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Relationship between the hydrological conditions and the distribution of vegetation communities within the Poyang Lake National Nature Reserve, China

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ABSTRACT

Hydrological characteristics have been recognized as major driving forces for wetland vegetation. The water cycle and hydrological processes of wetland are increasingly influenced by the ongoing climate change and more intensive human activities, which may in turn affect the distribution and structure of vegetation communities. Poyang Lake, located on the south bank of the lower reach of Yangtze River, receives inflows from five tributaries and discharges to the Yangtze River. The unique hydrological conditions of the Poyang Lake wetland create abundant wetland vegetation communities. As a major national hydraulic project, the Three Gorges Dam across the Yangtze River has changed the water regime of Poyang Lake and hence may affect the vegetation distribution. This work aims to investigate the influences of hydrological properties on vegetation structure at broad spatial and temporal scales. Histograms and sensitivity index are used to link the hydrological processes with the vegetation distribution across the Poyang Lake National Nature Reserve. The results show that different vegetation communities react differently to the hydrological conditions. Specifically, certain communities, e.g. *Carex* and *Eremochloa ophiuroides*, are able to survive a wide variety of mean water depth and percent time inundated, while others, like *Carex–Polygonum criopolitanum*, are found to be relatively sensitive to hydrological conditions. It is suggested that this work provides a new insight for evaluating the impact of hydro-engineering projects on vegetation communities and wetland vegetation restoration.

1. Introduction

Hydrological properties have been considered as the driving factors of a wetland ecosystem (Mitsch and Gosselink, 2007). The water regime influences the composition, productivity, stability, species diversity and succession of a wetland vegetation community. Therefore, the interplay of hydrological processes with the plant communities has been a research topic of interest for decades. Numerous studies have shown a strong relationship between vegetation communities and water regime which may be described by water level, water-table level, water depth, soil water content, percentage of time inundated days per year and so on (e.g. Allen-Diaz, 1991; Magee and Kentula, 2005; Merendino et al., 1990; Stromberg et al., 1996; Toogood and Joyce, 2009). Katz et al. (2009) recognized hydrology to be a key factor in shaping desert streamside plant communities. David (1996) suggested that even slight changes in the depth and period of inundation might influence the presence of certain plant communities. In Sierra Nevada meadows, hydric vegetation was found in the location where the water-table was 0–40 cm below the surface. Mesic vegetation existed where the water-table was 20–80 cm below the surface (Allen-Diaz, 1991). Along the San Pedro river in Arizona, obligate wetland herbaceous species thrived in the water-table 0–25 cm below the surface. Obligate and facultative wetland trees survived 140–380 cm below the surface, and facultative wetland shrubs 120–150 cm below the surface (Stromberg et al., 1996). Casanova and Brock (2000) designed an experiment to determine the importance of water regime (depth, duration or frequency of flooding) to the development of plant communities. Their results showed that depth, duration and frequency of inundation influenced significantly the plant community composition while depth was least important. The duration of individual flooding events was demonstrated to be important in segregating the plant communities. Minor changes in average water levels (±10 cm) might promote a shift from assemblages dominated by native species to those dominated by invasive or alien taxa (Magee and Kentula, 2005). Hydroperiod and water depth increased and soil depths decreased in the order of Tall Sawgrass, Sparse Sawgrass, and Spikerush Marsh in Shark Slough, Everglades National Park (Ross et al., 2003). Battaglia and Collins (2007) used an experimental approach to determine the pattern of vegetation expression from propagule banks of Carolina bays exposed to different hydrologic conditions and gradients. These results confirmed a tight mechanistic link between hydrology and vegetation patterns within Carolina bays and the linkage weakened

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with drier conditions as both facultative wetland and upland species recruited into the standing vegetation. Hammersmark et al. (2009) coupled a hydrologic model to a suite of individual plant species distribution models to predict species in the distribution of common meadow plant species in response to meadow restoration. Todd et al. (2010) linked hydrological dynamics with vegetation distribution across Everglades National Park using two datasets to analyze the probability structure of the frequency, duration, and depth of inundation events along with their relationships to vegetation distribution. This study was among the first to show hydrologic structuring of vegetation communities at wide spatial and temporal scales.

Poyang Lake, the largest freshwater body in China, is located at the south bank of Yangtze River in Jiangxi province between 115°49′–116°46′E and 28°24′–29°46′N. The Poyang Lake receives inflows from five tributaries, namely Xiushui River, Ganjiang River, Xinjiang River, Raohe River and Fuhe River, and discharges into the Yangtze River at Hukou. The water level of Poyang Lake, which is controlled by both the Yangtze River and the five branches (Min, 1995; Shankman et al., 2006), is high in summer and low in winter. Due to the unique hydrological regime and special geographical conditions, Poyang Lake wetland is famous for its abundant bio-diversity and it has been registered in the UN as one of the world's important wetlands in 1992. It hosts significant proportions of the Yangtze finless porpoise (*Neophocaena phocaenoides asiaeorientalis* Pilleri and Gihr), swan goose (*Anser cygnoides* L.), and some 95% of the entire population of endangered Siberian crane (*Grus leucogeranus* Pallas) in the whole world (Wu et al., 2009). Additionally, the periodic variation of the water regime has produced a variety of plant communities. The vegetation communities are distributed along the hydrological gradients in the Poyang Lake wetland. For example, *Carex* community, the most widespread of Poyang Lake wetland vegetation community, has been shown to favor areas where the ground surface elevation is between 14.5 m and 16.0 m above sea level (Yellow Sea Datum) and the groundwater level is between 0.4 m and 0.8 m. Meanwhile, the extreme water regime variation is a major factor limiting the development of aquatic plants. For instance, the severe large flood in Yangtze River basin in 1998 has had a huge impact on the vegetation of Poyang Lake and has seen that biomass of aquatic plants had reduced, the number of species had decreased (Li et al., 2004) and the vegetation productivity had declined dramatically (Cui et al., 2000).

The ecological and environmental conditions of Poyang Lake have been evolving rapidly due to climate change and human activities. One of such notable factors may be the construction of the Three Gorges Dam (TGD) which began to impound water on 1 June 2003. A number of different studies have shown that the scheduling mode of the TGD would affect the dynamics of Poyang Lake (Wang, 2002; Wang et al., 2005). The discharge of Yangtze River was increased from January to April for power generation, while from May to June the water level of the TGD should be lowered to create capacity for flood control during monsoon season. Wu (2007) suggested that the mean monthly water level of Poyang Lake at Hukou station would be raised by at least 0.5 m and as high as 1.31 m in June when the discharge of Yangtze River increased by from 6440 m^3/s to 82,243 m^3/s. The discharge of Yangtze River decreases from September to November to recharge the TGD. The mean monthly water level of Poyang Lake at Hukou station may drop by 1.0 m with the discharge of Yangtze River reduced by 5000 m^3/s (Wu, 2007). Therefore, the date of the beach of Poyang Lake wetland exposing to the air would be postponed in spring (from January to May) and ahead of time in autumn (from October to November), which would affect the growth and distribution of vegetation communities within the Poyang Lake.

The vegetation composition and distribution are the result of long-term effects of combined external environmental conditions. The existing studies on the connection between hydrological conditions and vegetation communities are generally based on field surveys or laboratory experiments, and focus more on individual species rather than communities, or riparian zones rather than wetlands. The implication of the problem to a broader scale is extrapolated from the conclusions made for the studies at relatively small temporal and spatial scales. Additionally, the effects of variable hydrology of Poyang Lake at large scales remain poorly understood, which make the issue more complex. Based on the long-term hydrological data and vegetation distribution data covering abroad spatial scale, the relationship between the hydrological conditions and vegetation distribution across the Poyang Lake National Nature Reserve (PLNNR) is analyzed in this paper. This analysis also discusses how the changes of discharges of Yangtze River caused by operation of the TGD influence plant distribution within the PLNNR.

