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Four decades of wetland changes of the largest freshwater lake in China: Possible linkage to the Three Gorges Dam?

Lian Feng [a], Xingxing Han [a], Chuanmin Hu [b], Xiaoling Chen [a,*]

[a] State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan 430079, China
[b] College of Marine Science, University of South Florida, 140 Seventh Avenue South, St. Petersburg, FL 33701, USA

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ABSTRACT

Wetlands provide important ecosystem functions for water alteration and conservation of bio-diversity, yet they are vulnerable to both human activities and climate changes. Using four decades of Landsat and HJ-1A/1B satellites observations and recently developed classification algorithms, long-term wetland changes in Poyang Lake, the largest freshwater lake of China, have been investigated in this study. In dry seasons, while the transitions from mudflat to vegetation and vice versa were comparable before 2001, vegetation area increased by 620.8 km^2 (16.6% of the lake area) between 2001 and 2013. In wet seasons, although no obvious land cover changes were observed between 1977 and 2003, ~30% of the Nanjishan Wetland National Nature Reserve (NWNNR) in the south lake changed from water to emerged plant during 2003 and 2014. The changing rate of the Normalized Difference Vegetation Index (NDVI) in dry seasons showed that the vegetation in the lake center regions flourished, while the growth of vegetation in the off-water areas was stressed. Rapid NDVI increase was also found in the NWNNR in the wet seasons. The relationships between the water levels and vegetation coverage also showed two regimes in both dry and wet seasons for the pre-Three Gorges Dam (TGD) period (before 2003) and post-TGD period (after 2003). Analyses of long-term hydrological and meteorological data clearly indicated that while local precipitation remained stable, the water level of Poyang Lake decreased significantly after the impoundment of the TGD, which is likely the main reason for the wetland expansion in recent years.

1. Introduction

Regardless of the valuable functions of manmade dams on flood control, power generation, agricultural irrigation, and many others, their potential environmental and ecological impacts received considerable concerns from the general public, governments, and the scientific communities (Graf, 1999). One typical example is the world's largest hydroelectric dam upstream the Yangtze River, the Three Gorges Dam (TGD, 30°49′ N and 111°0′ E) of China (see location in Fig. 1). Numerous studies have been conducted to find the potential linkages between the abrupt changes of the downstream ecosystems in recent years and the construction and/or operation of the TGD (Dai, Du, Li, Li, & Chen, 2008; Wu et al., 2004; Xie, 2003; Xu & Milliman, 2009; Yan et al., 2008; Yang et al., 2006). The Chinese government has also admitted the potential consequences of the TGD to the Yangtze River ecosystem recently (Lu, 2011), although scientific evidence is still generally lacking.

Connecting to the middle reaches of the Yangtze River, the environment of Poyang Lake, the largest freshwater lake of China, was not immune to the influence of the TGD. For example, observations through the use of the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite measurements between 2000 and 2010 showed a significant decreasing trend of the lake's inundation area since the impoundment of the TGD in 2003 (Feng, Hu, Chen, & Zhao, 2013). Consistent with this observation and based on hydrological modeling, Zhang et al. (2012) revealed a reduced water level of Poyang Lake over the dry seasons in the post-TGD period.

The Poyang Lake wetland is a complex system with the composition of water, sand, mudflat and numerous species of vegetation (Dronova et al., 2012; Dronova, Gong, & Wang, 2011). Although changes of the surface water area were understood through the above studies, the influence of the TGD to other types of wetland cover is generally unknown, making it difficult to conduct a comprehensive assessment of the ecological changes in the Poyang Lake wetland. The limited data coverage through traditional field surveys makes it difficult to monitor large-scale changes, not to mention understanding their responses to natural and/or anthropogenic impacts. Starting from the 1970s, satellite images collected by consecutive Landsat missions have provided >40-year continuous and frequent global observations with fine spatial resolutions, which have been widely used to investigate environmental changes in both terrestrial and aquatic systems all over the world (Wulder, Masek, Cohen, Loveland, & Woodcock, 2012). Thus, Landsat

* Corresponding author.
E-mail address: xiaoling_chen@whu.edu.cn (X. Chen).

