ORIGINAL RESEARCH

Soil Characteristics in Relation to Vegetation Communities in the Wetlands of Poyang Lake, China

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Abstract Poyang Lake is an important wetland with global ecological functions. Impact of plant species composition on soil physicochemical characteristics is potentially critical but is as yet poorly understood in this great, shallow and water passing lake wetland. Five dominant plant communities, *Phragmites communis* community (*Phragmites*), *Polygonum hydropiper* community (*P. hydropiper*), *Artemisia selengensis* community (*A. selengensis*), *Carex cinerascens* community (*C. cinerascens*) and *Phalaris ayuyldinacea* community (*Phalaris*) were surveyed to identify the influences of plant species composition on soil properties. Results show great heterogeneity in soil characters among studied vegetation communities. The lowest average values of pH and soil bulk density are presented in soil with *Phragmites*, while the highest ones are determined in *C. cinerascens* and *A. selengensis*, respectively. Moreover, *C. cinerascens* is determined with the highest average contents of total organic carbon (TOC) and total nitrogen (TN), whereas *Phalaris* community presents the lowest soil carbon and nutrient accumulation in surface soil. Plots of *C. cinerascens*, *Phragmites* and *Phalaris* are identified with obvious convergence patterns, while dispersive patterns are identified in *A. selengensis* and *P. hydropiper*, suggesting great heterogeneity in soil properties among typical communities in Poyang Lake.

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Introduction

Wetlands ecosystems have important global ecological functions in bearing traits of both terrestrial and aquatic ecosystems. Fluctuating hydrology, hydromorphic soils and hydrophilic plant communities are taken as the three key elements in wetland ecosystems that give rise to interplay between aerobic and anaerobic processes (Jessica et al. 2006; Mitsch and Gosselink 2007). During the past several decades great interesting has increased in understanding factors controlling wetland ecosystem processes (Friborg and Soegaard 2003; Anderson et al. 2005; Gan et al. 2009). Hydrological process has been considered as the driving influence that directly changes wetland environmental physicochemical properties, especially oxygen availability and related chemical properties of soils in wetland systems (Pezeshki 2001; Austin 2007). Environmental modifications, such as nutrient availability, pH variation and sediment accumulation, in turn influence the distribution and biodiversity of plant communities (Pakeman et al. 2008; Christensen and Crumpton 2010). As the physical foundation for wetland ecosystem, soil is the principal medium for substances conversion in wetland, as well as the major reservoir of chemical substances for most wetland plants, which can intensively reflects the complex interactions in wetland system evolution (Battaglia and Collins 2006; Hamdan et al. 2010). Like many other ecosystems, wetland biological taxa have feedback controlling on wetland hydrological processes and physicochemical environment. Wetland plants, especially large hydrophilic plants, are the major biological group affecting the ecological processes of wetland (Magnusson and Williams 2006; de Poi et al. 2009). Adapted to anaerobic environment of sediments, wetland plant plays a

dominant role in energy supporting, landscape shaping and nutrient accumulating in wetland systems (Bragazza et al. 2005; Christensen and Crumpton 2010). Through peat formation, sediment retention, nutrient absorption, water occlusion and transpiration process, plants change the physicochemical environment and affect the hydrological processes of wetland (Malmer et al. 2005; Leonard and Croft 2006; Luo and Xie 2009). Furthermore, by absorption and reallocation, wetland plant strongly influences the soil nutrient contents, especially in surface layer (Gathumbi et al. 2005; Dong et al. 2012a). However, the potentially critical impact of plant species composition on soil nutrient status is yet poorly understood under in post-re-flooding ecosystem.

Poyang Lake, the largest freshwater lake in China with international significance in biodiversity conservation, situates in the mid-to-lower reaches of the Yangtze River in Jiangxi province with a large seasonal water level fluctuation. The difference between the lowest mean monthly water level and the highest one is as large as more than 10 m, which exposes vast grass-covered marshland during the dry season from November to April of coming year (Zhu 1997; Wu and Ji 2002). The hydrology, soil and vegetation of Poyang Lake, as well as the interactions among them, have formed a unique wetland ecosystem, which delivers significant environmental services such as water resource supply, floodwater storage, biodiversity maintenance, as well as pollution retention and material provision. However, due to increasing stress from the rapid development of urbanization, industrialization and agricultural cultivation in watershed, Poyang Lake was experiencing water quality deterioration, vegetation succession acceleration and fish miniaturization in the past two decades, which have significantly degraded the wetland functions (Wang, 2005; Yu et al. 2011). Especially in recent years the water level of Poyang Lake exhibited unusual fluctuation after the construction of Three Gorges Dam. The research interest focusing on the wetland ecosystem processes of Poyang Lake has been greatly increased during the past decades (Peng et al. 2003; Dong et al. 2012b). Researches to date primarily focus on two areas: hydrological studies of ecological processes; and environmental studies of water quality and heavy metals distributions (Min 2000; Li and Liu 2002; Hu et al. 2011; Wang et al. 2012). Particularly, these studies have tended to focus on analyses on annual and seasonal variation of water level based on long-term database, and studies on the variations of water quality by quantitatively remote sensing (Wu et al. 2007; Wu et al. 2009; Jin et al. 2011). Previous studies have well indicated characters of hydrological regime and its dominant role in the wetland system functions, such as variation of water quality and plant distribution. However, little has been reported on the relationships between soil properties and vegetation distributing patterns. Moreover, the effluences of the vegetation communities characters on the variation of soil properties, such as biomass and biodiversity,

are yet not well known, which is crucial to understand the effects of vegetation community developing on migratory bird habitat maintenance, nutrient accumulation, as well as carbon cycle driven by water-level fluctuation. Keeping in view of the above mentioned situation, 5 zonal vegetation communities, which are dominant distributing in Poyang Lake, were investigated intensively. Main objectives of this paper were to compare the soil physicochemical properties among the 5 dominant vegetation communities, and to identify factors, such as characteristics of vegetation community and topographical variables influencing on variations of soil properties in Poyang Lake.