2. Study area

The Poyang Lake National Nature Reserve (PLNNR) is located at the northwest of Poyang Lake (Fig. 1) between latitudes 29°05′ and 29°15′ N and longitudes 115°55′ and 116°03′E (Wu and Ji, 2002). The nearly 224 km^2 PLNNR was established in 1988 to preserve wintering birds (Ji, 2000). The park plays an important role in protecting birds and most of them are endangered species in the world. For instance, 23 endangered species were found in the PLNNR and have been since listed in "international threatened birds list" published in 1998 by the Worldwide Conservation Group BirdLife International. Meanwhile, nearly 80% (about 2017) of the total Oriental Stork (*Ciconia boyciana*) around the world was found in the Poyang Lake and approximately 1755 wintered in PLNNR in 1998.

The PLNNR has nine small shallow lakes that connect with each other only in the summer when the water level is relatively high. During high water levels in summer, the nine small lakes also connect to Poyang Lake, and their water level is, thus, influenced by the Ganjiang

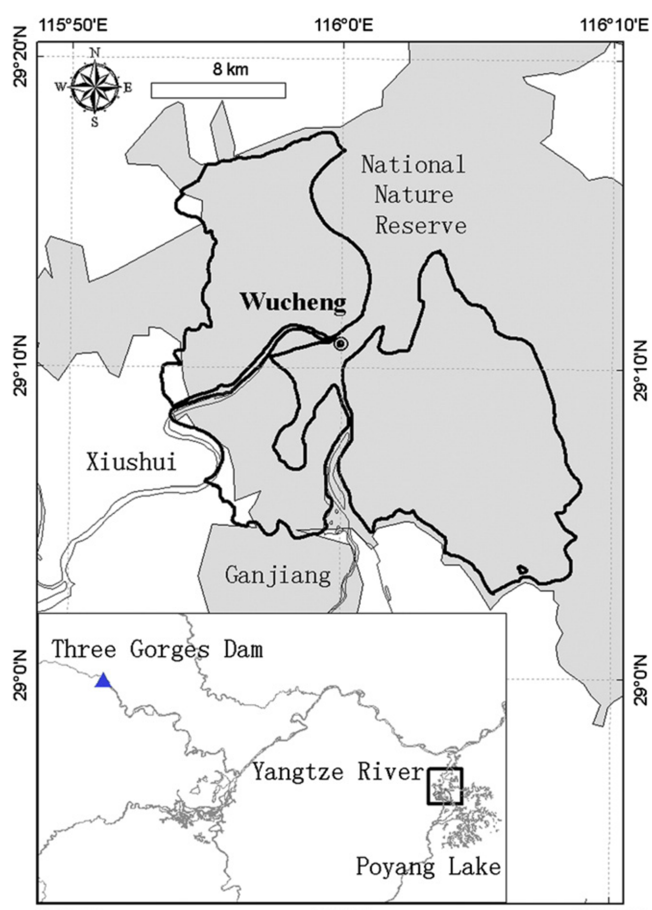

Fig. 1. Location of the Poyang Lake National Nature Reserve and Wucheng station.

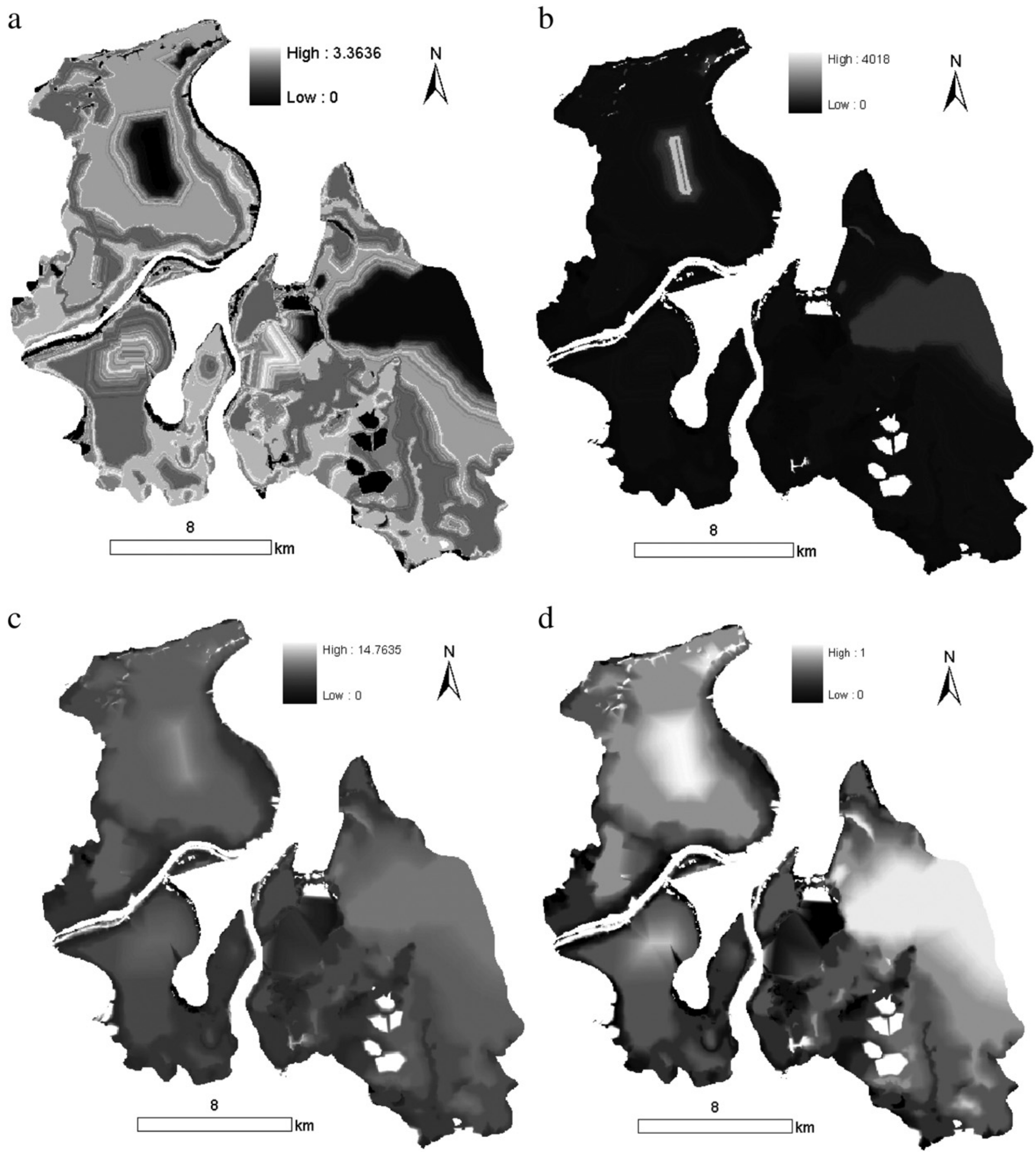

Fig. 2. Spatial distribution of (a) number of hydroperiods per year, (b) mean duration of a hydroperiod, (c) mean depth, and (d) percentage of time inundated across the Poyang Lake National Nature Reserve.

River, the Xiushui River and the Yangtze River. The water level of the PLNNR is controlled by Xiushui River and Gan Jiang from September to April when water level is relatively low. Wu et al. (2009) suggested that the water level of Lake Dahuchi within the PLNNR was linearly related to that of the Yangtze River at Hukou when the water level of Poyang Lake at Hukou was higher than 14 m (Yellow Sea Datum), and such a relationship no longer existed when the water level of Poyang Lake at Hukou was less than 14 m.

