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Responses of landscape pattern of China's two largest freshwater lakes to early dry season after the impoundment of Three-Gorges Dam

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ABSTRACT

The effects of hydrologic cycle change (caused by human activity and global climate change) on ecosystems attract the increasing attention around the world. As a result of impounding of the Three Gorges Dam (TGD), climate change and sand mining, the dry season of Poyang Lake and Dongting Lake (China's two largest freshwater lakes) came early after the TGD impoundment. It was the primary cause of the increasing need for sluice/dam construction to store water in the Lakes and attracted increasing attention. In this paper, we compared the landscape pattern between three hydrologic years with early dry season (EY) and three normal hydrologic years (NY) of each lake by remote sensing technology, to reveal the effect of early dry season on landscape pattern. The results showed that early dry season caused expanding of *Phalaris* to mudflat zone in Poyang Lake, while caused expanding of *Carex* to *Phalaris* zone and expanding of *Phalaris* to mudflat zone in Dongting Lake. In landscape level, there was no significant difference in landscape grain size, landscape grain shape, habitat connectivity and landscape diversity between EY and NY in the two lakes. While in habitat class level, there were significant changes in area of mudflat and *Phalaris* and grain size of mudflat in Poyang Lake, and in area of *Carex*, grain size of *Phalaris* and grain shape of *Carex* and *Phalaris* in Dongting Lake. These changes will impact migrating birds of East Asian and migratory fishes of Yangtze River.

1. Introduction

The damming of rivers has a global impact on river flow regimes and natural wetlands (Kellogg and Zhou, 2014; Wu et al., 2013; Zhao et al., 2012). Besides, climate change also caused further changes in the hydrologic cycle over the next 100 years (De Jager et al., 2012; Milly et al., 2002; Wu et al., 2015). The Three-Gorges Dam (TGD, in China) on the Yangtze River (Changjiang River) is the largest hydroelectric project in the world (Wu et al., 2013). The project began in 1993, and then commissioning started in 2003 and was completed in 2009. This project has played a key role in controlling frequent catastrophic floods downstream, generating hydropower (with an installed capacity of 18,200 MW), and improving navigation at the upper reaches of the Yangtze (CWRC, 1997). However, the project has caused environmental and ecological problems that have attracted the attention of environmental activists, researchers and communities around the world (Feng et al., 2013; Stone, 2008; Wu et al., 2015, 2003).

As a result of impounding of the TGD (Feng et al., 2013; Liang et al., 2012; Wang et al., 2013), climate change (Feng et al., 2014; Liang et al., 2012) and sand mining (Lai et al., 2014), the dry season of Poyang Lake and Dongting Lake (the downstream wetlands of the TGD, and the two largest freshwater lakes in China) came early after commissioning of the TGD. An early dry season in the two largest freshwater lakes in China is one of the important effects of the TGD and is the primary cause of the increasing need for sluice/dam construction to store water in the wetlands of Poyang Lake and Dongting Lake wetland (Li, 2009; Wu et al., 2015). It also attracted increasing attention from many people around the world. There was an obvious trend of early starting dates for the dry season of the Poyang Lake wetland (-7.35 days year^{-1}) and the Dongting Lake wetland (-3.42 days year^{-1}) from 2000 to 2009 (Feng et al., 2013). Zou et al. (2000) predicted that the average starting date of the dry season for the Dongting Lake wetland arrived 2, 7 and 35 days early in a high-flow year, a median-water year and a