Materials and Methods

Study Area

Poyang Lake is situated in the north part of Jiangxi Province with a humid subtropical climate as it is strongly influenced by the East Asian monsoon (Fig. 1). The mean annual temperature is 17.6 °C and the mean annual precipitation is 1,528 mm. The zonal soil in the lake is red soil or yellow brown soil, while the lakeshore is dominated by the azonal meadow soil. The lake receives water from five main rivers (Rao River, Xin River, Fu River, Ganjiang and Xiu River) and discharge water into the Yangtze River through a narrow passage. Accompanied by the fluctuating water level, the plant distribution is characterized with typical ringed pattern along the elevation gradient. Interactions among the hydrology, soil and plants of Poyang Lake have formed a unique wetland ecosystem, which delivers significant environmental services such as water resource supply, floodwater storage, biodiversity maintenance, as well as pollution retention and material provision. Due to diverse topography and complex hydrologic regime, Poyang Lake is one of the biggest bird conservation areas in the world, hosting millions of birds from over 300 species, with great importance to global wetland system protection. Particularly, it is crucial to the conservation of the endangered Siberian crane, as more than 95 % of its world population congregates in the lake during the winter (Wu and Ji 2002; Wang 2005).

Sampling Site and Field Surveying

Five absolutely dominant hydrophilic plant communities in Poyang Lake, *Phragmites communis* community (*Phragmites*), *Polygonum hydropiper* community *(P. hydropiper)*, *Artemisia selengensis* community *(A. selengensis)*, *Carex cinerascens* community (*C. cinerascens*) and *Phalaris ayuyldinacea* community (*Phalaris)*, were studied in this research. Two field researches of the whole lake area were conducted in April of 2010 and 2011 respectively,
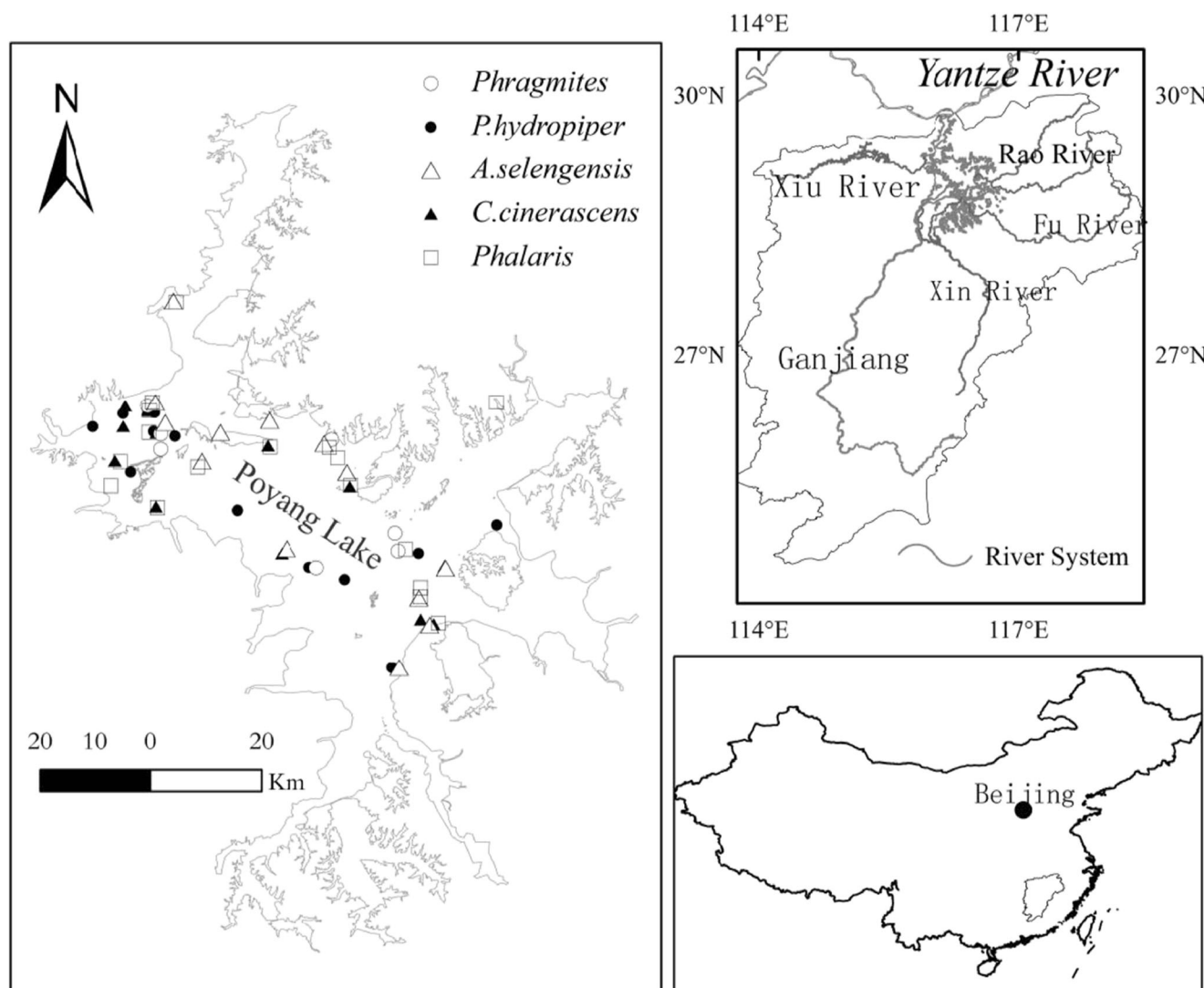
Fig. 1 Study area and surveying plot sites