3. Methodology and data

3.1. Hydrological information

In order to obtain the water depth, the water level and the ground surface elevation need to be prepared. In this study, the daily records of water level are available at Wucheng station for the PLNNR. The water level layer is generated by inputting water level data into GIS. From the topographic contour map of the Poyang Lake in 1998, the ground surface elevation is represented by a 50 m × 50 m grid obtained in CAD data format using Spatial Analysis Module in GIS (ArcGIS 9.2). The water depth is then calculated as the difference between the water level and the ground surface elevation. This analysis is restricted from 1/1/1996 to 31/12/2006 and to the area within the PLNNR (Fig. 1), with all of the above raw data obtained from Jiangxi Hydrological Bureau.

To quantify the effects of hydrological conditions on vegetation communities, four parameters are defined and used at each 50 m × 50 m pixel, which are respectively the number of hydroperiods per year (a hydroperiod is defined as an individual inundation episode, i.e. a single wetting-drying cycle), the mean duration (days) of a hydroperiod

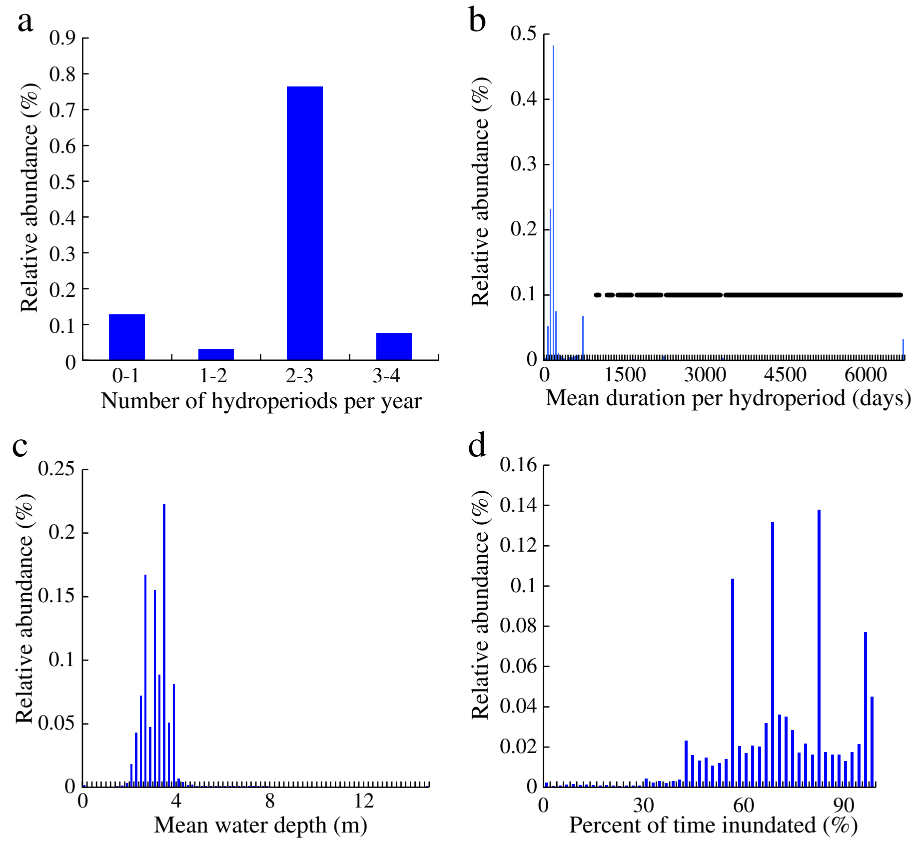

Fig. 3. Relative abundance of (a) number of hydroperiods per year, (b) mean duration per hydroperiod, (c) mean depth, and (d) percent time inundated across the Poyang Lake National Nature Reserve. The black bar in (b) suggests no data in these classes.

(defined as the average days for a hydroperiod), the mean water depth (m, defined as the mean depth of all inundated days), and the percentage of time inundated (the number of inundation days divided by the total number of days).

3.2. Vegetation information

The PLNNR is an area with diverse vegetation communities. A relatively accurate vegetation map is provided by the Jiangxi Hydrological Bureau for the whole Poyang Lake in JPG format and the part within the PLNNR is used in this analysis. The vegetation community layer is generated using the Editor Module in GIS (ArcGIS 9.2) on a 50 m × 50 m grid with 137,710 pixels to match the hydrological data.

Table 1
Percentage coverage of dominant vegetation community types within the PLNNR.

Vegetation type	Coverage (%)
Carex community	50.37
Carex–Triarrhena lutarioriparia community	10.81
Triarrhena lutarioriparia–Carex community	5.88
Carex–Phalaris arundinacea community	5.65
Phalaris arundinacea–Carex community	5.26
Carex–Polygonum criopolitanum community	4.68
Cynodon dactylon community	3.02
Polygonum japonicum community	2.39
Triarrhena lutarioriparia and *Carex* community complex	1.73
Carex–Potentilla limprichtii community	0.98
Arundinella hirta–Cynodon dactylon community	0.68
Triarrhena lutarioriparia community	0.63
Eremochloa ophiuroides community	0.62

Notes: Only those vegetation community types with a value greater than 0.6% are listed.

3.3. Analysis of hydrological and vegetation data

Histograms of the four hydrological parameters are created by extracting the same vegetation community type from all of the pixels to analyze the connection between hydrological parameters and vegetation communities. These histograms demonstrate the relationship between an individual plant community and the hydrological parameters. Following, an example is given to show how to create a histogram for the *Carex* community.

Out of the total of 137,710 pixels in the entire study area, there are 35,113 pixels with dominant *Carex* community (i.e. it takes up 25.5% of the total area). The four hydrological parameters lead to four histograms in each of the 35,113 pixels. Taking the mean water depth as an example, it is divided into 0.2 m intervals, each of which is defined as a “class”. The *Carex* community pixels with mean depth falling into the 0–0.2 m interval are considered to be one class, then 0.2–0.4 m until 14.6–14.8 m. Thus, a total of 74 classes are obtained as the mean water depth of the PLNNR ranges from 0 m to14.8 m. The height of bar for each class of histogram is the relative abundance, which is the ratio between the number of *Carex* community pixels in that class and the number of all pixels in the same class. For example, there are 1828 (out of 35,113) *Carex* community pixels in the 2.2–2.4 m mean depth class and 5963 pixels (out of 137,710) in the entire study area in the same class, which gives the relative abundance of 30.66%. The histograms of the other three hydrological parameters are created in a similar way. It is important to note that the number of classes for a given hydrological parameter is kept consistent for all of the vegetation