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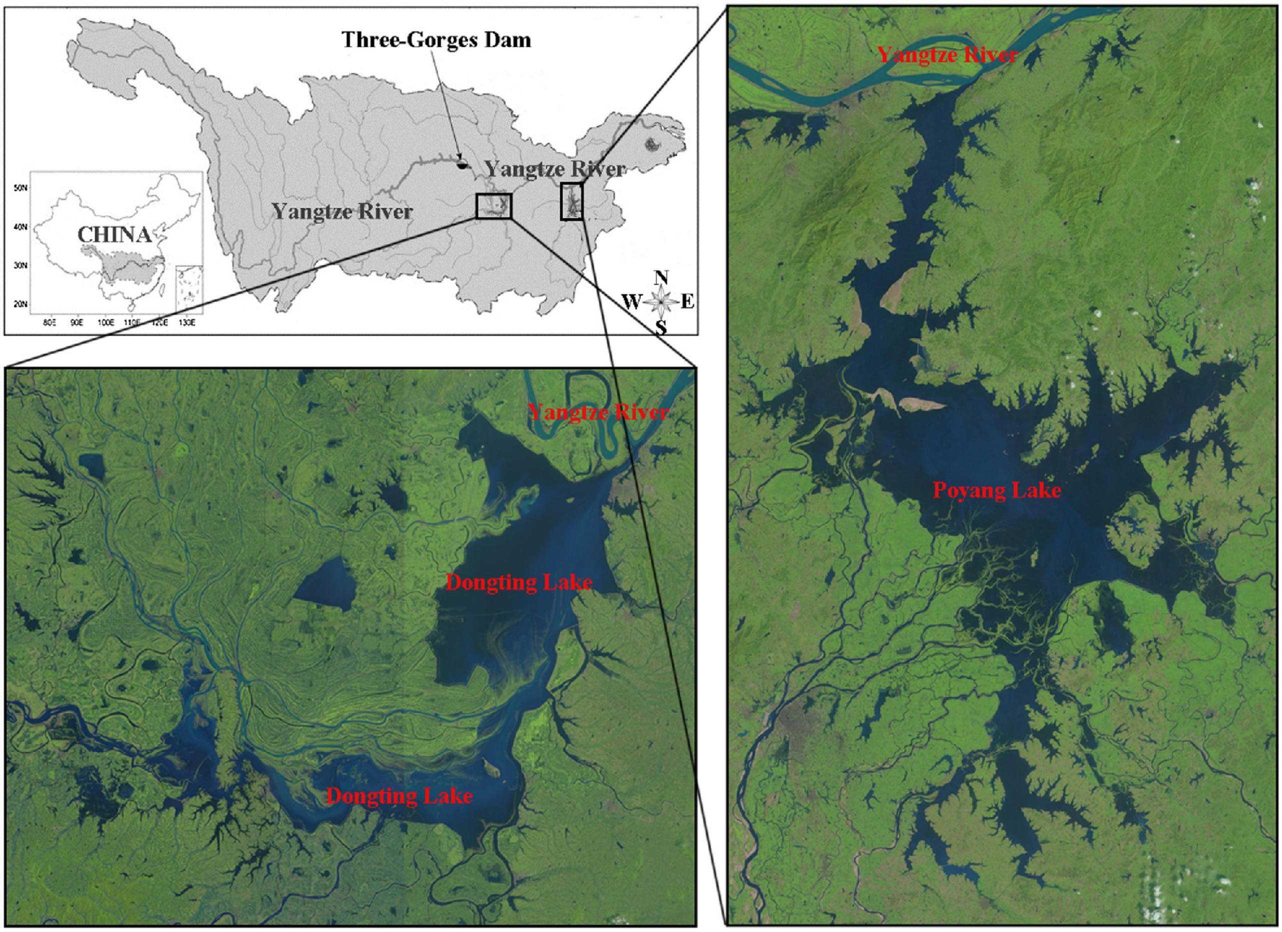

Fig. 1. Locations of Poyang Lake, Dongting Lake and Three-Gorges Dam (TGD).

low-flow year, respectively, during the early stages of the TGD construction and that this increase in lead time would continue for 50 years after impoundment of the TGD was constructed. Liang et al. (2012) found that the average starting date of the dry season for the Dongting Lake wetland in the post-TGD period (2003–2010) was 18 days earlier than that for the pre-TGD period (1981–2002).

Several studies have been conducted on the early dry season, but have primarily been focused on the prediction, verification and analysis of the early starting dates (Wu et al., 2015; Huang et al., 2008). However, little is known about the effect of the early dry season on landscape pattern (or vegetation). Landscape pattern is sensitive to local changes in the environmental conditions (Hoorn et al., 2010; Zeng et al., 2013b), biology (Gurnell, 2012; Zhang et al., 2016) and anthropogenic activity (Wright and Wimberly, 2013; Zeng et al., 2013a), and affects ecological progresses (Fahrig et al., 2011; Heffernan et al., 2014) and services of ecosystems (Gong et al., 2009; Lawler et al., 2014), biology population (Fischer and Lindenmayer, 2007; Xu et al., 2012) and biodiversity (Fahrig et al., 2011; Lawler et al., 2014). The change of hydrologic cycle could affect landscape pattern of wetland (De Jager et al., 2012; McClain et al., 2003; Tang et al., 2008). Therefore, the early dry season will impact landscape pattern (or vegetation) of the two largest freshwater lake wetlands in China (Wu et al., 2015). And the changes of landscape pattern of the two wetlands will impact migrating birds of East Asian and migratory fishes of Yangtze River.

In this study, we used TM/ETM data to investigate the landscape pattern of the Poyang Lake and Dongting Lake in hydrologic year which had an early dry season (EY) and which had normal dry season (NY), and analysis the effect of early dry season on landscape pattern. The dry season, had an obvious earlier starting day than the mean starting day before TGD, was EY. The dry season, had a starting day close to the mean starting day before TGD, was NY. The objectives of this study were as follows: (1) to analyze the responses of landscape pattern of the two largest freshwater lakes in China to the early dry season after impoundment of the TGD; and (2) to provides the basis for studies of the effect of early dry season on biology (especially migrating birds and migratory fishes).

2. Materials and methods

2.1. Study area

The Yangtze River (Changjiang River) is one of the major rivers on earth and plays a critical role in the global water cycle, sediment cycle, energy balance, climate change and ecological development (Dai et al., 2016; Wu et al., 2015). The river exhibits seasonal variability in the water level and area from monsoon-driven precipitation, such that there is a high water level and area in the wet season from May to October and a low water level and area in the dry season from November to the following April (Li et al., 2011; Zhang et al., 2007). The TGD is located 44 km upstream of Yichang station (the control point of the upper Yangtze River basin) (Hu et al., 2011; Wu et al., 2015). Many lakes are located downstream of the TGD. Among these lakes, Poyang Lake (28°11′–29°51′ N, 115°31′–117°06′ E) and Dongting Lake (28°30′–29°38′ N, 112°18′–113°15′ E) (Fig. 1) are the two largest freshwater lakes in China (Feng et al., 2013; Wu et al., 2015). In normal water periods, areas of Poyang Lake and Dongting Lake