when the lake beaches were emerged extensively and the dominated plants were in flowering and fruiting period. The number of plots for each vegetation communities was listed in Table 1, and the plot sites for each vegetation communities in 2011 were same to that of 2010. Three random subplots as duplicates were established through throwing 1 m×1 m pine quadrate frame at each plot of the five selected plant communities. At each plot, its geographic coordinates and elevation were recorded by GPS (GPS 60, GARMIN). Gradient was determined by a Multi-functional Slope Measuring Instrument (JZC-B2.050). While vegetation community coverage was estimated using the nine-grade Braun-Blanquet scale (Van der Welle et al. 2003). Soil type was estimated according to the ratio of sand and clay particles (Lu 1999). Detail information of each species in quadrate, including height, amount and phenological phase, were surveyed and recorded on spot. All plants in the quadrate were excavated carefully by a Stainless Steel Spade (WJQ-308) to 30 cm depth for *P. hydropiper*, *A.*

selengensi, *C. cinerascens* and *Phalaris*, and 40 cm depth for *Phragmites*, respectively. Aboveground and underground parts of all plants were sniped after removing soil particles on the stubbles and roots, and then weighed by electronic platform scale on the spot.

About 500 g undisturbed soil were sampled within 0–10 cm layer by stainless steel drilling and preserved in polyethylene sealed bag at each subplot. Besides, surface soil samples were collected by stainless steel cutting ring with inside diameter of 5 cm for soil bulk density (SBD) determination. The cutting ring was sealed immediately and weighed in laboratory to calculate the bulk density according soil moisture and volume of cutting ring (Lu 1999). All soil samples were stored at 4 °C and transported to laboratories within 24 h. These soil samples were analyzed for contents of total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), available nitrogen (AN) and available phosphorus (AP).

Table 1 Descriptions of plots for 5 typical vegetation communities in Poyang Lake

Vegetations Community (Abbreviation)	Plot number (n)	Elevation (m)	Gradient (%)	Soil type	Constructive species	Companion species
Phragmites	7	17–19	0–4	sandy/loam soil	*Phragmites communis* Trin	*Triarrhena lutarioriparia, Cynodon dactylon, Artemisia selengensis, Alopecurus aequalis*
P. hydropiper	12	16–19	0–3	loam soil	*Polygonum hydropiper* L.	*Carex brevicuspis, J. effusus, Potentilla chinensis, Carex lyrata, O.alismoides Pers,*
A. selengensis	14	15–18	1–6	loam soil	*Aremisia selengensis* Turcz	*Carex cinerascens, Carex longerostrata, Echinochloa crusgalli, otentilla chinensis, O.alismoides Pers, Carex argi*
C. cinerascens	18	14–16	0–2	loam/clay soil	*Carex cinerascens* Kukenth	*Cardamine lyrata, Carex argi, Artemisia selengensis,*
Phalaris	17	12–14	2–7	loam soil	*Phalaris arundinacea*	*J. effuses, Polygonum plebeium, Lobelia chinensis, Rumex japonicus, Hygroryza aristata,*

Sample Analysis and Data Analysis

Soil samples were homogenized in a grinder after removal of any visible live plant material, after which they were air dried and passed through a 0.15-mm sieve. Subsamples from each soil sample were oven dried at 105 °C for 24 h to determine moisture content. The soil bulk density for all the soil samples was then calculated based on the dry (oven-dried, 105 °C) weight. Besides, soil samples were equilibrated with deionized water (soil/water=1/2) for one week (to simulate conditions in the wetland), and pH of the equilibrated samples was determined. TOC and TN were measured using a Carlo Erba CNS Analyzer (Carlo Erba, Milan, Italy). TP was determined by the TP ashing method and analyzed by the ascorbic acid colorimetric procedure (Kuo 1996; Technicon Autoanalyzer II, Terrytown, NY). AN was measured using a 10-day anaerobic incubation, followed by extraction with 0.5 M K_2SO_4 (White and Reddy 2001). Extractions were analyzed for NH_4-N using an automated colorimetric analysis (EPA365.1 Technicon Autoanalyzer). AP was also determined using a 10-day anaerobic incubation (Lu 1999).

After data entry, importance value (IVc) of constructive species for each plot was calculated to value species dominance of the community. Equation used for calculating importance value is:

$$IVc = (RDc + RCc + RFc)/3 \qquad (1)$$

Where IV*c*, RD*c*, RC*c* and RF*c* refer to the importance value index, relative density, relative coverage and relative frequency of the constructive species, respectively (Tan 2009). Shannon-Wiener index was calculated to show the species diversity of the communities.

$$H_i = \sum_{i=1}^{S} pi \ln pi \qquad (2)$$

Where H_i is Shannon-Wiener index, representing species diversity of the *i*th plot; *pi* refers to the rate of the *i*th species amount to the sum amount of entire community in the *i*th plot; *S* is the number of plant species in the community.

Average data, range and standard deviation (S.D.) of physicochemical characteristics of surface soil and biomass, constructive species importance value and Shannon-Wiener index of the five dominant plant communities were determined based on pooled samples. Principal component analysis (PCA) was employed to sort the variables of water quality indicators and sampling stations based on datasets. Nonnormality of the data was treated by taking a logarithm or square root, whenever appropriate (Ludwig and Reynolds 1988). All statistic analyses were conducted using SPSS 13.0 statistical software package. Two-tailed test was conducted and significance was determined at the 95 % confidence level.

