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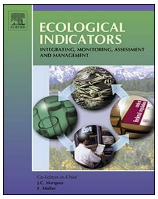

Original Articles

# Dynamic simulation of a duckweed-dominated wetland in north China based on a system dynamics model

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## ABSTRACT

Duckweed is a common category of floating plant which floats on or beneath the surface of still or slow-moving bodies of wetlands.Its growth has much effect on the hydro-ecological process of wetlands.However, in the existing wetland-ecosystem simulation models which contained floating- or emergent-plant modules, the shading effect of macrophytes and the relationship between macrophytes and phytoplankton in the wetland ecosystem were not considered sufficiently.When these models were directly used in the modeling of duckweed-dominated wetlands, the simulation effects of main state variables such as phytoplankton and dissolved inorganic phosphorus in water were poor and the models could not completely respond to the changes of the external variables. Through a field experiment and parameter calibrations, the shading effect of duckweed and the relationship between duckweed and phytoplankton were considered originally in this study. A duckweed-dominated wetland structurally dynamic (DWSD) model was developed for the Hanshiqiao wetland in Beijing. The development of this model included three procedures. (1) The relationship between the shading effect of duckweed and the biomass of duckweed was investigated based on a field experiment. (2)The equations of transmitted light intensity in water and of the growth of phytoplankton were revised according to the relationship obtained. (3)A module of duckweed was developed, and was incorporated into the structurally dynamic model. The DWSD model was calibrated and verified using the ecological survey data of the Hanshiqiao wetland in 2014. The decisive coefficients ($R^2$) and Nash-Sutcliffe coefficients ($E_{NS}$) for model calibration were not less than 0.9 in reproducing A and FP, and meanwhile $R^2$ and $E_{NS}$ of A and FP for model validation were all above 0.8. They showed that this model had acceptable simulation efficiencies both in calibration and verification. The DWSD model was used to predict changes of main state variables in 2015. As the simulation results showed, the module of duckweed posed significant impacts on the modeling of results, which performed in various aspects. For instance, the precision of this model was increased. The simulated values of phytoplankton and detritus in water for the DWSD model were all closer to the observed values than that without the module of duckweed. The transmitted light intensity in water from July to October was decreased. The growth of phytoplankton was inhibited and the simulated values of the content of detritus and the concentration of phosphorus in water were increased.

## 1. Introduction

Wetland-ecosystem simulation (WES) models reflect various physical, chemical, and biological processes in wetland ecosystems.The WES models could enable quantitative and qualitative analyses of constituents of wetland-ecosystem, so they have been widely applied to wetland-ecosystem management. The types of these models have experienced multiple stages from 1960s:from single-tier, single-chamber, and single-component to multi-tiers, multi-chambers, and multi-component models (Sakamoto,1966; Silow et al., 1995; Halfon and Lam,1978; Zhao et al., 2014; Lu et al., 2003 Halfon and Lam,1978; Zhao et al., 2014; Lu et al., 2003). Structurally dynamic WES models were the fifth generation of WES models. These models possessed a series of changeable parameters related to the constituents of wetland-ecosystem. The purpose for this was to reflect ecosystem adaptation under the changes of external conditions (Xu et al., 2013b).

In the initial stage of WES models development, many models did not contain modules of macrophytes. Jørgensen (1976) developed an ecosystem simulation model for an eutrophic shallow lake to describe the circulations of C, N, P and Si. Nyholm (1978) developed a Lavsoe

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ecological model to describe the seasonal circulations of algaes, transparency, and two nutrients (i.e. N and P). Jørgensen and de Bernardi (1998) established a structural dynamic model to explain the effectiveness of biomanipulation. With extensive exploration about the roles macrophytes played in entire wetland ecosystems, some scholars introduced macrophytes into the development of WES models. Xu et al. (1999) introduced a macrophyte module into a WES model to simulate the circulation of phosphorus and to analyze the impact of macrophyte restoration on ecological health in the Lake Chao; in their study, the macrophytes consisted of a kind of floating plant (i.e. water lettuce) and a kind of emergent plant (i.e. reed). To predict the nutrient retention under different hydrologic conditions, some scholars built phosphorus circulation models that contained the modules of emergent plants and periphyton for WES in coastal wetlands and constructed wetlands, respectively (Wang and Mitsch, 2000; William and Wang, 2000). Wang et al. (2013) and Xu et al. (2013b) established dynamical vegetation-growth WES models in which emergent plants and submerged plants were considered respectively.

The aforementioned WES models have been applied to the simulation of ecosystems in inland wetlands, coastal wetlands or constructed wetlands. The structures of these models differed from each other due to the variety of wetland characteristics with study areas. For the wetlands covered by submerged plants and emergent plants, there were many relevant WES models. As for the duckweed-dominated wetlands, few WES models were developed. This might be related to the complex roles duckweed played in an entire wetland ecosystem. To simulate the duckweed-dominated wetlands ecosystem accurately, the complex roles of duckweed in the duckweed-dominated wetland need to be investigated.