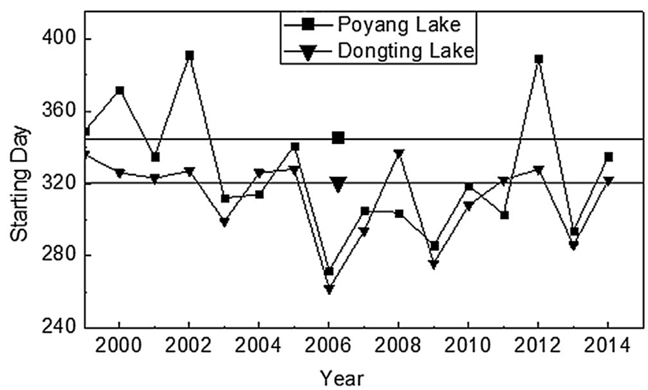

Fig. 2. The starting day of dry season (2001–2014) in Poyang Lake and Dongting Lake and mean value (indicated by the line) before TGD.

Table 1
Landsat images used in this study. Hydrologic year: from May to next April. *: Data of overlapping portions of Dongting Lake (above 90% Dongting Lake overlay appears on the 123/40 and 124/40 images) using this image.

Lake	Hydrologic year	Date	Path/Row	Sensor
Poyang Lake	1999	27/01/2000	121/40	TM
	2001	08/01/2002	121/40	TM
	2007	01/01/2008	121/40	ETM+
	2008	11/01/2009	121/40	TM
	2009	14/01/2010	121/40	TM
	2014	04/01/2015	121/40	ETM+
Dongting Lake	2003	27/01/2004*	124/40	ETM+
		05/02/2004	123/40	ETM+
	2004	06/01/2005*	123/40	ETM+
		28/12/2004	124/40	ETM+
	2005	09/01/2006 *	123/40	ETM+
		15/12/2005	124/40	ETM+
	2006	28/01/2007*	123/40	ETM+
		19/01/2007	124/40	ETM+
	2010	07/01/2011*	123/40	ETM+
		21/12/2010	124/40	TM
	2013	22/01/2014*	124/40	ETM+
		23/01/2014	123/40	OLI

are about 3490 km^2 and 2790 km^2 (Hu et al., 2015). Poyang lake exchanges water with the Yangtze River at Hukou in the north and mainly receives water from local rivers (Ganjiang River, Fuhe River, Xiushui River, Xinjiang River, and Raohe River) (Fan et al., 2008; Feng et al., 2013). Dongting Lake receives water from its four tributaries (Xiangjiang River, Yuanjiang River, Zishui River and Lishui River) and the Yangtze River and empties into the Yangtze River at Chenglingji (Wu et al., 2013). These lakes are the important wintering habitats and pathways for East Asian migratory birds (Zeng et al., 2015), and the important spawning grounds, feeding grounds and migration routes of migratory fishes. The starting date of dry season of the two lakes each year after impoundment of the TGD (2003–2014) and the average starting date of dry season of the two lakes before TGD (1950′s–2002) are shown in Fig. 2.

2.2. Datasets

Satellite images, field surveys and gauged hydrological measurements were used in this study. The satellite data collected by Landsat instruments, which including TM, ETM+, and OLI. These data were downloaded from United States Geological Survey (USGS) (http://www.usgs.gov). Considering the starting date of dry season, the large size of the Poyang Lake and Dongting Lake, and common cloudiness which limit frequent acquisition of high-resolution images, we chose 18 scenes (listed in Table 1) of Landsat image. The geometric correction of these satellite images was finished according to the previous approach (Hu et al., 2015).

Field surveys of ecology in the two wetlands were conducted in January of 2001–2015. *Phragmites*, *Carex*, *Phalaris*, sand, mudflat, shallow water (depth < 0.5 m), and deep water (depth ≥ 0.5 m) were the main types in Poyang Lake. *Phragmites*, *Carex*, *Phalaris*, mudflat, shallow water, and deep water were the main types in Dongting Lake. More than 20 zones (60 × 60 m) of each type in each lake were surveyed in January. The geographic coordinates (located by GPS locator) of the zone center was recorded. These data were used as reference data of landscape classification process.

Hydrological data of Xingzi hydrologic station and Chenglingji hydrologic station represent the hydrology of the Poyang Lake and Dongting Lake, respectively, and was used in this study. 2006, 2007 and 2009 hydrologic year (from May to next April) of Poyang Lake and 2003, 2006, 2013 hydrologic year of Dongting Lake were elected as the EY's representative. And 1999, 2001 and 2014 hydrologic year of Poyang Lake and 2004, 2005 and 2010 hydrologic year of Dongting Lake were elected as the NY's representative.