Results

Physicochemical Characteristics of Surface Soil in Typical Vegetation Communities

Table 2 showed the average values, varying ranges and S.D. of eight common physicochemical parameters of surface soil in typical vegetation communities in Poyang Lake. The average pH values varied in the range of 5.8–6.7 and the lowest was determined in soil with *Phragmites,* while the highest in *C. cinerascens*. Range of average SBD was 0.87 g/cm^3– 1.16 g/cm^3. Soil of *P. communis* had the lowest average SBD, followed by those of *C. cinerascens*, *P. hydropiper* and *A. selengensis*. Average moisture values varied from 29 % to 46 % among five typical vegetation communities. Soil moisture values of *Phragmites* (29 %) and *P. hydropiper*

Table 2 Physiochemical properties of surface soil of 5 typical vegetation communities in Poyang Lake

Vegetations community		pH	SBD (g/cm³)	Moisture (%)	TOC (g/kg)	TN (g/kg)	TP (g/kg)	AN (mg/kg)	AP (mg/kg)
	Average	5.8	0.87	29	30.62	2.11	0.832	211.78	32.27
Phragmites	Range	4.3–6.5	0.76–1.01	19–35	15.35–54.74	1.56–2.97	0.641–0.957	186.30–267.17	17.86–43.55
	S.D.	0.9	0.09	7	8.57	0.24	0.124	20.93	4.61
	Average	6.2	0.98	33	25.51	2.60	0.773	225.89	26.35
P. hydropiper	Range	4.9–6.8	0.85–1.18	28–41	17.83–42.57	1.42–3.73	0.523–0.817	276.38–351.06	10.23–35.64
	S.D.	1.1	0.10	5	5.63	0.57	0.110	18.39	4.68
	Average	6.3	1.16	36	18.24	2.09	0.612	157.03	19.87
A. selengensis	Range	5.3–6.9	0.84–1.25	25–46	6.47–22.86	0.62–2.57	0.316–0.733	54.35–209.83	7.04–24.35
	S.D.	0.6	0.3	5	3.55	0.53	0.106	48.97	4.25
	Average	6.7	0.91	46	34.77	3.15	0.817	308.25	27.59
C. cinerascens	Range	6.3–7.0	0.82–1.14	39–49	22.37–58.91	1.96–4.59	0.624–1.139	247.31–396.24	22.63–39.54
	S.D.	0.2	0.08	4	6.54	0.71	0.176	35.37	3.54
	Average	6.5	1.12	42	12.37	1.04	0.611	112.55	15.87
Phalaris	Range	5.2–7.1	0.98–1.37	31–49	7.54–27.63	0.23–1.25	0.329–0.691	81.35–135.89	7.51–21.28
	S.D.	0.5	0.11	6	4.69	0.19	0.104	14.69	2.91

S.D. refers to Standard Deviation

(33 %) were obviously lower than that of other communities, whereas *C. cinerascens* had the highest soil moisture level with the value of 46 %. As for soil nutrient accumulation, *Phalaris* community presented the lowest contents of TOC, TN, TP, AN and AP, with the values of 12.37 g/kg, 1.04 g/kg, 0.611 g/kg, 112.55 g/kg and 15.87 mg/kg, respectively. The highest average contents of TOC, TN and AN were determined in *C. cinerascens* with the values of 34.77 g/kg, 3.15 g/kg and 308.25 mg/kg, respectively. The highest TP and AP contents were found in soil with *Phragmites,* followed by that with *C. cinerascens* and *P. hydropiper.*

Ecological Characteristics of Typical Vegetation Communities

Phragmites had the significantly highest average value of the constructive species height (2.64 m), followed by those of *A. selengensis* (0.87 m), *Phalaris* (0.72 m), *P. hydropiper* (0.43 m) and *C. cinerascens* (0.36 m) (Fig. 2). Furthermore, constructive species were absolutely predominant in each community, with the average importance values of 93.8 in *C. cinerascens*, 83.2 in *A. selengensis*, 81.5 in *Phalaris*, 74.7 in *P. hydropiper* and 68.6 in *Phragmites*, respectively. As shown in Fig. 3, *C. cinerascens* and *Phragmites* had significantly higher coverage than the others, with the value of 95 % and 90 %, respectively. Conversely, *A. selengensis* and *Phalaris* presented relatively lower value of coverage (75 % and 70 %, respectively). As an important index of community characteristics, the average Shannon-Wiener index in the five communities varied in the range of 0.35–1.64, and the significantly highest biodiversity were determined in *Phragmites* (1.64),

followed by those of *P. hydropiper* (1.06) and *A. selengensis* (0.82). *C. cinerascens*, with the highest value of community coverage, showed a significantly lower biodiversity than that of other communities with the index value of 0.35.

Aboveground biomass and underground biomasses of five typical vegetation communities were shown in Fig. 4. The lowest aboveground biomass was determined in *Phalaris* with the value of 1,483.5 g/m². Whereas *Phragmites* showed the significantly highest aboveground biomass with the value of 5,187.3 g/m², followed by that of *C. cinerascens* (3,134.6 g/m²), *A. selengensis* (2,718.8 g/m²) and *P. hydropiper* (2,651.2 g/m²) with no significant difference among these three communities. The underground biomasses of *C. cinerascens* and *Phragmites* were significantly higher than that of the other communities with the average values of 1,681.2 g/m² and 1,470.5 g/m², while *Phalaris* had the lowest underground biomass with the value of 447.2 g/m².