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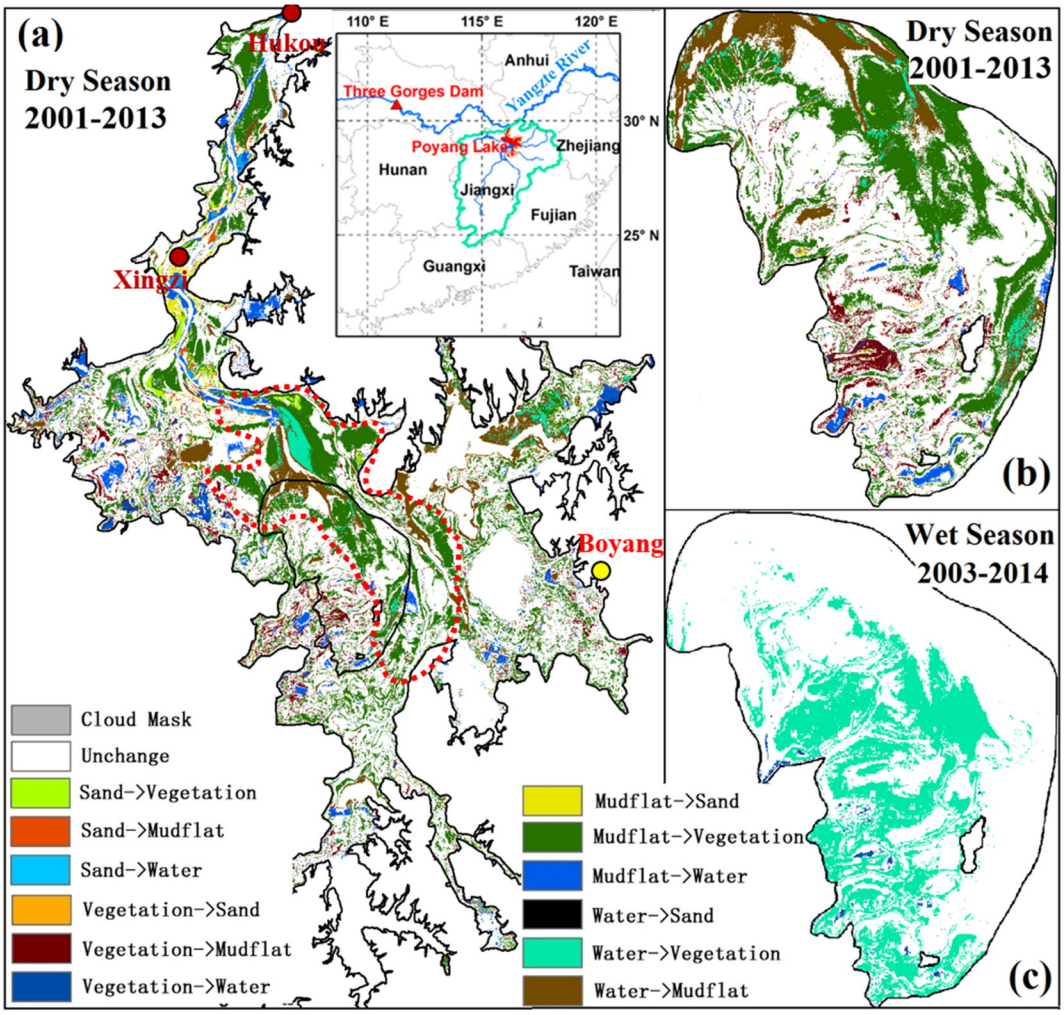

Fig. 1. (a) Transition map of Poyang Lake wetland between 2001 and 2013 in dry seasons. The locations of two hydrological stations (Hukou and Xingzi) and one meteorological station (Boyang) are annotated. The red circled region is the lake center area where significant amount of mudflat transitioned into vegetation during this period. The details of the NWNNR (outlined in black) reserves are enlarged in (b). (c) Transition map of NWNNR between 2003 and 2014 in wet seasons. The inset in (a) shows the location of Poyang Lake and the Three Gorges Dam. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

observations appear particularly suitable for large scale wetlands studies.

In this study, we combined wetland classification maps from Landsat images and hydrologic and meteorological measurements to study the long-term changes in the Poyang Lake wetland, with the following two objectives: 1, to document major wetland changes of Poyang Lake in the last four decades in both dry and wet seasons, with particular focus on the changes after the impoundment of the TGD in 2003; 2, and to understand whether the wetland changes could be attributed to local climate variability, regional human or animal activities, or the TGD.

2. Study area and datasets

Located in the north of Jiangxi Province (28°22′–29°45′N and 11°47′–116°45′E, Fig. 1), Poyang Lake is the largest freshwater lake in China. The lake receives water from five tributaries in the south and discharges into Yangtze River at Hukou in the north. The precipitation of the Poyang Lake drainage shows great seasonality due to subtropical monsoons, leading to significant runoff variability of the tributaries every year. April to September is the wet season of the lake, when the inundation area reaches to >3000 km^2; and October to March is the dry season, with the inundation area shrinking to <1000 km^2 (Feng et al., 2012; Guo, Hu, Zhang, & Feng, 2012). During low-water stages, a large area of the lake's bottom emerged, serving as the habitat for most of the water birds from Siberia (Kanai et al., 2002). The critical ecological functions of Poyang Lake make it one of the most important wetland in the world, as recognized by the International Union for the Conservation of Nature (Finlayson, Harris, McCartney, Lew, & Zhang, 2010). The Chinese government has established two national nature reserves to protect the endangered migratory birds and the wetland ecosystem of Poyang Lake, and the largest one is the Nanjishan Wetland National Nature Reserve (NWNNR, ~370 km^2) in the south (see locations in Fig. 1). The Poyang Lake boundary used in this study is the same as that defined in Feng et al. (2012), which was delineated through the largest inundation in the wet season.

Long-term remote sensing images during both wet and dry seasons of Poyang Lake were used in this study to investigate the wetland changes under different hydrological conditions. The data collected by the Landsat instruments (i.e., MSS, TM, ETM + and OLI) were obtained from the United States Geological Survey (USGS) (http://www.usgs.gov/) and the Remote Sensing Data Sharing Center of China (http://ids.ceode.ac.cn/). In total, 11 cloud free images in dry seasons between 1973 and 2013 were selected (see Table 1), where the acquisition dates are in December of each year (except for 2001). Additional data in December were obtained here as compared to that in Han, Chen, and Feng (2015), which is a result of the recent Landsat Global Archive Consolidation effort. Similarly, 10 high-quality images between July and