Ecological Engineering 81 (2015) 123–132

Contents lists available at ScienceDirect

Ecological Engineering

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

Modelling the role of epiphyton and water level for submerged macrophyte development with a modified submerged aquatic vegetation model in a shallow reservoir in China

Chen Zhang [a,*], Xueping Gao [a], Liyi Wang [b], Xiaojun Chen [b]

[a] State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China
[b] Yuqiao Reservoir Administrative Bureau of Luan River-Tianjin Water Diversion Project, Tianjin 301900, China

ARTICLE INFO

Article history:
Received 22 August 2014
Received in revised form 19 January 2015
Accepted 5 April 2015
Available online 11 April 2015

Keywords:
Submerged macrophytes
Modified SAVM
Light attenuation
Epiphyton
Water-level fluctuations
Yuqiao Reservoir

ABSTRACT

Light intensity plays an important role in determining the distribution of submerged macrophyte. A modified SAVM (M-SAVM) was constructed to simulate the role of epiphyton and water level for the biomass and distribution of *Potamogeton crispus* in the Yuqiao Reservoir in China. M-SAVM is developed by modification of the light attenuation equation, which is determined by the water transparency (Secchi depth) and epiphyton. The model was calibrated and verified by biomass using two datasets, from the seedling establishment until dying out, in 2008 and 2009. Five hydraulic scenarios were simulated by M-SAVM to analyze the relationship between biomass and water depth. Results showed that epiphyton increase had a slightly low light intensity limitation coefficient to suppress plant growth in M-SAVM. Significant negative correlation ($p < 0.01$, $r = -0.97$) between biomass and water depth existed in the reservoir. The biomass increases under low water levels due to increasing underwater light intensity and decreases when the water level is raised. M-SAVM could be a useful tool for submerged macrophyte management in the reservoir and for maintaining intermediate vegetation biomass by fluctuating water level strategies in shallow lakes.

1. Introduction

Shallow lakes have been the subject of intensive research on eutrophication and extensive efforts to limit phytoplankton production. They are typically in one of two self-stabilizing equilibrium states: a 'clear' state with submerged macrophytes or a 'turbid' state dominated by phytoplankton (Scheffer et al., 1993b; Janse et al., 2008, 2010). Submerged macrophyte and phytoplankton components of eutrophic, shallow lakes frequently undergo dynamic changes in composition and abundance with important consequences for lake functioning and stability (Sayer et al., 2010; Spoljar et al., 2012). Eutrophication is likely a major cause of reductions in submerged macrophyte (Jeppesen et al., 1997; Boesch et al., 2001).

Aquatic vegetation sometimes plays a significant role in the ecological functioning of lake ecosystems. Submerged macrophyte is considered an important tool for lake restoration. Previous studies suggest that nutrient levels are generally lower in submerged macrophyte dominated waterbodies (e.g., Li et al., 2007; Kosten et al., 2009; Moreno, 2011). Watershed-derived nutrient loading has also caused an increase in algal biomass and a degradation and loss of macrophyte habitat. Examples are the soft water lakes of northern Europe e.g., Lake Ladoga, Russia (Murphy, 2002) as well as the estuarine system e.g., Chesapeake Bay USA (Boesch et al., 2001) and Waquoit Bay USA (Deegan et al., 2002).

In general, the main benefit of abundant submerged macrophytes is that vegetation seems to be the obvious solution to restore shallow lakes by phosphorus and nitrogen removal. The submerged macrophyte dominated lake and river systems in Florida (Knight et al., 2003; Dierberg et al., 2005), Lake Chiemsee and Lake Starnberg in Germany (Melzer, 1999), and freshwater wetland of the Upper Cooper River Estuary in South Carolina (McKellar et al., 2007) are some examples. Furthermore, submerged macrophytes of lakes are valuable as fisheries economically and for recreational tourism. Enhanced submerged macrophytes under management strategies would increase fishery production (Ma et al., 2010). Restoration work, such as reinforcing the lakes' shoreline vegetation, has been achieved in shallow Dutch lakes (Gulati and Van Donk, 2002).

However, dense beds of aquatic macrophytes are often a nuisance to boaters and swimmers and may obstruct water flow

* Corresponding author. Tel.: +86 22 27404178; fax: +86 22 27890287.
E-mail addresses: emil@tju.edu.cn (C. Zhang), xpgao@tju.edu.cn (X. Gao), liyi_wang@sohu.com (L. Wang), xjchen2004@126.com (X. Chen).

http://dx.doi.org/10.1016/j.ecoleng.2015.04.048

(Van Nes et al., 1999; Wang et al., 2006). Rooted submerged macrophytes can be a nuisance for surface water systems, affecting the channel hydraulics by restricting the conveyance volume, they also affect the water quality by plant cycling of nutrients and inorganic carbon and the impacts of biomass after sloughing (Berger and Wells, 2008). Therefore, aiming for an intermediate level of vegetation biomass seems to be a good initial solution for this controversy.

Submerged macrophyte growth is limited by light, temperature, nutrients, and other factors such as salinity and self-shading. Epiphyton also plays an important role in submerged macrophyte development. In previous research, the relationships among the nutrients, submerged macrophytes, epiphyton, phytoplankton, and grazing invertebrates were studied in shallow lakes (Phillips et al., 1978; Brönmark & Weisner 1992; Jones et al., 1998, 2002; Jones and Sayer, 2003; Beresford and Jones, 2010). Increased epiphyton loads are detrimental to the plant growth through competition for light and carbon dioxide (Sand-Jensen, 1977; Jones et al., 2002).