Relationships between Typical Vegetation Communities and Related Environmental Variables

PCA is one of the simplest eigenvalue analysis based ordination methods for quantitative community data (Lau and Lane 2002). In this study, PCA was performed to identify relationships between community characteristics of surface soil and typical vegetation communities, as well as related environmental variables based on the data sets in all plots. The significant factors (i.e., eigenvalue>1) loading matrix of PCA was listed in Table 3 and the according plot of loadings shown in Fig. 5. Three significant factors (i.e., eigenvalue>1) were extracted by PCA, which explain 83 % of the total
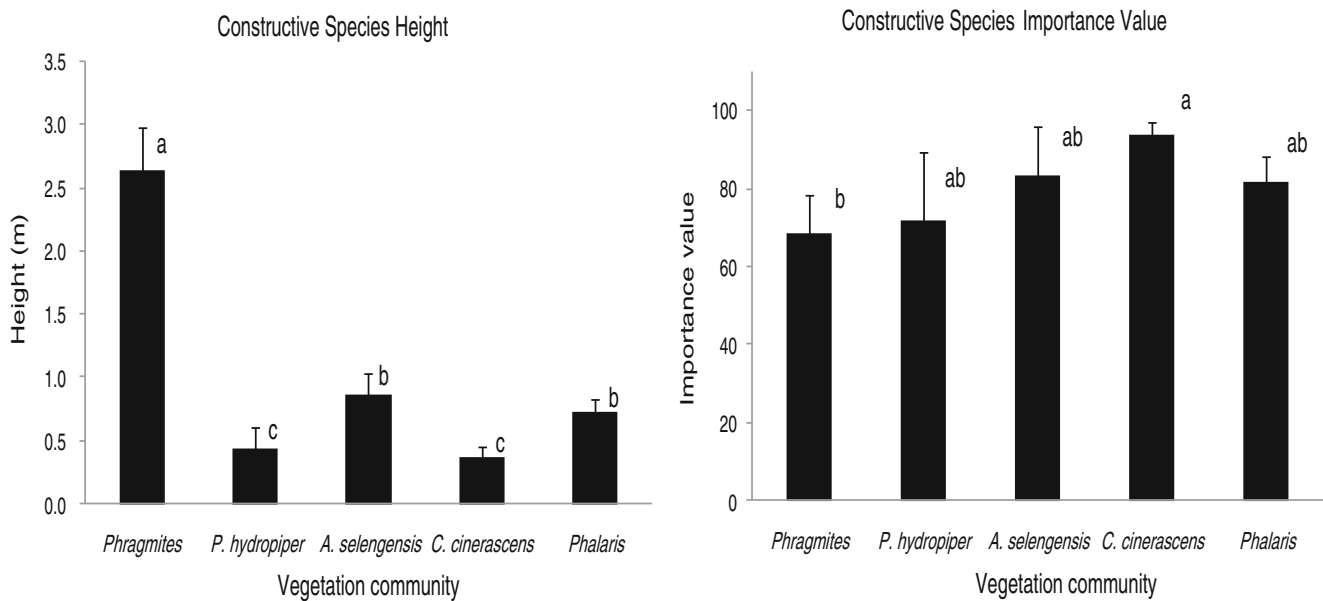
Fig. 2 Height and importance value of constructive species of typical vegetation communities in Poyang Lake (Different letters indicate significant differences for $p \leq 0.05$)

variation (with eigenvalues of 4.92 for factor 1, 1.93 for factor 2 and 1.17 for factor 3, respectively). The first factor accounted for 51 % of the total variance and was positively related to soil nutrient variables (TOC, TN, TP, AN and AP), vegetable biomass (aboveground and underground biomasses) and coverage, and negatively related to SBD significantly. Factor 2 explained 20 % of the total variance and was positively related only to Gradient, while negatively related to height and importance value of constructive species, elevation and soil moisture significantly. Factor 3 accounted for 12 % of

the total variance, positively related to pH and negatively to community biodiversity.

The ordination results of samples plots by PCA (calculated by regression) were shown in Fig. 6. Plots of *C. cinerasces* distributed collectively at upper right corner distinctively with high concentrations of nutrient. Similarly, in accordance with high nutrient contents, the plots of *Phragmites* also showed collective distributing pattern. Conversely, most plots of *Phalaris* were located close to the origin, but showed less relationship with nutrient contents. However, dispersive
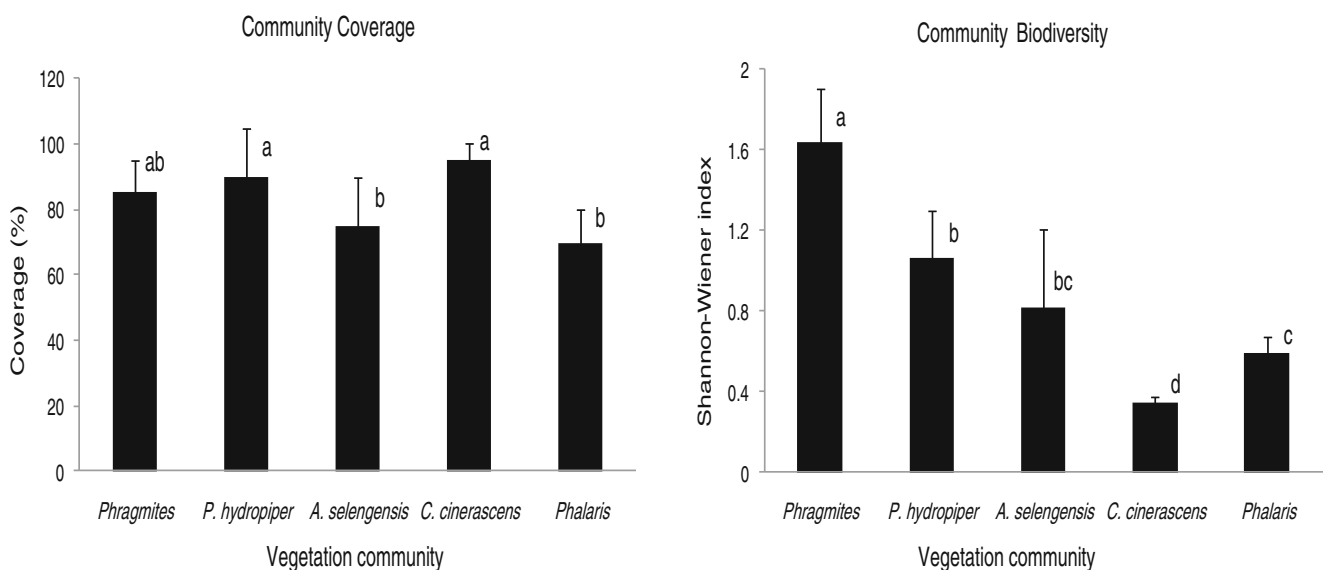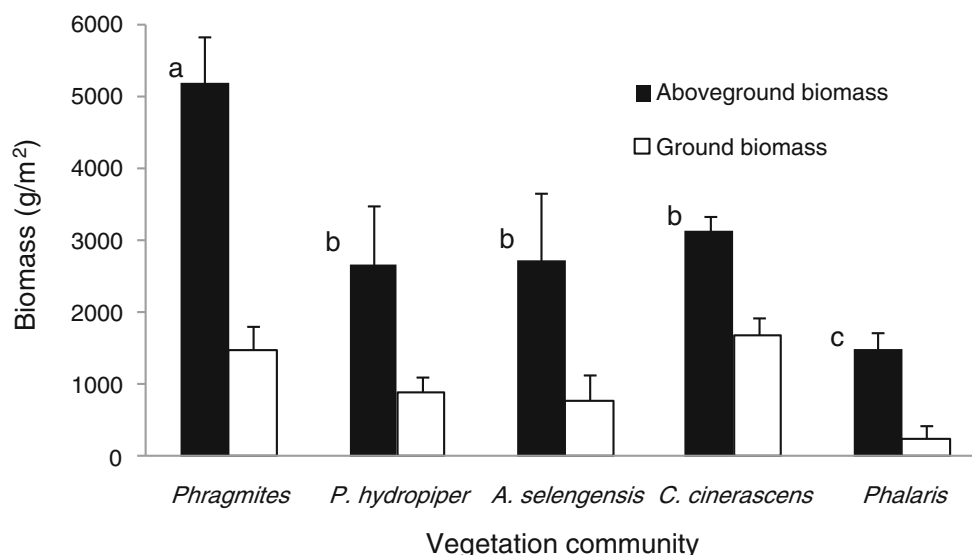