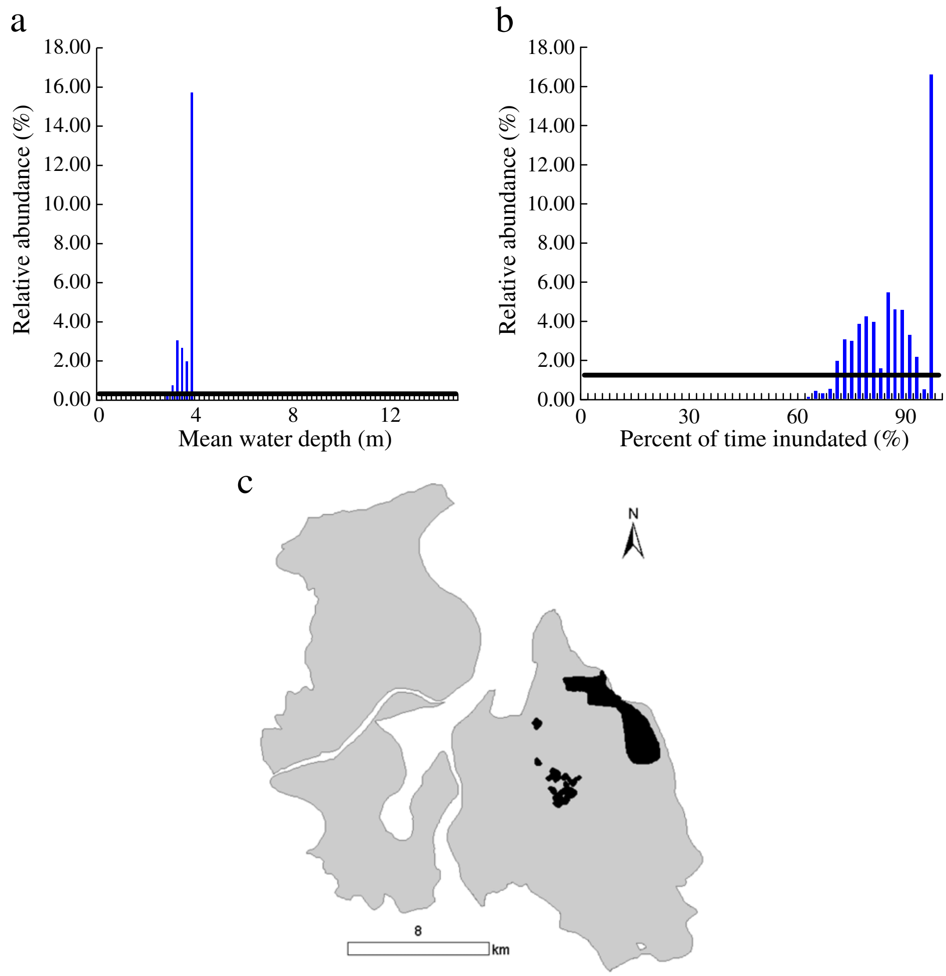

Fig. 4. Relative abundance for (a) mean depth, (b) percent time inundated and (c) spatial distribution of the *Carex–Polygonum criopolitanum* community. Black horizontal lines in (a) and (b) indicate the average value of relative abundance of the given vegetation community across the entire PLNNR. Black regions in (c) indicate the spatial distribution of the given vegetation community.

communities within the PLNNR in order to ensure consistent interspecific comparison.

To evaluate the differences among different vegetation communities for a single hydrological parameter, a Sensitivity Index (SI) is defined:

$$SI = \frac{1}{c}\sqrt{\frac{\sum_{i=1}^{n}(b_i - c)^2}{n}} \tag{1}$$

where n is the number of total classes in the histogram for a given hydrological parameter; b_i is the relative abundance of the ith class; c is the average value of relative abundance for a given vegetation community across the entire PLNNR. For an individual vegetation community, four SIs, one for each hydrological parameter, are calculated. For example, there are 1828 pixels in the 2.2–2.4 m mean depth class for *Carex* community and b_i is 30.66% (=1828/35,113×100). C is the average value of all bars in the histogram and it is 19.74%. There are 74 classes for mean depth and so n is 74. Then SI of mean depth for *Carex* community is 0.43. As mentioned before, the values of SI imply whether the plant community is sensitive to a given hydrological parameter. Specifically, high values of SI mean the vegetation community has high preference to the given hydrological parameter.

Table 2
SI values for dominant vegetation community types related to the four hydrological parameters.

Vegetation types	NH	MDH	MD	PTI
Carex community	0.36	0.84	0.43	0.37
Carex-Triarrhena lutarioriparia community	0.37	1.13	0.54	0.61
Triarrhena lutarioriparia-Carex community	0.66	1.33	1.02	0.96
Carex-Phalaris arundinacea community	0.88	1.35	5.06	2.06
*Phalaris arundinacea-Carex*community	0.61	1.20	4.94	2.48
Carex-Polygonum criopolitanum community	1.20	2.79	5.33	2.26
Cynodon dactylon community	0.60	1.27	0.84	1.25
Polygonum japonicum community	0.48	1.03	2.07	0.91
Triarrhena lutarioriparia and *Carex* community complex	1.02	3.21	4.69	1.91
Carex-Potentilla limprichtii community	0.54	1.98	2.51	1.83
*Arundinella hirta-Cynodon dactylon*community	0.55	3.33	4.46	1.45
Triarrhena lutarioriparia community	0.45	1.49	4.46	1.45
Eremochloa ophiuroides community	0.72	1.33	1.09	1.24

Notes: Only those vegetation types making up more than 0.6% area listed. *NH*, *MDH*, *MD* and *PTI* represent number of hydroperiods per year, mean duration of a hydroperiod, mean depth and percentage of time inundated, respectively. The grey shaded cells represent the three highest SI values for each of the hydrological parameters.

4. Results

A total of 137,710 50 m×50 m cells are created to represent the PLNNR. The spatial distribution of the four hydrological parameters is shown in Fig. 2. The number of hydroperiods per year averages 2.29, ranging between 0 and 3.36 hydroperiods per year (Fig. 3a). The pixels with

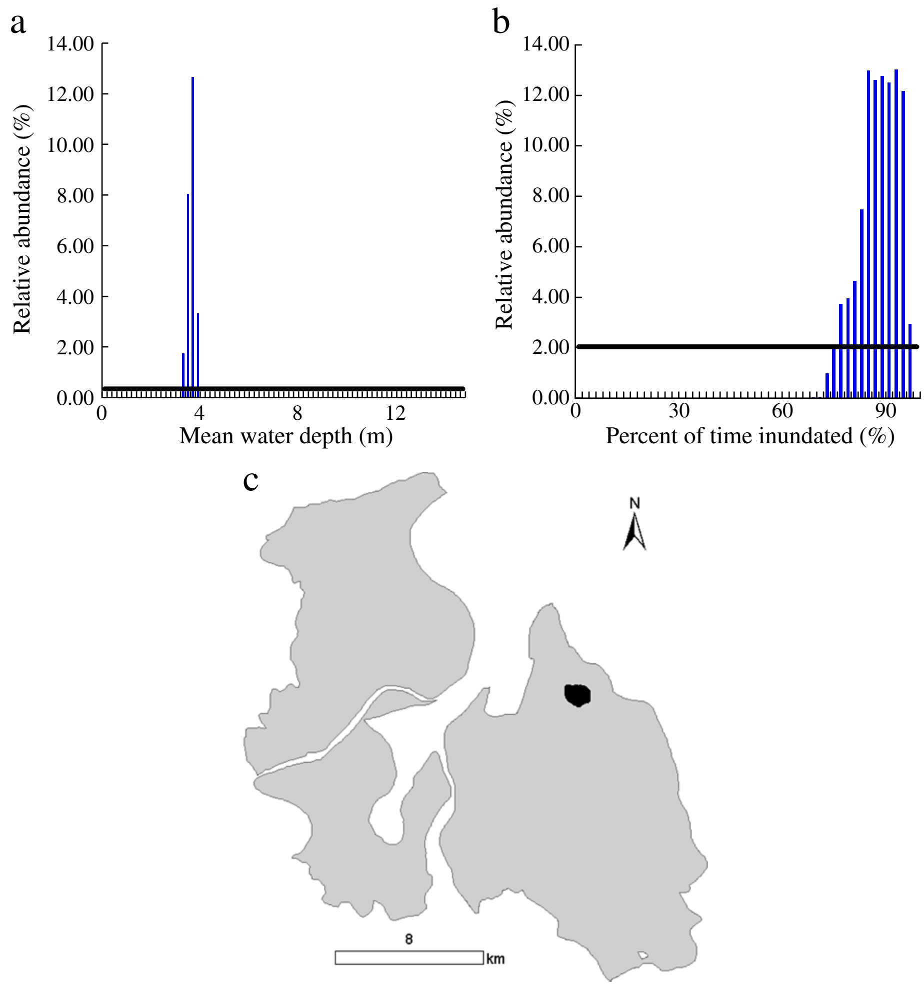

Fig. 5. Relative abundance for (a) mean depth, (b) percent time inundated, and (c) spatial distribution of the *Carex–Phalaris arundinacea* community. Black lines in (a) and (b) indicate the average value of relative abundance of the given vegetation community across the entire PLNNR. Black regions in (c) indicate the spatial distribution of the given vegetation community.