2.3. Landscape classification

Maximum likelihood method, one of typical supervised classification method, was an effective approach for wetland landscape type classification (Jensen, 1996). Landscape type of Poyang Lake was classified as *Phragmites*, *Carex*, *Phalaris*, sand, mudflat, shallow water (depth < 0.5 m), and deep water (depth ≥ 0.5 m). There was chromatic aberration between shallow water and deep water on satellite images, and it made that shallow water and deep water could be classed using maximum likelihood method. Landscape type of Dongting Lake was classified as *Phragmites*, *Carex*, *Phalaris*, mudflat, shallow water, and deep water. Water body was classified as shallow water and deep water because shallow water and deep water had significant different habitat suitability for migrating birds and fishes. Landscape types of each scene (listed in Table 1) of Landsat image were classified according to the Maximum Likelihood methods using ENVI 4.8 software. Then image mosaic of the results of the two scenes of Dongting Lake of each year was finished. Above 90% of Dongting Lake overlay appears on the two images and data of overlapping portions of Dongting Lake using the image (marked by *) to get the high quality and similar time image of each year. Finally we isolated the main each lake area from their surroundings by the masks developed from images of the highest flood extent of wet season.

2.4. Applying landscape pattern indices

Table 2 shows the landscape pattern indices applied in this study (Corry, 2005; Tischendorf, 2001). These indices contained two levels: landscape level and habitat class level. Landscape level indices contained Largest patch index (LPI), Mean patch size (MPS), Area-weighted mean patch fractal dimension index (AWMPFDI), Mean nearest neighbor distance (MNN), Interspersion & juxtaposition index (IJI), and Simpson's diversity index (SDI) of the whole landscape. Habitat class level indices contained Total area (TA), Largest patch index (LPI), Mean patch size (MPS), Area-weighted mean patch fractal dimension index (AWMPFDI), Mean nearest neighbor distance (MNN), and Interspersion & juxtaposition index (IJI) of each wetland cover types (*Phragmites*, *Carex*, *Phalaris*, sand, mudflat, shallow water, and deep water). Calculation of landscape indicators of each year were conducted using Fragstats (version 3.3) software.

2.5. Data analysis

The mean values of indices of EY and NY were compared by one way analysis of variance (ANOVA) to assess significant differences ($p < 0.05$) in all values. The correlations between the starting date

Table 2
Landscape pattern attributes, indices, and abbreviation used in this study.

	Landscape attributes	Landscape indices	Abbreviation
Landscape-level	Landscape grain size	Largest patch index	LPI
		Mean patch size	MPS
	Landscape grain shape	Area-weighted mean patch fractal dimension index	AWMPFDI
	Habitat connectivity	Mean nearest neighbor distance	MNN
		Interspersion & juxtaposition index	IJI
	Landscape diversity	Simpson's diversity index	SDI
Class-level	Class area	Total area	TA
	Class grain size	Largest patch index	LPI
		Mean patch size	MPS
	Class grain shape	Area-weighted mean patch fractal dimension index	AWMPFDI
	Habitat connectivity	Mean nearest neighbor distance	MNN
		Interspersion & juxtaposition index	IJI

of dry season and each landscape pattern indices were tested by Pearson correlation analysis. All of the analyses were finished using SPSS (version 19).

3. Results

3.1. Expanding of vegetation

Fig. 3 shows the classification maps of Poyang Lake and Dongting Lake of each studied hydrologic year. The spatial distributions of all wetland cover types of the two largest lakes were clearly demonstrated within each figure. In general, the wetland cover types changed from vegetation to mudflat and finally to water body from the boundary to the center of Poyang Lake and Dongting Lake. Besides, the differences between EY and NY were also revealed across each map. In general, the early dry season caused expanding of *Phalaris* to mudflat zone in Poyang Lake. While it caused expanding of *Carex* to *Phalaris* zone and expanding of *Phalaris* to mudflat zone in Dongting Lake.

In Poyang Lake, *Phalaris* respectively covered 16.55% and 8.25% of the total area in EY and NY. *Carex* and *Phragmites* respectively covered 26.53% and 3.69% of the total area in EY and 23.99% and 4.22% of the total area in NY. And vegetation (*Phalaris*, *Carex* and *Phragmites*) respectively covered 46.78% and 36.67% of the total area in EY and NY. Deep water, shallow water, mudflat and sand respectively covered 24.89%, 12.12%, 14.64% and 1.58% of the total area in EY and 28.98%, 9.89%, 22.82% and 1.63% of the total area in NY.

In Dongting Lake, *Carex* respectively covered 32.09% and 26.87% of the total area in EY and NY. *Phalaris* and *Phragmites* respectively covered 12.74% and 16.68% of the total area in EY and 13.15% and 17.58% of the total area in NY. And vegetation (*Phalaris*, *Carex* and *Phragmites*) respectively covered 61.51% and 57.60% of the total area in EY and NY. Deep water, shallow water and mudflat respectively covered 17.50%, 5.94% and 15.05% of the total area in EY and 16.12%, 8.20% and 18.08% of the total area in NY.

3.2. Responses of indices to early dry season

The values of landscape level indices of the two largest lakes are shown in Table 3. In Poyang Lake, there was no significant difference in LPI, MPS, AWMPFDI, MNN, IJI and SDI between EY and NY. In Dongting Lake, there was also no significant difference in these landscape level indices.

Fig. 4 shows habitat class level indices of each wetland cover type of Poyang Lake and Dongting Lake in NY and EY. In Poyang Lake, TA of *Phalaris* in EY was significant higher than that of NY. However, TA of deep water and mudflat in EY was significant lower than that of NY. TA of shallow water, sand, *Carex* and *Phragmites* had no significant difference between NY and EY. LPI of mudflat in EY was significant lower than that of NY. While LPI of other cover types had no significant difference between NY and EY. IJI of sand in EY was significant higher than that of NY. While IJI of *Phragmites* in EY was significant lower than that of NY. And IJI of other cover types had no significant difference between NY and EY. Besides, MPS, AWMPFDI and MNN of each cover type also had no significant difference between NY and EY.

