Ecological Engineering 96 (2016) 214–223

Contents lists available at ScienceDirect

Ecological Engineering

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

Construction and application of an aquatic ecological model for an emergent-macrophyte-dominated wetland: A case of Hanshiqiao wetland

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ARTICLE INFO

Article history:
Received 30 April 2015
Received in revised form
14 December 2015
Accepted 18 December 2015
Available online 6 January 2016

Keywords:
Aquatic ecological model
Ecological model
Wetland
Ecological restoration

ABSTRACT

Aquatic ecological models can effectively simulate material flows and structural changes in complex ecosystems, and are thus widely used for pollution control and ecosystem management of wetlands. The emergent-macrophyte-dominated wetland is an important wetland type, but the ecological model researches for this wetland type are relatively limited. The Hanshiqiao wetland, located in the riparian floodplain of the Chaobai River, is a typical emergent-macrophyte-dominated wetland. In this research, it was adopted as the study case to develop an aquatic ecological model. In this model, the emergent macrophyte (*Phragmites australis*) was specifically considered. Two key processes were taken into account: the uptake nutrients of this emergent macrophyte, and its artificial harvesting. The results showed that the simulation effects using the new aquatic ecological model considering emergent aquatic plants are more accurate than those from previous models. Furthermore, using the proposed method, the ecological effects of four ecological restoration measures were compared. Results showed that the effect of biomass enhancement on ecological restoration was not obvious in the wetland and that increasing the water supplement was a little more effective than improving the water quality.

1. Introduction

Wetlands are one of the most important environmental resources, and have been described as "the kidney of the landscape" (EPA, 1985; Edward, 1997; Costanza et al., 1997; Cui and Yang, 2001; Dodds et al., 2008). Because of the dual effects of natural factors and human activities, however, wetlands are faced with area reduction, serious pollution, ecological damage and deterioration of function (An et al., 2008), and wetland protection and scientific management practices are urgently required.

Aquatic ecological models have been widely used for these purposes (Niu et al., 2013). These models provide for the simulation of a range of variables, and have obvious advantages in evaluating environmental problems and understanding their ecological processes in wetlands (Missaghi and Hondzo, 2010; Bilaletdin et al., 2011; He et al., 2011; Ciric et al., 2012). Many aquatic ecological models have been developed over the past several decades (Wang and William, 2000; Zhang and Jørgensen, 2003). Jørgensen (1986) proposed the necessity of establishing models with dynamic structure, and illustrated that a structurally dynamic model (SDM) could greatly improve the prognosis results by modifying the submodels with changeable parameters (Jørgensen, 1992). Later, these models were widely used to predict the quantitative structural changes of wetland ecosystems as a result of human activities and natural changes. STELLA has become a relatively popular modeling technology. It can effectively simulate the states of wetlands and has been widely used in researching wetlands. Ouyan et al. (2011) developed a STELLA model to predict N loads based on the relationship between chlorophyll and N as well as on river discharge. Xu et al. (2011, 2013) developed a STELLA model for the structure of nutrient and phosphorus cycling within the food web, and evaluated and predicted the health status of Baiyangdian wetland. The model established was shown to reasonably reflect the health status responses of different water areas to the changes of forcing functions. Zhao et al. (2014) sought to establish a zoning-based environmental-ecological-coupled model for Baiyangdian wetland, and to assess the effects of different ecological restoration schemes by modeling the phosphorus cycle. That research, though,

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http://dx.doi.org/10.1016/j.ecoleng.2015.12.032
0925-8574/