the 2–3 hydroperiods per year take up 76% of the total gird cells within the PLNNR. Mean duration of a hydroperiod averages 264.71 days, vary from 0 to 4018 days (Fig. 3b). Nearly 85% of the pixels inundates between 50 days and 300 days for a hydroperiod. Mean water depth averages 3.27 m, having a range between 0 and 14.7 m (Fig. 3c). Nearly 94% (about 130,382) of the pixels has a mean depth ranging from 2.0 to 3.8 m. Across the PLNNR, there are 200 grid cells that are never inundated and so the mean depth for these cells is zero. On the other hand, there are 4312 pixels that are always wet and hence the percent time inundated for these grid cells is 100%. As a whole, the percentage of time inundated ranges between 0 and 100% with an average of 71.9% (Fig. 3d). Pixels with percent time inundated over 40% account for about 96% of the total landscape in the entire study area, which indicates that the percentage of time inundated is most commonly between 40% and 100%. The mean duration per hydroperiod and the number of hydroperiods per year are not appropriate for the following analysis because the mean duration per hydroperiod has classes in which no data are found (black bars in Fig. 3b) and the number of hydroperiods per year has only a total of four classes. Since the other two hydrological parameters, i.e. mean depth and percentage of time inundated, are more regularly distributed, the following analysis will be focused on identifying the relationship between these two hydrological parameters and vegetation communities.

The water regime in Poyang Lake is affected by the Yangtze River and the aforementioned five tributaries. With complex hydrological characteristics, the Poyang Lake is also a dynamic and diverse area in terms of vegetation communities. There are 2 vegetation types, 3 subtypes and 55 formations according to the criteria of vegetation division provided by “Vegetation in China” (CVEC, 1980). Inside the LNNR, a total of 36 vegetation communities are found, out of a total of 73 across the Poyang Lake. Actually, a total of 42 community types are identified, with 4 non-vegetation community types (i.e. “mud bank”, “sand bank”, “small island” and “open water”) and 2 cultivated community types (i.e. “paddy field” and “garden plot”). 13 vegetation communities constitute more than 0.6% of the total landscape (Table 1) and cover more than 92.71% of all pixels cumulatively within the PLNNR (Table 1). Specifically, the *Carex* community, covering over 50% of the total area, is the most widely distributed plant. The percentage coverage of *Triarrhena lutarioriparia–Carex* community is 10.81%, being the second highest, while that of the rest community types is all below 10% (Table 1).

Herein, we focus on the analysis for two hydrological parameters, i.e. the mean water depth and the percent time inundated, as mentioned previously. Histograms of a vegetation community facilitate the identification of the most preferable hydrological conditions. For example, 4.68% of whole area is covered by the Carex–*P. criopolitanum* community that prefers more humid habitats (Fig. 4c). It predominantly distributes at locations with a mean depth between 2.6 m and 3.8 m (Fig. 4a) and percent time inundated over 70% (Fig. 4b). *Carex–P. criopolitanum* community is more sensitive to hydrological conditions, which could be reflected by the relatively high SI values, i.e. 5.33 and 2.26 calculated for the mean depth and the percent time inundated, respectively (Table 2). Carex -*P. arundinacea* community and *P. arundinacea–Carex* community are found to habitat similar

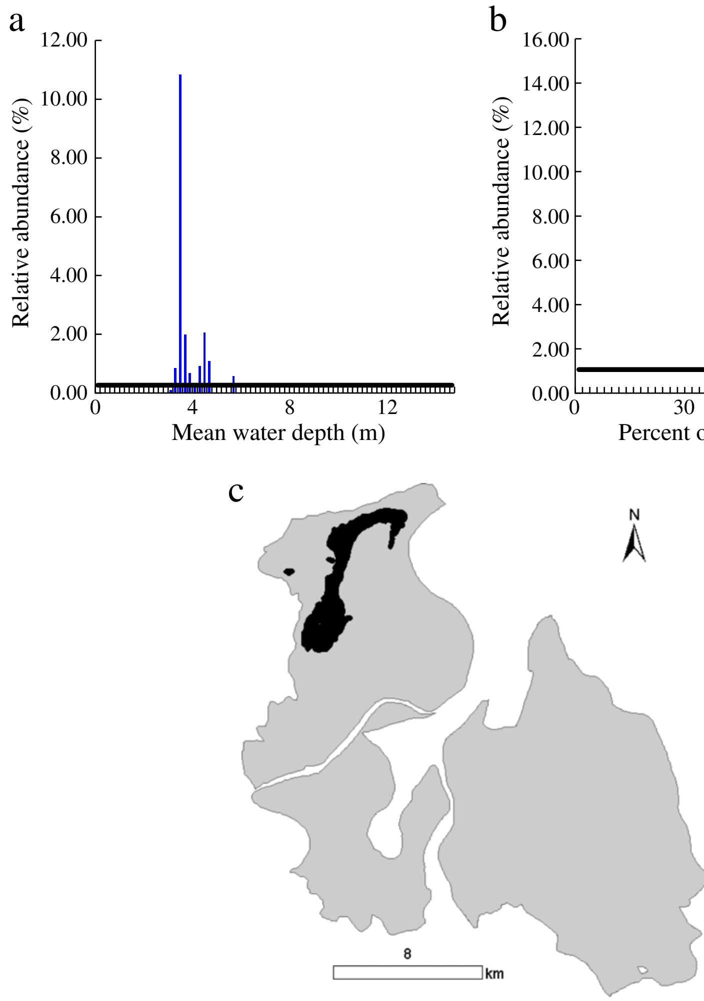

Fig. 6. Relative abundance for (a) the mean depth, (b) the percent time inundated, and (c) spatial distribution of the *Phalaris arundinacea–Carex* community. Black lines in (a) and (b) indicate the average value of relative abundance of the given vegetation community across the entire PLNNR. Black regions in (c) indicate the spatial distribution of the given vegetation community.

hydrological conditions. The *Carex–P. arundinacea* community prefers a mean depth between 3 m and 3.8 m (Fig. 5a) and the percent time inundated over 70% (Fig. 5b), which cannot be detected when the mean water depth is less than 3 m (Fig. 5a). The SI values of *Carex–P. arundinacea* community are also relatively high, being 5.06 and 2.06 for the mean depth and the percent time inundated, respectively (Table 2). The *P. arundinacea–Carex* community occupies the areas with a mean depth ranging from 3.4 m to 4.6 m (Fig. 6a) and the percent time inundated over 75% (Fig. 6b). The corresponding SI values are 4.94 and 2.48, respectively (Table 2).