Light intensity is identified as a primary controlling factor for submerged macrophyte growth. The deeper into water that the light can penetrate, the deeper the depths at which photosynthesis can occur. Depths depend on water-level fluctuations (WLFs) may strongly affect light available for submerged macrophyte in shallow lakes. Managed WLFs have become an important and useful tool for lake management in European lakes since the end of the last century (e.g., Ter Heerdt and Drost, 1994; Coops and Hosper, 2002; Naselli-Flores and Barone, 2005; Hilt et al., 2006; Leira and Cantonati, 2008; Paillisson and Marion, 2011). WLFs may have a strong impact on sediment and nutrient fluxes in shallow lakes, mainly through the development of vegetation covering both the shorelines and the lake bottoms (Coops and Hosper, 2002). Consequently, understanding the role of WLFs in ecosystem functioning has become even more crucial e.g., temporal and spatial scales, biotic responses, regional differences, influence of climate and climate change (Coops et al., 2003).

For almost 30 years, mathematical models have guided management efforts to reduce eutrophication in waterbodies. Many eutrophication models are well-established e.g., CE-QUAL-W2 (Cole and Buchak, 1995; Berger and Wells, 2008), CE-QUAL-ICM (Cerco and Cole, 1993, 1994), EFDC (Hamrick, 1992), WASP (Wool et al., 2002), and MIKE 3 (DHI, 2001). Complex ecosystem models with a macrophyte component have already been developed, such as Megaplant (Scheffer et al., 1993a), SAGA (Hootsmans, 1994, 1999), PCLake (Janse, 1997, 2005; Janse et al., 2008, 2010), SAVM (Cerco and Moore, 2001; Cerco et al., 2002; Jin et al., 2007; Jin and Ji, 2013), and Charisma (Van Nes et al., 2002, 2003). All of these models have light attenuation equations available; nevertheless, the empirical coefficient (background light attenuation coefficient) plays a critical role in the equations. Thus, the light attenuation equation is tried to modify, which is determined by the water transparency and epiphyton – a modified SAVM (M-SAVM).

The objectives of this paper are: (1) to utilize M-SAVM to analyze the role of epiphyton for light attenuation and submerged macrophyte development in the Yuqiao Reservoir, (2) to illustrate the quantitative relationship between biomass and water depth. This study would provide information for the management of submerged macrophytes in a shallow reservoir or a shallow lake using hydraulic control strategies.

2. Material and methods

2.1. Study area

The Yuqiao Reservoir (Fig. 1) is located in Tianjin, China, and has been the only water supply source in Tianjin since 1983. This shallow reservoir (Z_{max} 12.16 m, Z_{mean} 4.74 m) has a watershed area of 2060 km^2, storage capacity of 0.385 billion m^3 and surface area

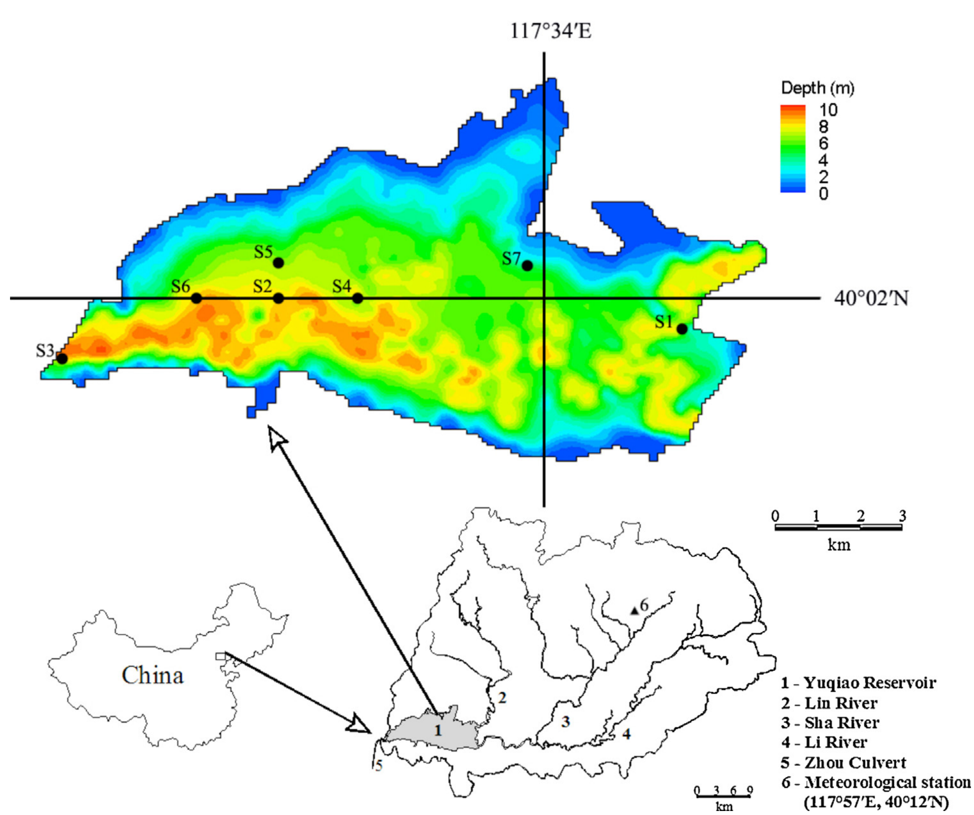

Fig. 1. Yuqiao Reservoir (117°34′E, 40°02′N) watershed and the monitoring stations (Stations S1–S7).