In Dongting Lake, TA of *Carex* in EY was significant higher than that of NY. However, TA of deep water, shallow water, mudflat, *Phalaris* and *Phragmites* had no significant difference between NY and EY. LPI of shallow water and *Phalaris* in EY was significant lower than that of NY. While LPI of other cover types had no significant difference between NY and EY. AWMPFDI of *Phalaris* in EY was significant lower than that of NY, while AWMPFDI of *Carex* in EY was significant higher than that of NY. AWMPFDI of other cover types had no significant difference between NY and EY. Besides, MPS, MNN and IJI of each cover type also had no significant difference between NY and EY.

Table 4 shows the correlations between the starting date of dry season and habitat class level indices. In Poyang Lake, there were significant positive correlations between TA of mudflat, LPI of mudflat and IJI of *Phragmites* and the starting date of dry season, a significant negative correlation between IJI of sand and the starting date of dry season, and no significant correlation between other indices and the starting date of dry season. In Dongting Lake, there were significant positive correlations between LPI of shallow water, LPI of *Phalaris* and AWMPFDI of *Phalaris* and the starting date of dry season, a significant negative correlation between IJI of *Phragmites* and the starting date of dry season, and no significant correlation between other indices and the starting date of dry season.

4. Discussion

4.1. Responses of landscape pattern to early dry season

Other studies also showed roughly similar distributions of cover types in Poyang Lake and Dongting Lake (Han et al., 2015; Hu et al., 2015; Wang et al., 2012). Some statistical data was also coincident. Such as, Hu et al. (2015) found *Phragmites* and *Carex* respectively covered 2–5% and 24–31% of Poyang Lake area. These demonstrated the classification result of this study was credible. There were also some differences of total areas of other cover types between this study and above studies. This was because 1) the date of images of remote sensing was different. The images applied in this study mostly were in January (middle time of dry season) and the date was similar in each hydrological year. However, the images applied in above studies were not in January and the date was not close in each hydrological year. And 2) the boundary of Dongting Lake was different. The boundary of Dongting Lake in this study was limited to the main body of the lake. However, that of Hu et al. (2015) was contained the main body of the lake and wide benchland around the lake.