Meanwhile, plotting a vegetation community and a hydrological parameter also illustrates the sensitivity of the plant type to the given hydrological condition. For instance, although covering 0.62% of the entire study area (Table 1) and scattering in the PLNNR (Fig. 7c), the *Eremochloa ophiuroides* community survives a relatively wide variety of hydrological conditions. It can be found at those areas with the mean depth ranging from 1.8 m to 14.6 m (Fig. 7a) and the percent time inundated between 12% and 100% (Fig. 7b), which implies that the *E. ophiuroides* community is not sensitive to hydrological conditions and may survive at a very wide variety of hydrological processes. As shown in Table 2, the SI values for the *E. ophiuroides* community, 1.09 and 1.24 for the mean depth and the percent time inundated, are lower compared with other vegetation communities with coverage below 2%.

The *Carex* community is the most extensively dominant species within the PLNNR (Fig. 8c), also in the Poyang Lake wetland. Nearly 50.37% of total landscape is covered by the *Carex* community (Table 1). It has been found at locations with a mean depth ranging from 0 m to 14.6 m (Fig. 8a) and the percent time inundated between 0% and 100% (Fig. 8b), which suggests that the *Carex* community is able to tolerate a wide range of hydrological conditions. The low SI values, 0.43 and 0.37 for the mean depth and the percent time inundated respectively (Table 2), also reflect the fact that it is not sensitive to hydrological conditions.

5. Discussion

Previous studies have suggested that multiple factors, such as soil structure, soil water content, nutrition, hydrological conditions, etc., may influence vegetation communities (Allen-Diaz, 1991; Magee and Kentula, 2005; Merendino et al., 1990; Stromberg et al., 1996). The current study supports the contention and implies that distribution of vegetation communities are affected by hydrological gradients in a dynamic and diverse area such as the PLNNR. The hydrological parameters, such as mean depth and percentage of time inundated, are major factors affecting many vegetation community types within the PLNNR. These findings are consistent with the previous studies in that the structure of the Poyang Lake wetland plant ecosystem is closely related to the ground surface elevation, the duration time without water and the water level (Hu et al., 2010). Additionally, Zhang et al. (2009) suggested that the site elevation determining the water depth could affect community composition and species diversity in the East Dongting Lake that is located at the south bank of

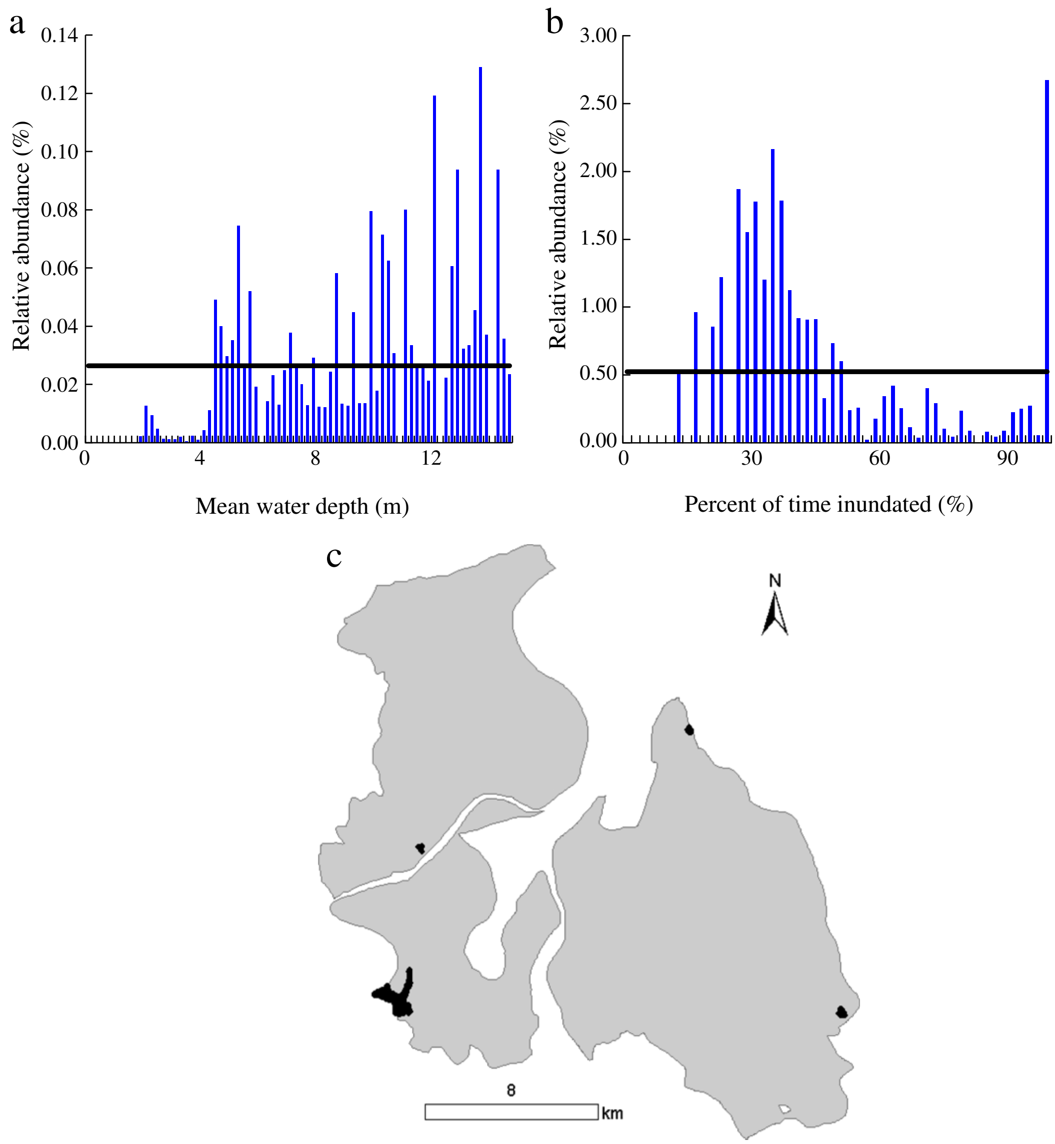

Fig. 7. Relative abundance for (a) mean depth, (b) percent time inundated, and (c) spatial distribution of the *Eremochloa ophiuroides* community. Black lines in (a) and (b) indicate the average value of relative abundance of the given vegetation community across the entire PLNNR. Black regions in (c) indicate the spatial distribution of the given vegetation community.

the Yangtze River and shares similar hydrological conditions and vegetation community types with the Poyang Lake.

Plotting the vegetation community relative abundance with hydrological conditions indicated by the four parameters helps us to analyze the differences among vegetation community types within the PLNNR. The *Carex* community is the most abundant vegetation and covers nearly 50.37% (Table 1) of the vegetation landscape. Histograms illustrate that the *Carex* community can tolerate a wide range of water depth and inundation periods as it is found across all classes (Fig. 8a). The graph of the percent times inundated demonstrates that the *Carex* community is sensitive to the inundation periods compared with the mean water depth. Fig. 8b shows that, while the *Carex* community is found across all classes of percent times inundated, it is much more frequently found at places with percent times inundated between 30% and 80% and it is relatively less frequently detected at locations with inundation periods that are extremely long or short.

The *T. lutarioriparia* community has only been found in specific locations within PLNNR, and makes up 0.63% of the entire study area (Table 1). The *T. lutarioriparia* community mainly distributes in these areas with elevation between 16 m and 17 m above Yellow Sea Datum (Hu et al., 2010), which is slightly higher than that of the *Carex* community. Unlike the *Carex* community, the *T. lutarioriparia* community is predominantly at more xeric environments. For instance, the *T. lutarioriparia* community is found in areas with percent time inundated less than 70%, and it is found most frequently at percent time inundated between 15% and 40% (Fig. 9b). These results support previous conclusions that the *T. lutarioriparia* community grows in the beach of Poyang Lake with higher elevation and relatively short inundation duration (approximately 5–94 days annually) (CRAES, 2009). Furthermore, the *T. lutarioriparia* community, which is found predominantly at locations with mean water depth between 2.2 m and 2.4 m (Fig. 9a), does not live at mean depth greater than 2.6 m which is much less than that of the PLNNR landscape of 3.27 m (Fig. 3c). This indicates that the *T. lutarioriparia* community cannot survive in flooding for a long time.