Fig. 3 Coverage and community biodiversity of typical vegetation communities in Poyang Lake (Different letters indicate significant differences for $p \leq 0.05$)

Fig. 4 Community biomass of typical vegetation communities in Poyang Lake (Different letters indicate significant differences for $p \leq 0.05$)

Discussion

Differences in Soil Properties among Typical Vegetation Communities

Variation of soil characteristics in wetland system is a complicated process and is affected by multiple factors, among

patterns were illustrated in distribution of *A. selengensis* and *P. hydropiper* plots.

Table 3 Rotated component matrix of PCA on date sets in all plots

Variables	Factor 1	Factor 2	Factor 3
Elevation	0.351	−0.801	−0.252
Gradient	−0.357	0.905	0.021
Soil moisture	−0.214	−0.786	0.482
Soil bulk density	−0.863	0.452	0.312
pH	−0.297	0.217	0.862
TOC	0.917	−0.351	0.487
TN	0.893	−0.443	0.297
TP	0.725	−0.453	0.219
AN	0.947	−0.217	0.075
AP	0.809	−0.372	−0.114
Height	0.364	−0.868	−0.127
Coverage	0.723	−0.075	−0.334
Importance value	0.217	0.723	−0.382
Aboveground biomass	0.769	−0.221	−0.308
Underground biomass	0.865	−0.442	−0.217
Diversity	−0.352	0.405	−0.856
Eigenvalues	4.92	1.93	1.17
% total variance	51 %	20 %	12 %

which vegetations are regarded as one dominated role in the processing of the soil development and nutrient accumulation (Gary et al. 2002; Silvan et al. 2004). Wetland plants are often distributed in distinct zones and these species composition strongly affect the nutrient content of the soil, which are the most important influences on the spatial variation of soil quality (Yoo et al. 2006; Zhang et al. 2010). In this study, the average values of pH in surface soils varied in the range of 5.8–6.7 among 5 studied vegetation communities, which were higher in comparison to that of soils in upper reaches areas, such as farmland and woodland (Wang 2005; Tang et al. 2008). Soil pH value is an indicative index reflecting the soil fertility and is strongly related to soil type, plant grown on it and saturation, which usually rise accompanying to moisture content increment in red soil (Inubushi et al. 2005; Peng et al. 2005). Thus seasonal flooding and organic matter accumulation in Poyang Lake could increase the pH value of soils. Furthermore, *Phragmites* community was characterized with relatively low pH values compared to that of other vegetation communities. It could be attributed to the longer exposure terms of *Phragmites* community promoting the decomposition rate of organic matter, which released polymeric humic substances decreasing significantly the pH values in surface soil (Thackera et al. 2005; Poi et al. 2009). Moreover, high consistency had been determined between the gradient variations of pH and moisture contents from *Phragmites* to *C. cinerascens*, which indicated hydrologic processes played a major role in the heterogeneity of soil pH in Poyang Lake, since water table of surface soil was strongly influenced by flooding, underground water level and precipitation (Juutinen et al. 2001; Luo and Xing 2010). Generally, bulk density of surface soil was closely related to plant root growth and productivity, and decreased with increasing organic matter content in wetland (Rokosch et al. 2009). In Poyang Lake, *Phragmites* and *C. cinerascens* communities were determined