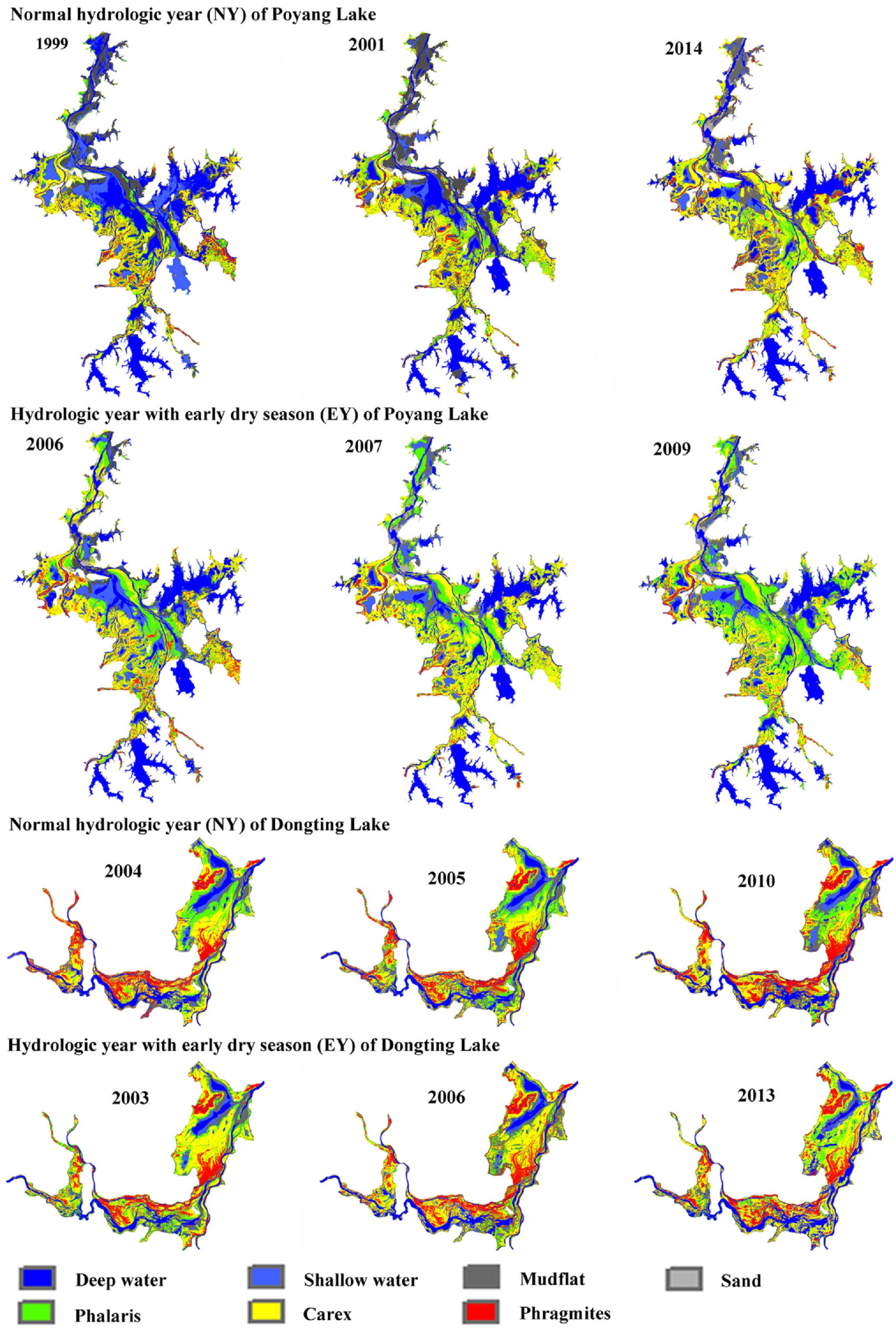

Fig. 3. The distributions of each cover type of each hydrologic year (from May to next April) in Poyang Lake and Dongting Lake.

This study showed that early dry season caused the expansion of *Carex* and *Phalaris*. This was because the duration of flood inundation and beach emergence is a critical environmental factor that affects the vegetation of floodplains (Auble et al., 1994; De Jager et al., 2012; Wu et al., 2015). *Phragmites*, *Carex*, *Phalaris* and mudflat were distributed along the decrease of duration of beach

Table 3
The values of landscape level landscape pattern indices of NY (hydrologic year with early dry season) and EY (normal hydrologic year) in Poyang Lake and Dongting Lake. *ns* indicates no significant (*P > 0.05*) differences between NY and EY.

Indices	Poyang Lake			Dongting Lake		
	NY	EY		NY	EY	
LPI	8.53 ± 4.27	4.58 ± 0.61	*ns*	8.45 ± 5.32	8.23 ± 3.62	*ns*
MPS	3.28 ± 0.64	3.24 ± 1.00	*ns*	2.96 ± 0.12	2.58 ± 0.50	*ns*
AWMPFDI	1.22 ± 0.02	1.22 ± 0.02	*ns*	1.23 ± 0.01	1.22 ± 0.00	*ns*
MNN	84.25 ± 15.40	80.59 ± 15.62	*ns*	69.63 ± 4.00	69.56 ± 3.35	*ns*
IJI	72.24 ± 3.33	70.77 ± 2.18	*ns*	77.12 ± 1.72	81.65 ± 4.49	*ns*
SDI	0.78 ± 0.01	0.80 ± 0.01	*ns*	0.81 ± 0.01	0.79 ± 0.01	*ns*