In contrast, the other vegetation communities, like the *Carex–P. criopolitanum* community, the *Carex–P. arundinacea* community and the *P. arundinacea–Carex* community, are found to favor relatively wet conditions. The three communities are found at locations with percentage of time inundated higher than 70% (Figs. 4b, 5b, 6b) and the mean water depth greater than 3 m (Fig. 4a, 5a, 6a). Histograms

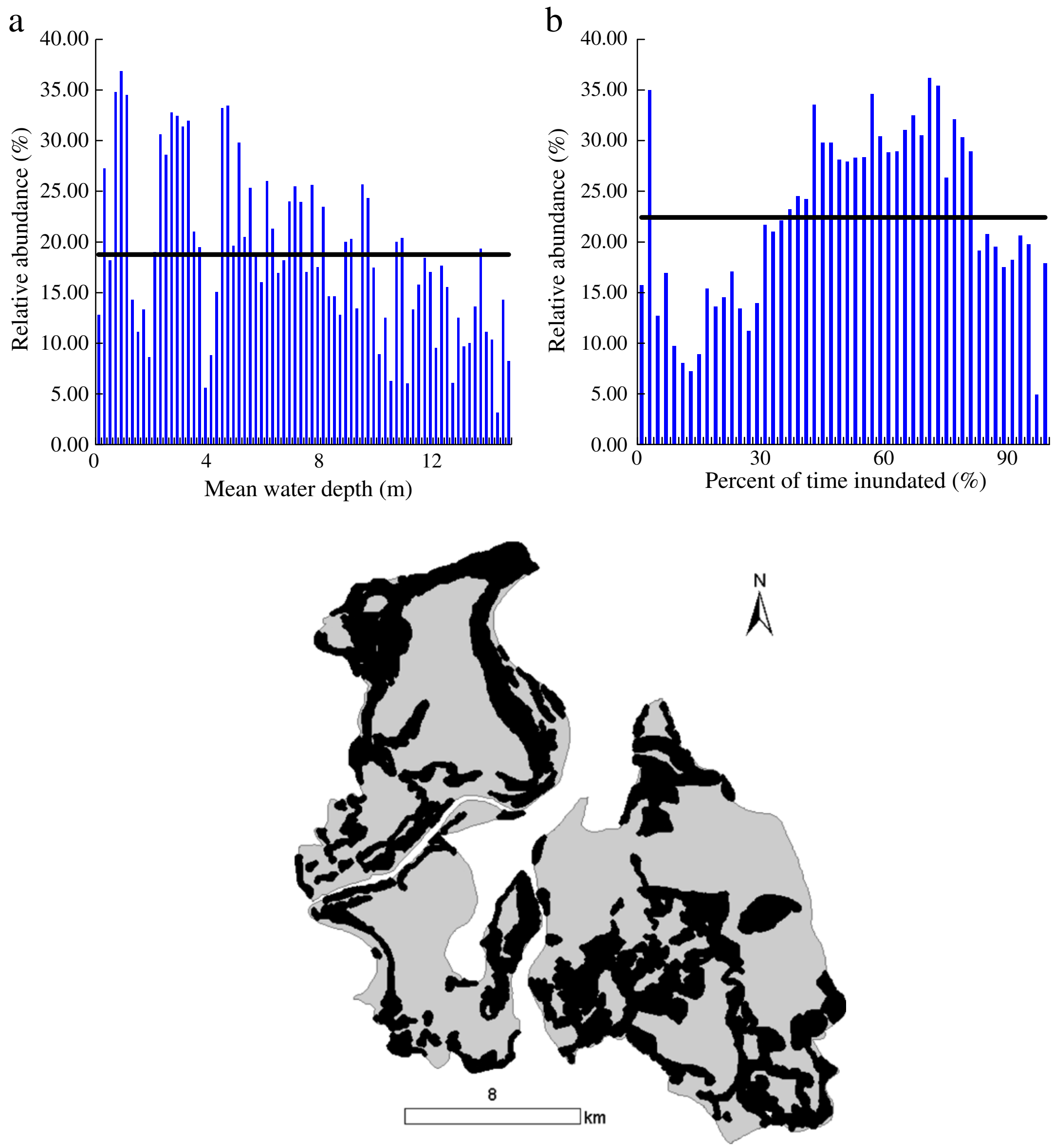

Fig. 8. Relative abundance for (a) mean depth, (b) the percent time inundated and (c) spatial distribution of the *Carex* community. Black lines in (a) and (b) indicate the average value of relative abundance of the given vegetation community across the entire PLNNR. Black regions in (c) indicate the spatial distribution of the given vegetation community.

of relative abundance for the three plant communities indicate that they desire more humid environments within the PLNNR. This implies that these areas originally dominated by the three communities would be replaced by *Carex* community due to the decreased inundation and shorter hydroperiods. The inundation duration of the same site may be shortened and the water level of the PLNNR may become lowered with the discharge of Yangtze River changed due to the operation of the Three Gorges Dam.

While they demonstrate the relationship between individual vegetation community type and hydrological processes, histograms cannot make direct quantitative comparison among vegetation community types. This work therefore defines a Sensitivity Index (SI) to describe the differences among plant community types against hydrological parameters. SI values of a vegetation community indicate whether it is readily influenced by surrounding hydrological conditions. The SI values of 13 vegetation community types are calculated based on four hydrological measures (Table 2). For all of the four hydrological parameters, the SI values of *Carex* community are the lowest, which is reinforced by the graphical evidence (Fig. 8c) and concludes that it may survive a wide variety of hydrological conditions. The SI values also help us to distinguish those vegetation community types which are more “sensitive” to hydrological variations, compared with the other plant communities. For example, the *Carex–P. criopolitanum* community (Table 2) ranks in the top three highest values of SI for all of the four hydrological parameters, which indicate that it may be structured by multiple hydrological variables and it is only able to tolerate a narrow range of hydrological conditions (Fig. 4). Meanwhile, the *Carex–P. criopolitanum* community, the *Carex–P. arundinacea* community and the *P. arundinacea–Carex* community have the top three highest SI values for the two hydrological parameters focused by in this paper, i.e. mean water depth and percent time inundated (Table 2). Additionally, the *Arundinella hirta–Cynodon dactylon* community (Table 2) has the highest value of SI for mean duration of inundation, which reflects the fact that its distribution may be determined by a single hydrological variable. In other words, the *A. hirta–C. dactylon* community can survive if the mean duration satisfies its physiological demands.