Fig. 5 Plot of factor loadings by the PCA on the variables of soil, typical vegetation and related environmental variables based on the data sets in all plots, among which A-biomass refer to Aboveground biomass, G-biomass refer to underground biomass
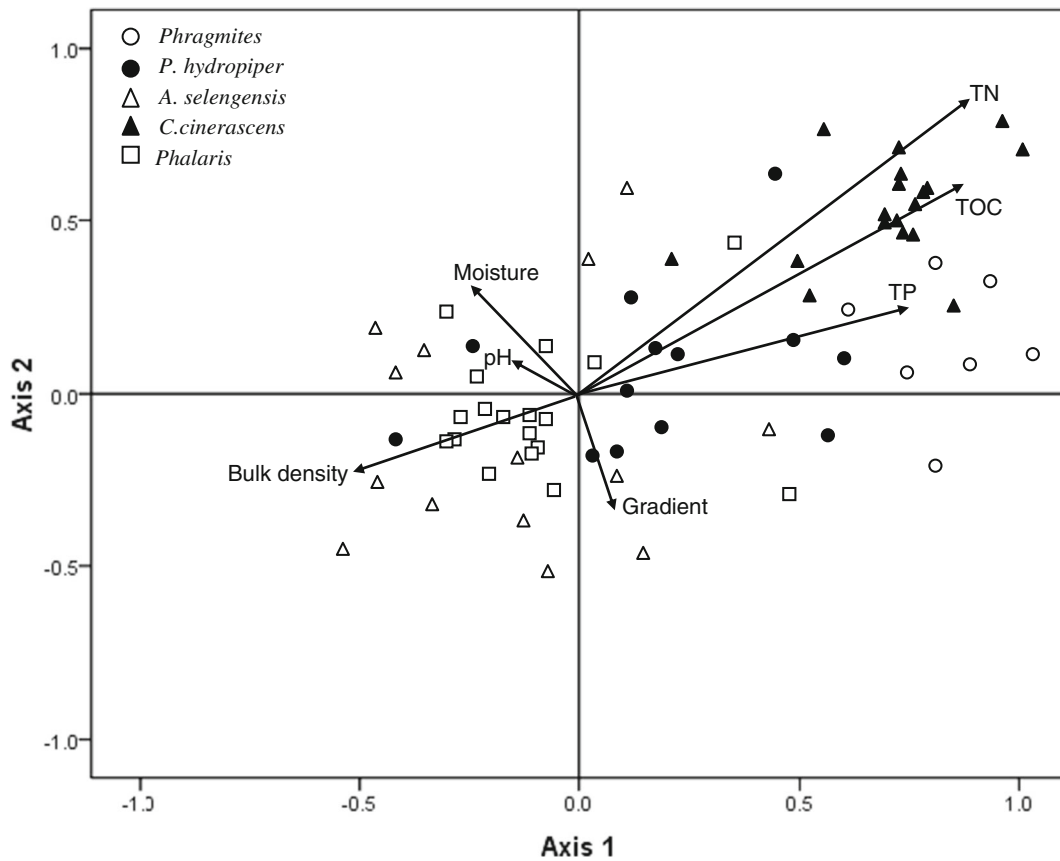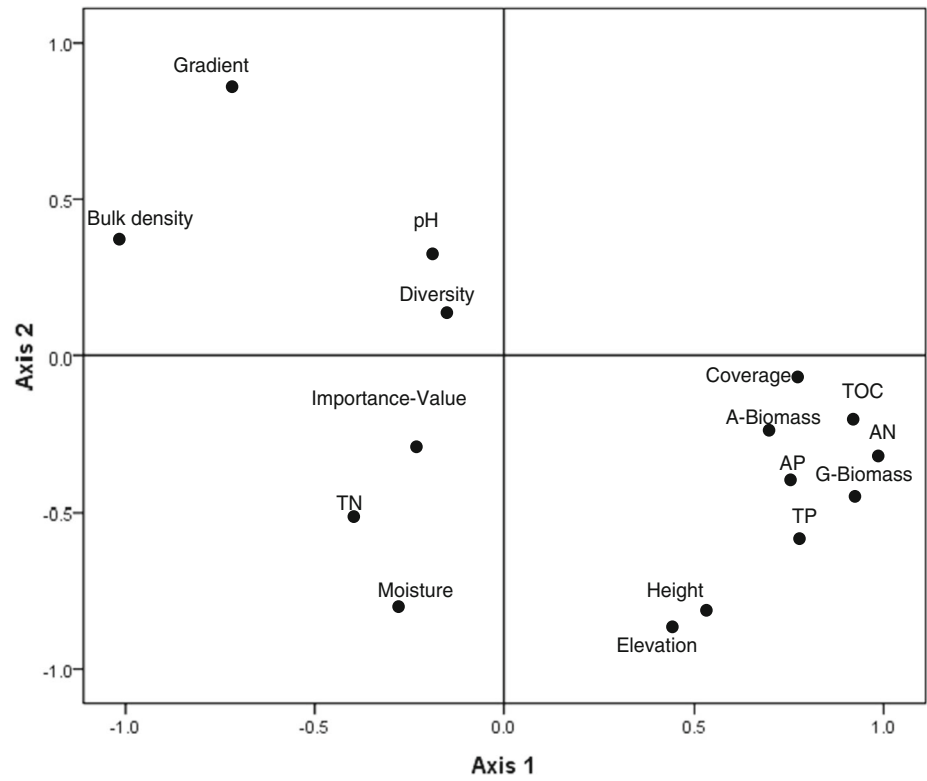

Fig. 6 The ordination plot of samples plots by PCA based on the data sets of variables of soil, typical vegetation and related environmental variables in all plots

