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Dynamics of the wetland vegetation in large lakes of the Yangtze Plain in response to both fertilizer consumption and climatic changes

Xuejiao Hou[a,b], Lian Feng[a,c,d,*], Xiaoling Chen[b], Yunlin Zhang[c]

[a] School of Environmental Science and Engineering, Southern University of Science and Technology of China, Shenzhen 518055, China
[b] State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan 430079, China
[c] State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China
[d] Guangdong Provincial Key Laboratory of Soil and Groundwater Pollution Control, School of Environmental Science and Engineering, Southern University of Science and Technology, Shenzhen 518055, China

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ABSTRACT

Using moderate-resolution imaging spectroradiometer (MODIS) data that cover the 15-year period from 2000 to 2014 and a phenology-based classification method, the long-term changes in the wetland vegetation of 25 large lakes on the Yangtze Plain were obtained. The classification method was developed based on the phenological information extracted from time series of MODIS observations, which demonstrated mean user's/producer's accuracies of 76.17% and 84.58%, respectively. The first comprehensive record of the spatial distribution and temporal dynamics of wetland vegetation in the large lakes on the Yangtze Plain was created. Of the 25 lakes examined, 17 showed a decreasing trend of vegetation area percentages (VAPs) during the study period, and 7 were statistically significant ($p < 0.05$). The same number of lakes was found to display decreasing trends in vegetation greenness over this 15-year period, and these decreasing trends were statistically significant ($p < 0.05$) for 11 of the lakes. Substantially fewer lakes showed increases in either their VAPs or their vegetation greenness values. Analysis using a multiple general linear model revealed that the amounts of chemical fertilizer used for farmlands surrounding the lakes, precipitation, daily sunshine hours, temperature and water turbidity played the most important roles in regulating the interannual changes in vegetation greenness in 40% (10/25), 12% (3/25), 4% (1/25), 20% (5/25) and 12% (3/25) of the lake wetlands, respectively. On average, the combined effects of these five driving factors above explained 89.08 ± 7.89% of the variation in greenness over this 15-year period for the 25 lakes. This wetland vegetation environmental data record (EDR) of large lakes in Yangtze Plain demonstration will provide a crucial baseline information for the wetland environment conservation and restoration.

1. Introduction

As one of the most important components of wetland ecosystems, vegetation plays important roles that include providing food and habitat for aquatic organisms, maintaining water quality, and storing carbon (Scheffer et al., 1993; Jeppesen et al., 1998; Xiao et al., 2015). Changes in wetland vegetation have been considered a key ecological indicator for transitions in the safety and sustainability of the water environment (Martin et al., 2010; Feng et al., 2016; Zhang et al., 2016a). Unfortunately, global wetland vegetation loss is accelerating (Zhang et al., 2017a), mainly due to stress from anthropogenic activities, such as aquaculture and reclamation, as well as climate extremes (floods, etc.) and global warming (Sand-Jensen et al., 2000; Short et al., 2016), which will cause numerous environmental problems and have an adverse impact on ecological functions. The wetlands of the inland lakes on the Yangtze Plain examined in this study are susceptible to these problems (Han et al., 2015; Song et al., 2016; Zhang et al., 2016b).

Accurate knowledge of the distribution changes of wetland vegetation is the first step in assessing potential changes in the ecological functions of wetlands. Mapping the spatial patterns of vegetation in large wetland systems is often challenging, due to the heterogeneous distributions and compositions of different wetland cover types (Houlahan et al., 2006; Szantoi et al., 2013). Traditional field surveys can provide accurate data, but they are always labor and time intensive, and for the phenological change of wetland vegetation, frequent field measurements should be taken to obtain updated information to monitor wetland changes effectively, which will be more time-

* Corresponding authors at: School of Environmental Science and Engineering, Southern University of Science and Technology of China, Shenzhen 518055, China.
E-mail address: fengl@sustc.edu.cn (L. Feng).

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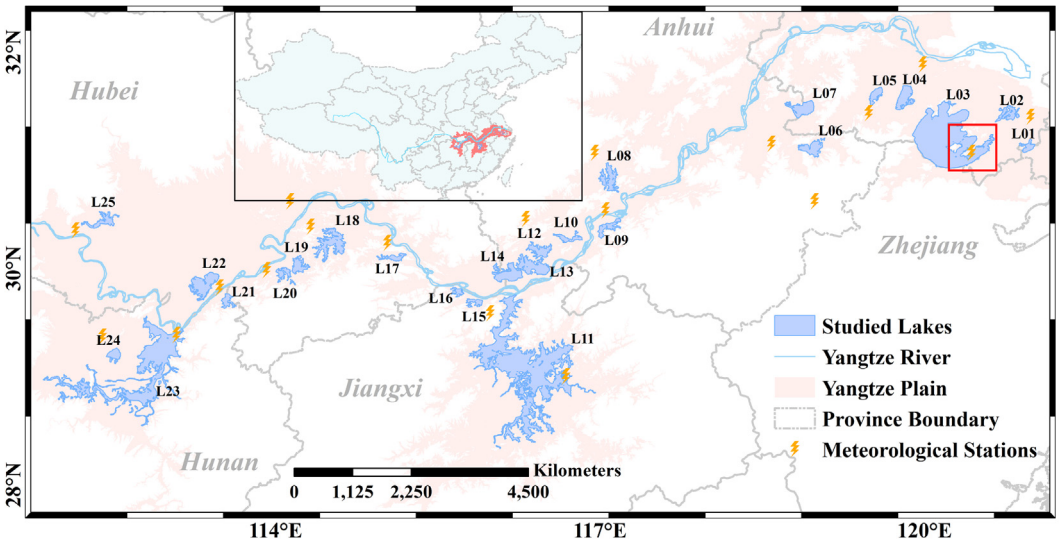