There are 9 small lakes in the PLNNR (Hu et al., 1997). The 9 small lakes are connected to Poyang Lake during higher water level in the summer, and separated from the Poyang Lake when water levels are low in other seasons. Among these small lakes, the water level in

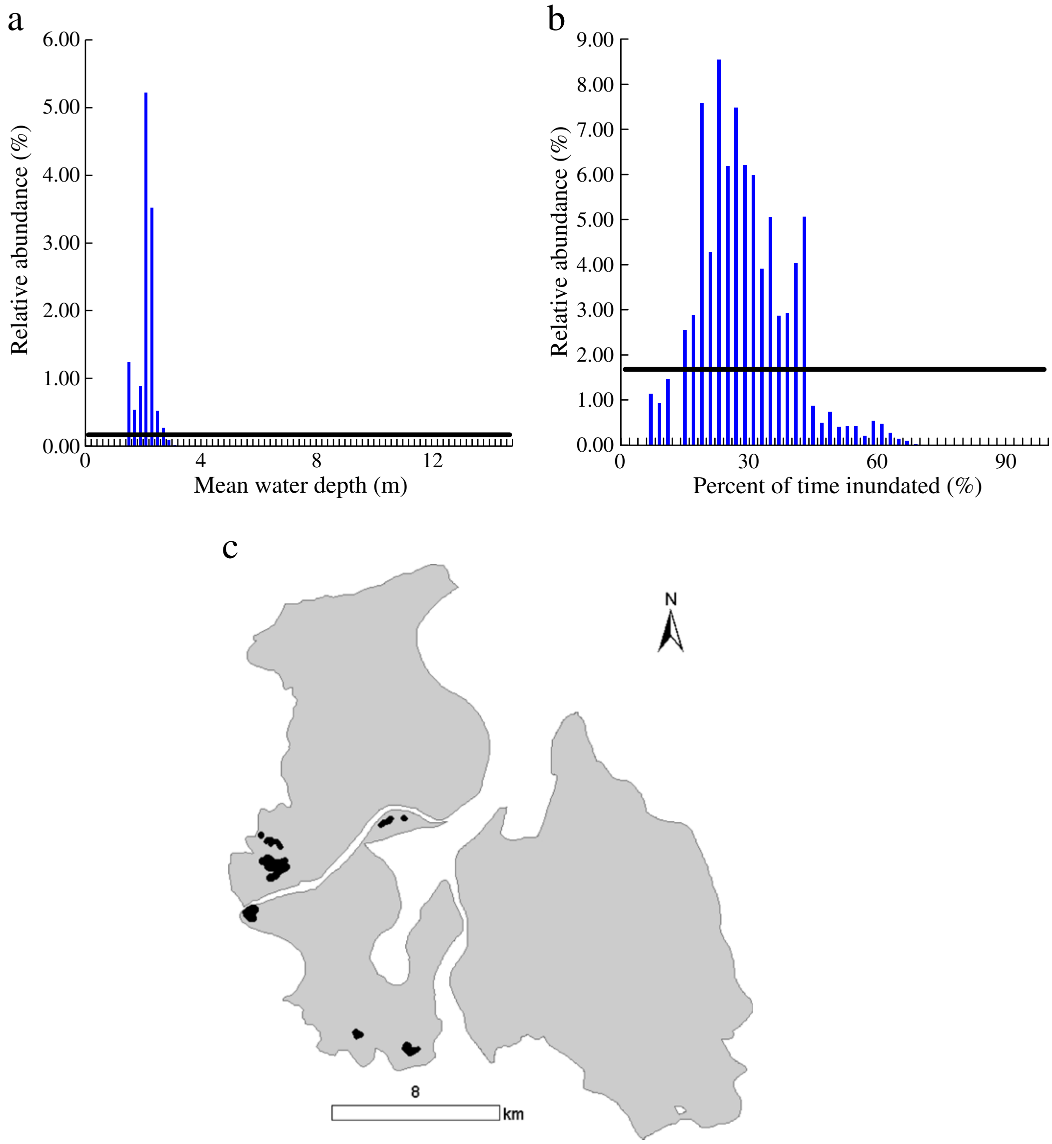

Fig. 9. Relative abundance for (a) mean depth, (b) percent time inundated, and (c) spatial distribution of the *Triarrhena lutarioriparia* community. Black lines in (a) and (b) indicate the average value of relative abundance of the given vegetation community across the entire PLNNR. Black regions in (c) indicate the spatial distribution of the given vegetation community.

Lake Dahuchi has a linear relationship to that of the Poyang Lake when its water level at Hukou is higher than 14 m, otherwise the two lakes are disconnected (Wu et al., 2009). As indicated in Fig. 1, Wucheng station is located on Xiushui River and the local water level is affected by both the Xiushui River and Poyang Lake. This work adopts the water level at Wucheng station to represent that of the entire study area and to calculate the water depth. This choice is made due to the lack of long-term hydrological data for PLNNR and may slightly influence the results.

It may be argued that the vegetation distribution map used in this work represents only a snapshot of the vegetation landscape of the PLNNR and may not accurately reflect the vegetation changes. It is true that the vegetation communities in some places could have changed, but this paper uses a vegetation distribution map covering the entire PLNNR rather than an individual plant community collecting at several sampling quadrates. Thereby, the vegetation distribution map at large scales reduces the chance that a change of plant communities at a single location influences all of the results. Additionally, some physiological factors, such as vegetation biomass and vegetation height, would change with varying external environmental conditions. But the structure of vegetation community types across the PLNNR did not markedly change over ten years. Combined with the fact that we are relating the vegetation communities to hydrological processes over a long period (~10 years), we believe that this analysis gives a good representation of the relationship between the distribution of vegetation communities and the hydrological conditions across the PLNNR.

It is important to note that the vegetation communities grow seasonally with the water regime fluctuating within the Poyang Lake. Some vegetation communities have two growth cycles, one in spring and the other in autumn, while other communities only germinate in spring. For example, some dominant species or constructive species like the *Carex* community and *T. lutarioriparia* community could be found both in spring and autumn. Some associated plants, such as the *Alopecurus aequalis* community, the *Astragalus sinicus* community and the *Medicago sativa* community, only grow in spring and could not be found in autumn (Wu et al., 2010). The vegetation map used in this analysis is made in November and only reprents distribution of vegetation communities in the autumn. Therefore, not all of the vegetation communities within the PLNNR are included in this study, especially those having a single growth cycle in spring. However, the "dominant" vegetation community types are all identified, which can decrease the influences to a certain degree.

6. Conclusion

The importance of spatial and temporal scales in vegetation analysis has been recognized in the last decades. By using hydrological data at a long temporal scale and vegetation community distribution at a large spatial scale, this paper intends to link the hydrological processes with vegetation communities. Although the differences, which is caused by using water levels at Wucheng station to represent that of the entire study area, may affect the values of hydrological parameters. The one-time snapshot vegetation distribution map could not represent the “true” vegetation landscape. However, we believe that the methodology employed in this paper provides a new insight in relating hydrological conditions to vegetation community distribution at wide spatial and temporal scales.

Poyang Lake National Nature Reserve is a highly dynamic and diverse area with abundant vegetation communities along different hydrological gradients. This paper shows the driving hydrological factors for vegetation communities at the ecosystem scale across the entire PLNNR. By plotting the relative abundance of four hydrological parameters and calculating Sensitivity Index, we illustrate that plant communities react differently to hydrological conditions. Specifically, some communities like *Carex* community could grow at a wide variety of hydrological processes while other communities like *Carex–P. criopolitanum* community are only able to survive a relatively narrow range of hydrological conditions.

This work is focused on demonstrating the relationship between hydrological processes and vegetation community distribution. The operation of the Three Gorges Dam will change the water level of Yangtze River (Wang et al., 2005), thereby the water regime of the PLNNR which is controlled both by the Yangtze River and the five tributaries would be changed. The distribution and prevalence of vegetation communities would hence be influenced by the ongoing threats from both climate change and the human actions, especially from the hydro-engineering projects within the watershed (e.g. the Three Gorges Dam). It remains difficult to assess how much vegetation communities would be influenced by the changing hydrological processes due to construction of the Three Gorges Dam. However, the main findings from this work suggest that the change of hydrological environment undoubtedly has great impact on vegetation community distribution. The results could also provide a new insight for the evaluation of hydro-engineering projects on vegetation communities and wetland vegetation restoration.

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