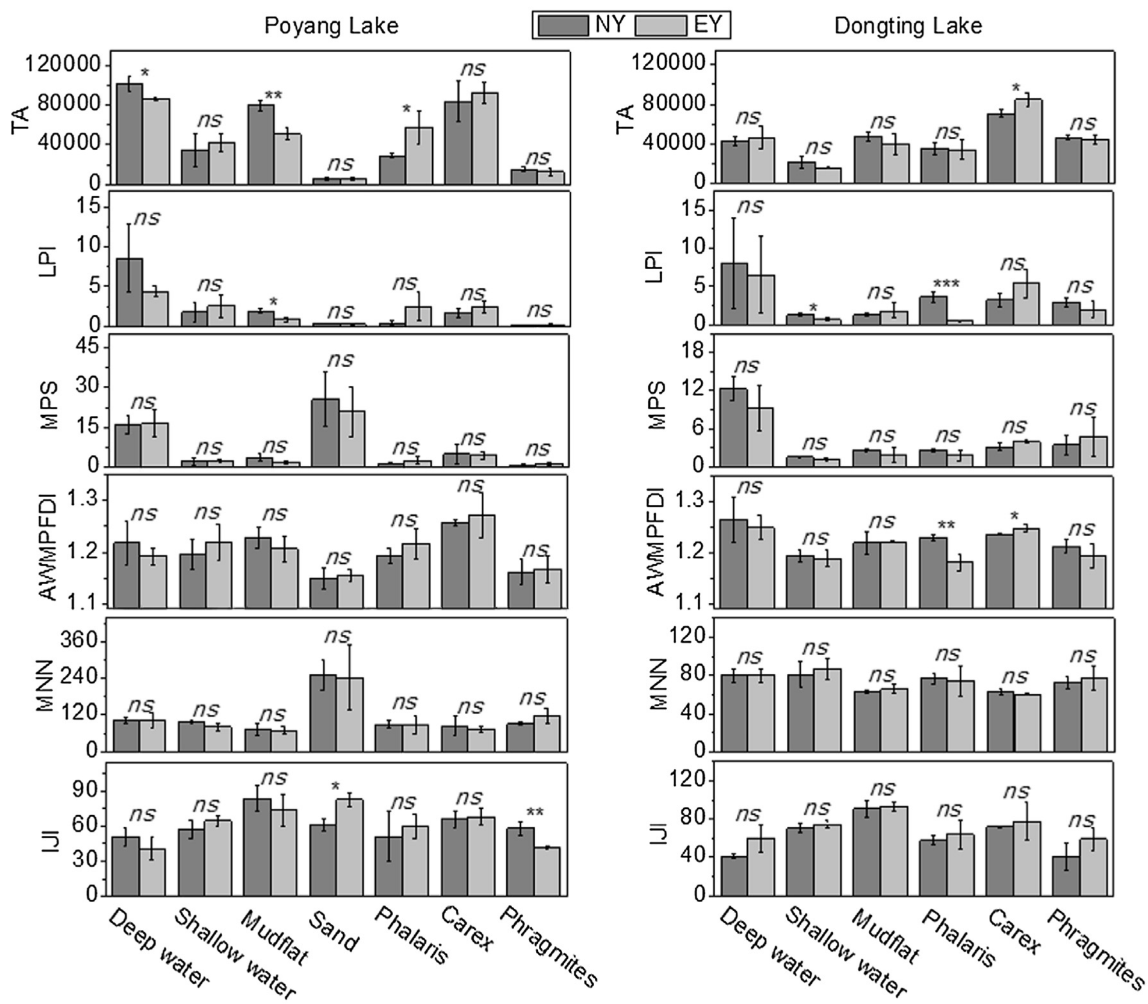

Fig. 4. The values (means ± SD) of habitat class level landscape pattern indices of NY (hydrologic year with early dry season) and EY (normal hydrologic year) in Poyang Lake and Dongting Lake. Significant differences between NY and EY are indicated by * (p < 0.05), ** (p < 0.01), *** (p < 0.001), while no significant difference (p > 0.05) was indicated by *ns*.

Table 4
Correlation coefficient between the habitat class level indices and starting day of dry season. Superscript was significance of the correlation.

Wetland	Class	TA	LPI	MPS	AWMPFDI	MNN	IJI
Poyang Lake	Deep water	$0.810^{0.051}$	$0.525^{0.285}$	$-0.297^{0.567}$	$0.410^{0.420}$	$-0.237^{0.651}$	$0.648^{0.164}$
	Shallow water	$-0.303^{0.560}$	$-0.413^{0.415}$	$0.135^{0.799}$	$-0.518^{0.292}$	$0.720^{0.106}$	$-0.755^{0.082}$
	Mudflat	$0.890^{0.017}$	$0.853^{0.031}$	$0.750^{0.086}$	$0.471^{0.345}$	$0.101^{0.849}$	$0.699^{0.122}$
	Sand	$0.148^{0.780}$	$0.796^{0.058}$	$0.144^{0.786}$	$-0.279^{0.592}$	$-0.099^{0.851}$	$-0.917^{0.010}$
	Phalaris	$-0.721^{0.106}$	$-0.675^{0.141}$	$-0.775^{0.070}$	$-0.562^{0.245}$	$-0.154^{0.771}$	$-0.232^{0.658}$
	Carex	$-0.323^{0.533}$	$-0.693^{0.127}$	$0.292^{0.574}$	$-0.550^{0.258}$	$0.308^{0.553}$	$-0.437^{0.386}$
	Phragmites	$0.179^{0.734}$	$-0.446^{0.376}$	$-0.630^{0.180}$	$-0.135^{0.799}$	$-0.537^{0.272}$	$0.868^{0.025}$
Dongting Lake	Deep water	$-0.296^{0.569}$	$-0.088^{0.868}$	$0.544^{0.265}$	$-0.133^{0.802}$	$0.405^{0.426}$	$-0.666^{0.149}$
	Shallow water	$0.707^{0.116}$	$0.942^{0.005}$	$0.440^{0.383}$	$-0.077^{0.885}$	$-0.326^{0.529}$	$-0.246^{0.639}$
	Mudflat	$0.214^{0.684}$	$-0.128^{0.809}$	$0.568^{0.239}$	$-0.315^{0.544}$	$-0.057^{0.915}$	$-0.496^{0.316}$
	Phalaris	$0.455^{0.365}$	$0.877^{0.022}$	$0.711^{0.113}$	$0.867^{0.025}$	$0.045^{0.932}$	$-0.317^{0.540}$
	Carex	$-0.619^{0.190}$	$-0.261^{0.618}$	$-0.654^{0.159}$	$-0.500^{0.313}$	$0.091^{0.864}$	$-0.324^{0.531}$
	Phragmites	$-0.169^{0.749}$	$0.512^{0.289}$	$0.092^{0.862}$	$0.555^{0.253}$	$0.052^{0.923}$	$-0.881^{0.020}$

emergence. Early dry season would change the vegetation of lake wetlands of the middle and lower reaches of the Yangtze River (including the two largest freshwater lake wetlands) (Wu et al., 2015). Early dry season caused longer duration of beach emergence, which lead to some mudflat zone could accord with growing conditions of *Phalaris* and some *Phalaris* zone could accord with growing conditions of *Carex*. Therefore, the early dry season caused expansion of *Phalaris* to mudflat zone and expansion of *Carex* to *Phalaris* zone. These expansions caused the changes of landscape pattern of the two largest freshwater lakes. The correlation of TA, LPI and IJI and the starting date of dry season also verified this theory.