Duckweed is a common category of floating plants on or beneath the surface of still or slow-moving bodies of wetlands in southern and northern China (Zhang et al., 2009; Lan et al., 2013). This plant primarily affected the hydro-ecological process in a wetland by three pathways similar to the other floating plants. (1) Duckweed could cut down the transmitted light intensity in water (Mangas-Ramirez and Elias-Gutierrez, 2004). In warm and nutrient-abundant wetlands, duckweed could outperform phytoplankton in the competition for light (de Tezanos Pinto et al., 2007; O'Farrell et al., 2007). (2) Duckweed could absorb the nutrients in water in the growing process (Ayala et al., 2007). Lasfar et al. (2007) concluded that the inherent growth rate of duckweed was associated with temperature, photoperiod, and the concentration of nitrogen and phosphorus. Shen et al. (2004) and Cai et al. (2011a) studied the dynamic characteristics of duckweed absorbing nutrients from water. (3) Duckweed could increase the sedimentation of suspended solids (Bicudo et al. 2007). However, the three ways were rarely introduced into the development of Wetland-ecosystem simulation models in quantitative ways. Meanwhile, duckweed has a unique pathway compared to other floating plants. Duckweed could secrete allelochemicals to the water (Crossetti et al., 2008).

In the existing WES models which contain floating-or emergent-plant modules, the shading effects of macrophytes and the relationships between macrophytes and phytoplankton in wetland ecosystems were not considered sufficiently. The reason of this may be the difficulty of combining field experiment with modeling process when involving the shading effects and the relationships into the development WES models. The macrophyte module in the model developed by Xu et al. (1999) only considered the extinction effect of macrophyte while ignoring the shading effect of macrophyte. In Wang and Mitsch (2000), the shading effect of emergent plants on the growth of periphyton was considered, while that on phytoplankton was not. In Scheffer et al. (2003), the transformation mechanism of duckweed-dominated lake shifting from submerged-plant dominance to floating-plant dominance was studied, while the specific changes of state variables in duckweed-dominated wetland were not considered. When the existing WES models were directly used to simulate the circulation of materials in duckweed-dominated wetlands, the efficiencies of simulating main state variables were poor and the models could not reflect the changes of the external variables robustly. It is necessary to develop DWSD models based on consideration of the shading effect of duckweed and the relationship between duckweed and phytoplankton.

Therefore, the objectives of this study consisted of: correcting the parameters of some physical and biological process simulation equations based on field experiments, developing a structurally dynamical model for ecosystem simulation in duckweed-dominated wetlands, and revealing the impacts of duckweed on main state variables of the model. Specifically, phytoplankton was taken as a medium which connected the growth of duckweed with the whole hydro-ecological process of wetlands. The relationship between the coverage condition of duckweed and transmitted light intensity in water was investigated through a field experiment. By means of the relationship acquired, a module of duckweed was linked to a module of phytoplankton in the structurally dynamic model. The duckweed-dominated wetland studied in this paper was Hanshiqiao wetland in Beijing, China.

## 2. Materials and methods

### 2.1. General situation of the research area

The Hanshiqiao wetland (116°48′–116°50′N , 40°7′–40°8′E) is located in Shunyi district of Beijing and its area reaches 1900 ha. This is a typically shallow and duckweed-dominated wetland in northern China. Water in the core region of this wetland is supplied by reclaimed water from a sewage treatment plant in Yang Town and the runoff of Caijia River. From 2000, Caijia River suffered from seasonal cutoffs due to continuous droughts. Because of water-supply deficiency, the bad water quality of the reclaimed water, and the impact of non-point source pollution of agriculture, water eutrophication was severe in Hanshiqiao wetland in recent years (Wu et al., 2015; Tan et al., 2011). The eutrophication in the core region of this wetland was even worse than that in sightseeing regions. The core region was covered by a large area of duckweed in the months from July to October in recent years.

### 2.2. Data sources

Three sampling sites were chosen according to the distribution of duckweed. The site #1 was the inlet of the core region of the wetland (Fig. 1). An ecological investigation was conducted once a month (except for a freeze up period from December 2013 to February 2014) from April 2013 to October 2014 at 3 sampling sites (Fig. 1) in the core region. The water quality, aquatic organism, and sediment indexes were investigated.

The water quality investigation indexes, including water

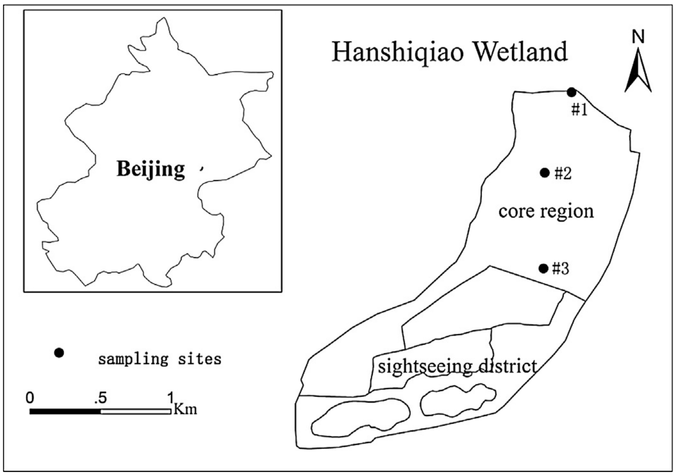

**Fig. 1.** The distribution diagram of sampling sites in the Hanshiqiao wetland.