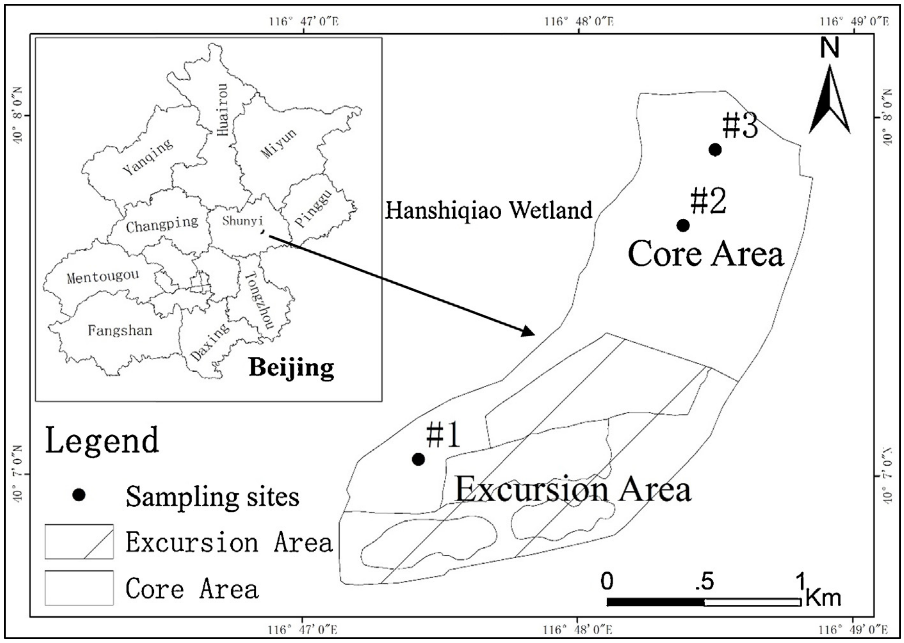

Fig. 1. Schematic map of the study area.

considered only the phosphorus cycle, rather than the entire nutrient cycle, although nitrogen and phosphorus are both important nutrients in wetlands, and play important roles in ecological processes. This oversight greatly limited the understanding of the relationships in aquatic ecological systems. In these studies, the research cases were almost wetlands where the dominant macrophytes are mostly submerged plants or floating plants, and thus emergent aquatic plants such as *Phragmites australis* were ignored in the models.

Emergent macrophytes are typical vegetation in many wetlands; in fact, they are often the dominant plant type. Emergent macrophytes have more supportive tissues than floating macrophytes; their roots are attached to the soil and play an important role in taking up heavy metals and nutrients from the soil sediment (Sangeeta and Savita, 2009). The emergent macrophyte *P. australis* is an excellent water purification plant, and can purify wastewater in many kinds of organic and inorganic matter; it plays an important role in ecological processes (Seidal, 1976). Juwarker et al. (1995) reported 78–91% removal of BOD, nitrogen reduction from 30.8 to 9.8 mg/l and phosphate reduction from 14.9 to 9.6 mg/l using the emergent macrophytes *Typha latiofolia* and *Phragmites carka*. Sollie and Verhoeven (2008) investigated the nutrient retention and reed effect on surface water quality in a reed-dominated littoral zone. The results indicated that nutrient concentrations in sediment, soil pore water and surface water were significantly lower in the vegetated than in the unvegetated zone. It is clear, therefore, that emergent macrophytes can assimilate nutrients from a wetland ecosystem, are characterized by high biomass production, and can remove a large number of nutrients if a timely harvest is conducted. Lu et al. (2009a, 2009b) investigated N and P removal from agricultural runoff by *P. australis* and *Zizania caduciflora* in a constructed wetland. The results showed that these two kinds of plants had large biomass and also good N and P absorption capability, and plant harvesting was more important in wetland-treated agricultural runoff than in domestic wastewater under the stable climate and intermittent inflow in the wetland. Thus, emergent macrophytes can produce obvious effects on the water quality in wetlands, and aquatic ecological models for wetlands dominated by emergent macrophytes should take into account the effects of emergent macrophytes.

The Hanshiqiao wetland, located in the riparian floodplain of the Chaobai River, is a typical emergent-macrophyte-dominated wetland. It was chosen as the study case to develop an aquatic ecological model. STELLA was used to construct the model, taking into consideration the inner nutrient cycling and the phosphorus cycle, based on sample collection and analysis over a 1 year period. *P. australis*, a typical emerged plant, was used in the model. To illustrate the effectiveness of the proposed model in ecological restoration, four ecological restoration measures were developed, and the ecological effects were predicted and compared using the model.

2. Study area

The Hanshiqiao wetland is located in the riparian floodplain of the Chaobai River and has an area of about 19 km^2 (Fig. 1). It is a typical emergent-macrophyte-dominated wetland. Under the influence of urban and agricultural development and other activities, the ecological functions of Hanshiqiao wetland have been seriously damaged. The "wetlands versus golf course" proposal aroused popular concern for this wetland and led to its protection (Gao and Wen, 2004). In 2005 the Hanshiqiao wetland nature reserve was established, and the ecological remediation had a great impact on delaying the wetland's degradation (Chen, 2008; Huang, 2009). However, at present, the Hanshiqiao wetland has no supply of upstream water and the recycled water supply is limited. The resulting water shortage, combined with agricultural and tourist activities, has caused the Hanshiqiao wetland to develop a high eutrophication level, and the pollution of the core area is obviously more serious than that in the tourist area (Wu et al., 2014). Its unique environment has been gradually disappearing, with severe negative effects on the lake ecosystem health.

3. Methods

3.1. Data sources

Three sampling sites were selected in the core area (Fig. 1). Water quality data and ecological data were collected by monthly field sampling from April 2013 to October 2014. Sample collection