., 2006) and marine environments (Alves-de-Souza et al., 2008; Smayda and Reynolds, 2001, 2003). Kruk et al. (2011) studied 211 lakes worldwide ranging from subpolar to tropical regions, concluding that phytoplankton biomass can be better predicted from environmental variables using the morpho-functional classification than considering the taxonomic group classification.

In this work, we formulate two mechanistic water quality models, whose main difference is the representation of phytoplankton community. The first model aggregates phytoplankton species based on their taxonomic characteristics and the second one, on their morpho-functional properties following Reynolds' classification. We carry out parameter estimation subject to differential algebraic constraints and validation for both models, using collected data from Paso de las Piedras Reservoir (Argentina), along one year and a half. Finally, we compare both models performance and discuss the convenience of including additional complexity in phytoplankton community representation. This paper is structured as follows: Section 2 provides a brief description of the study site and sampling methods for data used in model calibration and validation; Section 3 describes both water quality models and the methodology for solving the parameter estimation problem, as well as statistical tests of model performance. Section 4 presents numerical results and discussion. Finally; Section 5 presents conclusions and future work.

2. Material and methods

2.1. Case study

Paso de las Piedras Reservoir is located in the south of Buenos Aires Province, in Argentina (38–39°S, 61–62°W) (Fig. 1). This artificial water body was built in 1978 by damming Sauce Grande River in its confluence with El Divisorio Stream, to supply drinking water to more than 450,000 inhabitants of two cities and for industrial activities at a petrochemical complex nearby. The reservoir has a surface area of 36 km^2, with a mean depth of 8.2 m and a retention time of 4 years. It is a non-stratified lake, mainly due to wind effects (intense and constant essentially in spring and summer), low topology of the surrounding area and the large retention time (Intartaglia and Sala, 1989). Furthermore, the reservoir is eutrophic-hypereutrophic as result of high nutrient loading from several diffuse sources (Fernandez et al., 2009). Climatic factors, as well as nutrient concentration, give rise to recurrent phytoplankton blooms during summer and early autumn (Intartaglia and Sala, 1989; Parodi et al., 2004; Fernandez et al., 2009) which cause severe problems in water supply.

2.2. Sampling

Sample collection was carried out between January and December 2004. Four sampling sites were considered: S_1 (in the water intake tower of the purifying plant), S_3 (next to El Divisorio Creek), S_2 and S_4 in coastal zones (Fig. 1). Samples were taken at two depths (0.5 and 10 m).

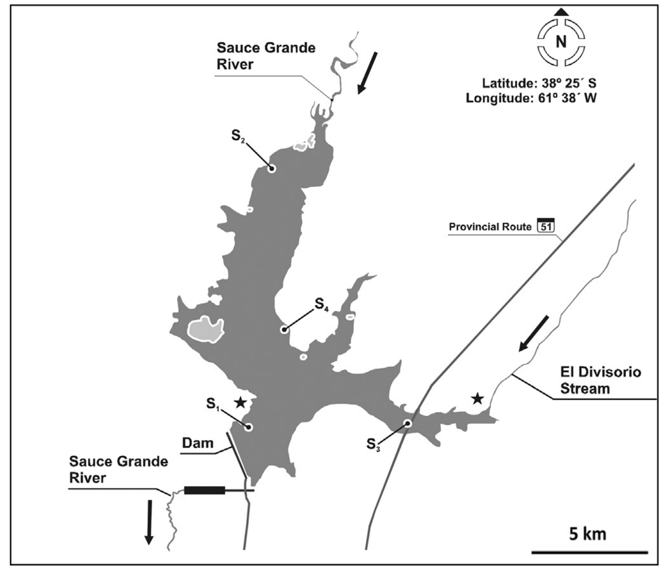

Fig. 1. Paso de las Piedras Reservoir. S_1, S_2, S_3 and S_4: sampling stations and (★) meteorological station.

When working with dynamic systems, it is necessary to take into account the variable with fastest time response to determine if the sampling frequency is adequate to represent the dynamics of the system (Jørgensen et al., 1981; Hangos and Cameron, 2001). Fig. 2 shows cyanobacteria dynamics as obtained with a monthly frequency (mid-month) and a twice a week frequency, respectively. As it can be seen, in winter cyanobacteria concentration variability is low, so the sampling frequency can be lower, while during the warm periods it can be underestimated. Based on these considerations, biological variables, temperature and dissolved oxygen were sampled twice a week; while nutrients were sampled once a week. Samples for qualitative analysis were taken with a 30-µm-mesh plankton net and a van Dorn bottle. Some samples were not fixed, while others were fixed immediately with 4% formaldehyde. Samples for quantitative analyses were collected with a van Dorn bottle and fixed immediately with Lugol's solution.

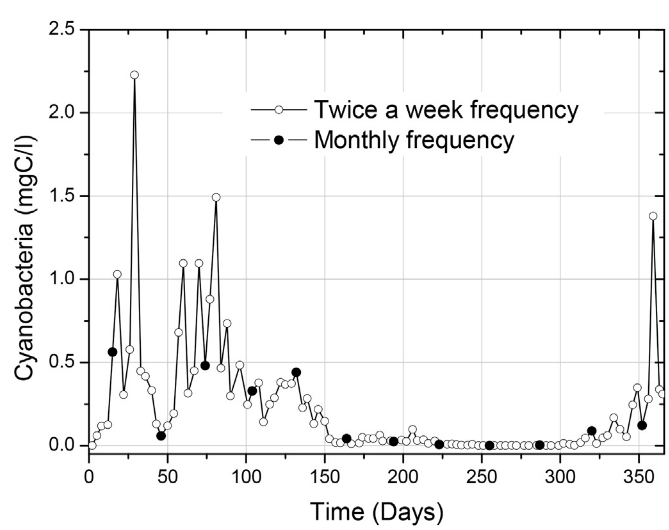

Fig. 2. Cyanobacteria biomass concentration vs. time for two sampling frequencies.