Fig. 1. Hydrological map of the Yangtze Plain (pink shaded area) and the spatial distribution of the studied lakes. The locations of meteorological stations are indicated by the orange markers, where ground-based measurements were used to assess the driving factors affecting the wetlands. The location of the Yangtze Plain in China is shown in the inset. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

consuming and expensive (Ozge et al., 2009; Han et al., 2015). As such, it is very difficult to collect spatially and temporally representative vegetation records for the wetland systems of large lakes across the entire Yangtze Plain or understand the changes in vegetation in this region using field surveys.

Given their ability to collect synoptic observations frequently, remote sensing techniques have become effective tools in studying wetland vegetation (Li et al., 2013; Han et al., 2015; Luo et al., 2016; Chen et al., 2018). Satellite remote sensing imagery with spatial resolutions ranging from < 10 m (such as Quickbird, IKONOS, Unmanned Aerial Vehicle, SAR images) to several kilometers have been used worldwide to map wetland vegetation (Ozge et al., 2009; Laba et al., 2010; Yu and Hu, 2013; Betbeder et al., 2015; Jing et al., 2017; Liu and Abd-Elrahman, 2018). The methods used to classify wetland vegetation from remote sensing images have also evolved from visual interpretation to computerized methods (i.e., the threshold method, unsupervised and supervised classification, Object-based classification, principal component analysis and hybrid classification) and subsequently to highly advanced artificial intelligence-based methods (Maxa and Bolstad, 2009; Wang and Bao, 2010; Dronova et al., 2015; Szantoi et al., 2015; Villa et al., 2015; Liu and Abd-Elrahman, 2018). Several studies also try to estimate the coverage and community of wetland vegetation using remote sensing imagery (Ozge et al., 2009; Laba et al., 2010; Dronova et al., 2015; Villa et al., 2015), and in situ data were used to train model and validate accuracy.

The lakes, ponds and reservoirs on the Yangtze Plain account for over three-quarters of the freshwater lake area in the downstream portion of the Yangtze Basin, where the wetlands can provide water resources for millions of local people and play critical roles in regulating the regional environmental and ecological systems (Guo, 2007; Han et al., 2015). Indeed, considerable efforts have been made to understand the changes in the surface area, land cover, and water quality of these lakes, among many other characteristics (Feng et al., 2012a, 2012b; Wang et al., 2014, 2017; Cai et al., 2016; Hou et al., 2017; Xie et al., 2017). The wetland vegetation of large lakes in this region has also been studied in a number of pioneering studies starting in the 1970s, such as Poyang Lake, Dongting Lake, etc. (Wu, 1977; Liu et al., 1981; Deng et al., 2014; Luo et al., 2017; Chen et al., 2018).

Unfortunately, published studies of the wetland vegetation of the Yangtze Plain have several limitations. First, some of these studies use data from only one to two years, which prevents the analysis of long-term changes and their potential trends (Luo et al., 2017). Second, some of the studies conducted with remote sensing data covering longer periods suffer from nonconsecutive observations, which prevent the assessment of short-term vegetation variability (Li et al., 2013; Han et al., 2015). Third, the available information on wetland vegetation provided by field surveys and remote sensing focuses only on one lake in the Yangtze Plain, prohibiting comprehensive assessment of the basin-scale wetland conditions (Luo et al., 2016; Chen et al., 2018; Han et al., 2018). Prompted by the urgent need for an accurate decadal environmental data record (EDR) of the wetland vegetation of the inland lakes of the Yangtze Plain, the current study is designed to address the issues described above. The objectives of the study are as follows: (1) To develop a phenology-based classification method using time series of the 250-m moderate-resolution imaging spectroradiometer (MODIS) data and to document the spatial and temporal variability of the vegetation changes in 25 large lakes on the Yangtze Plain between 2000 and 2014; (2) To explore the potential driving forces of the changes in greenness in these wetlands using anthropogenic activities data, meteorological and water quality data obtained through both ground-based measurements and remote sensing.

2. Study area and datasets

2.1. Study area

The Yangtze Plain, which covers an area of ~140,000 km^2 (see Fig. 1), accounts for ~18% of the total area of the downstream Yangtze Basin (Wang et al., 2014). The freshwater lakes in this region include those connected with the Yangtze River (such as Poyang, Dongting, and Shijiu Lake), whose intra-annual changes in their inundation areas are impacted by the Yangtze River (Feng et al., 2012a; Wang et al., 2014), as well as those that have no direct interaction with the Yangtze River. However, due to the increase in anthropogenic activities, many lake wetlands have experienced significant degradation over the past several decades (Ma et al., 2008; Zhang et al., 2016a, 2016b). Recently, a new review paper by Zhang et al. (2017a) stated that of the 35 lakes with aquatic vegetation loss in China, many were distributed in the Yangtze Plain. However, hitherto no systematic reports on the long-term wetland vegetation changes in the Yangtze Plain are available, while information on these changes is critical for protection and restoration of the lake environment. Notably, the words “lake” and “wetland” are interchangeable in this study, as lake is also one type of wetland according to the definition of Ramsar convention (Secretariat, 2013)