There was no significant difference in area of *Phragmites* between EY and NY. This was because *Phragmites* distributed on high marshlands, where the low water level of dry season could not effect (Hu et al., 2015; Tang et al., 2014). This study did not found early dry season cause significant changes in area of deep water and shallow water in the two largest freshwater lakes (except deep water in Poyang Lake). This was because area of water body was significant correlated with water level (Cai et al., 2012; Hu et al., 2015).

In landscape level indices, no significant difference in LPI, MPS, AWMPFDI, MNN, IJI and SDI between EY and NY indicated that there was no significant difference in landscape grain size, landscape grain shape, habitat connectivity and landscape diversity in the two largest freshwater lakes.

In Poyang Lake, the significant changes in TA of mudflat and *Phalaris* and LPI of mudflat indicated that there were significant changes in class area of mudflat and *Phalaris* and class grain size of mudflat. The significant changes in IJI of sand and *Phragmites* indicated that there were significant changes in habitat connectivity of sand and *Phragmites*, which maybe because that the smallest values of area and grain size of them made IJI was very sensitive to changes. In Dongting Lake, the significant changes in TA of *Carex*, LPI of *Phalaris* and AWMPFDI of *Carex* and *Phalaris* indicated that there were significant changes in class area of *Carex*, class grain size of *Phalaris* and class grain shape of *Carex* and *Phalaris*.

4.2. Reasons of different responses in Poyang lake and Dongting lake

This study showed that the early dry season caused expanding of *Phalaris* to mudflat zone in Poyang Lake, but it caused expanding of *Carex* to *Phalaris* zone and expanding of *Phalaris* to mudflat zone in Dongting Lake. This was because variation of the water level of the two lakes in dry season was different. In dry season, water level of the Poyang lakes was about 8–10 m (Xingzi hydrologic station), but that of Dongting Lake was 20–24 m (Chenglingji hydrologic station). Variation of Dongting Lake was larger than that of Poyang Lake. *Phragmites*, *Carex*, *Phalaris* and mudflat were distributed along the decrease of duration of beach emergence and the decrease of beach altitude (Hu et al., 2015). The difference of this presumably because the variation of water level in dry season could only affect *Phalaris* and mudflat zone in Poyang Lake, but could affect *Carex*, *Phalaris* and mudflat zone in Dongting Lake.

We also found change ranges of Poyang Lake was greater than that of Dongting Lake, such as:, 1) And TA of vegetation (*Phalaris*, *Carex* and *Phragmites*) of EY was increased from 36.67% to 46.78% in Poyang Lake, while it increased from 57.60% to 61.51% in Dongting Lake; 2) TA of *Phalaris* was increased from 8.25% to 16.55% in Poyang Lake, while TA of *Carex* was increased from 26.87% to 32.09% in Dongting Lake; and 3) TA of mudflat was deceased from 22.82% to 14.64% in Poyang Lake, while it had no significant changes (from 18.08% to 15.05%). This was because 1) the starting date of dry season of Poyang Lake was ahead longer time than that of Dongting Lake (Feng et al., 2013), and 2) high marshlands accounted for about 3% of Poyang Lake and 40% of Dongting Lake and mid-and−low marshlands constituted over 50% of Poyang Lake and about 42% of Dongting Lake (Hu et al., 2015). Same change in hydrology with mid-and-low water level would cause greater changes in mid-and-low marshlands of Poyang Lake than that of Dongting Lake. Therefore, the early dry season could cause greater changes of Poyang Lake than that of Dongting Lake.

4.3. Implication of these changes

These changes in landscape pattern of these wetlands are important for the wintering habitats of East Asian migratory birds and would affect birds and other animals (Wu et al., 2015). It was because landscape type and distribution could affect predation of birds, fishes and mammals (Myers et al., 2000). And the early dry season caused 1) the expanding of *Phalaris* to mudflat zone in Poyang Lake, expanding of *Carex* to *Phalaris* zone and expanding of *Phalaris* to mudflat zone in Dongting Lake, and 2) significant changes in class area mudflat and *Phalaris* and class grain size of mudflat in Poyang Lake and in class area of *Carex*, class grain size of *Phalaris* and class grain shape of *Carex* and *Phalaris* in Dongting Lake. These would affect birds of East Asian, and fishes and mammals in Yangtze River basin. Therefore, further study is required to determine the effects of an early dry season on birds (especially East Asian migratory birds), fishes and animals in Yangtze River basin (Wu et al., 2015).

5. Conclusion

The paper showed that early dry season caused expanding of *Phalaris* (from 8.25% to 16.55% of total area in the lake) to mudflat zone (from 22.82% to 14.64% of total area in the lake) in Poyang Lake, while caused expanding of *Carex* (from 26.87% to 32.09% of total area in the lake) to *Phalaris* zone (from 13.15% to 12.74% of total area in the lake) and expanding of *Phalaris* to mudflat zone (from 18.08% to 15.05% of total area in the lake) in Dongting Lake. In landscape level, there was no significant difference in landscape grain size, landscape grain shape, habitat connectivity and landscape diversity between EY and NY in the two lakes. While in habitat class level, there were also significant changes in grain size (LPI: from 1.89 to 0.81) of mudflat in Poyang Lake, and in grain size of *Phalaris* (LPI: from 3.64 to 0.53), and grain shape of *Carex* (AWMPFDI: from 1.24 to 1.25) and *Phalaris* (AWMPFDI: from 1.23 to 1.18) in Dongting Lake.

Notes

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