with relatively high underground biomasses, while lower value of SBD than that of others. Many studies have found that vegetation type markedly affects organic matter content and nitrogen accumulations in soil by changing the litter fall mass, root growth and soil microbial activity (Huett et al. 2005; Rothman and Bouchard 2007; Luo and Xing 2010; Zhang et al. 2010). In this study, soil with *C. cinerascens* showed the highest average contents of TOC, TN and AN in surface soil layer, despite that *Phragmites* was determined with the significantly highest aboveground biomass. It suggested underground biomass might be more important to soil organic matter and nitrogen retentions than other factors in Poyang Lake. Generally, water-level fluctuation of Poyang Lake was characterized by rapid flooding and receding, which weaken the retention of plant litters aboveground. On the other hand, nutrient cycling is also highly responsive to fluctuating hydrology and oxygen availability. It was argued that decomposition of organic matter was greatly restrained in anaerobic conditions, and return organic carbon and nutrients were accumulated in soil (Malmer et al. 2005; Philippot et al. 2009). Because of shorter inundation period and better permeability, decomposition and mineralization were more active in *Phragmites* community, which partially explained why its organic matter and nitrogen contents were relative lower in comparison to that of *C. cinerascens*. In recent years, due to the continuous low water level, *Phragmites* expanded downward significantly and had occupied greatly the distributing space of *C. cinerascens* in Poyang Lake (Yu et al. 2011). This evolution trend might weaken the function of fixing carbon in Poyang Lake, in view that *Phragmites* and *C. cinerascens* were dominant vegetation communities with the largest distribution area in Poyang Lake (Zhu 1997; Wang et al. 2012). However, the highest contents of TP and AP were found in soil of *Phragmites*, which was contrary to that of nitrogen. It indicated inconsistency in nutrient accumulating process in surface soil under the influence of different plant communities. This had been well elaborated that, due to the significant distinction in the cycling and transforming processes, nitrogen and phosphorus usually presented spatio-temporal difference in their distribution patterns in wetland ecosystems (Heinscha et al. 2004; Song et al. 2008; Wang et al. 2012). Whereas the lowest contents of TOC and nutrient were found in surface soil of *Phalaris*, well fitting the tendency in the distinctions of aboveground and underground biomasses among plant communities.

Factors Influencing the Variations of Soil Properties in Typical Vegetation Communities

Effluences of the vegetation communities on soil properties were examined by using PCA. Soil nutrient variables, combined with vegetation community coverage, vegetation biomass and soil bulk density, had constituted the first components explaining the most part of total variance. Researchers had argued in previous studies that, ascribed to the absorption by plants and fluviraption, the soil nutrient contents in Poyang Lake kept at relatively low levels in comparison to that of other wetlands in China (Wang 2005; Wang et al. 2010; Dong et al. 2012). However, positive relationships are found between nutrients variables and plant biomass in Poyang Lake area in this study, which indicated that plants played a dominant role in nutrient enrichment in surface soil, mainly by plant residue return and decomposition. Though litter fall could be carried away by lake current, underground biomass of plants and root exudates contributes primarily to the organic carbon and nutrient accumulations in Poyang Lake. It had been previously demonstrated that soil bulk density in constructed wetland was influenced significantly by human disturbance, such as deep tillage, surface soil replacement and compaction by machines (Silvan et al. 2004; Marsha and Suzanne 2009). As a protected wetland with international significance, soil bulk density of grassland in Poyang Lake is mainly affected by root growth as the marshland endures fewer compaction activities due to the obstructing by river branchs, which partly explains the correlations between soil bulk density and plant biomass, as well as nutrient contents, in view that accumulation of organic substances could improved the soil quality and decreased the value of soil bulk density (Bellamy et al. 2005; Peng et al. 2005). Furthermore, it indicated that soil bulk density is the potential index reflecting the comprehensive influences by biological, chemical, and anthropogenic processes.

Generally, in water-controlled ecosystems, such as wetlands, plant formations are developed mainly in response to the water balance. Water level fluctuation, rather than soil water content, is the controlling factor to the vegetation development in wetland systems (Pezeshki 2001; Battaglia and Collins 2006). However, according to the results of PCA, soil moisture was significantly related to the height and the importance value of constructive species, suggesting that the variation of soil moisture was also crucial to the species competition and community stability in Poyang Lake. On the other hand, soil moisture was strongly determined by underground water level, vegetation coverage and inundation, which contributed to the high consistency between soil moisture and elevation, resulting in the legible gradient distribution of soil moisture from upland to bottom (Yoo et al. 2006; Sigrid and Kai 2010). Compared to other soil parameters, pH had less influence on plant but important influence on community biodiversity, which consisted of the third independent factor combined with the indicator of biodiversity. It had been observed that significant correlation exists between pH and plant species richness in temperate wetlands, because the modifying processes of community structure were always accompanied by change of pH value (Petra et al. 2006; Mitsch and Gosselink 2007). According to the ordination results of

sampling plots by PCA, significant inconsistency of soil characters had been obtained among the studied typical communities, which suggested that they had developed great heterogeneity in soil characters due to influences of different plant composition. Plots of *C. cinerascens* were identified with obvious convergence, indicating relatively less difference in the surface soil quality among sampling plots, which was similar to that of *Phragmites* and *Phalaris*. On the contrary, it also suggested more discrepancy within *A. selengensis* and *P. hydropiper* communities, respectively, considering the dispersive patterns of their sampling plots.

Conclusions

As a national protected wetland with global significance, Poyang Lake is a vast, highly diverse landscape with numerous vegetative communities subject to a multitude of hydrologic conditions. Five typical vegetative communities, presenting the most wildly distributed vegetations, were investigated intensively across the entire lake. High heterogeneity in properties of surface soil has been identified among typical vegetation communities. Surface soils with *C. cinerascens* and *Phragmites* are determined with relatively high contents of nutrients; while soils with *Phalaris* are characterized with less nutrient accumulation than that of others. As for other parameters, variation of soil bulk density is similar to that of nutrients, and significantly related to the content of soil organic carbon and aboveground biomass, Remarkable positive relationships are found between nutrients variables and plant biomass, especially to underground biomass. Plots of *C. cinerascens*, *Phragmites* and *Phalaris* are clarified with obvious convergence patterns; however, dispersive patterns are identified within the plots of *A. selengensis* and *P. hydropiper*, approving great heterogeneity in soil properties among typical communities. Understanding the variation of soil properties along vegetation gradient and its driving factors are essential to protection of Poyang Lake. Future research on Poyang Lake area should focus upon vegetation evolution pattern and its influences on the ecological functions of the wetland.

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