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ORIGINAL ARTICLE

Response of herbivorous geese to wintering habitat changes: conservation insights from long-term population monitoring in the East Dongting Lake, China

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Abstract The majority of Eastern China's herbivorous geese overwinter in the East Dongting Lake, China, and there is growing concern about how changes in their habitats can affect the goose populations. General linear regressions were used to analyze the relationship between changes in the abundances of three herbivorous geese (Eastern Tundra Bean Goose *Anser fabalis serrirostris*, Lesser White-fronted Geese *Anser erythropus*, and Greater White-fronted Goose *Anser albifrons frontalis*) and their wintering habitats in the East Dongting Lake during 2002/2003–2014/2015. The fluctuations in three herbivorous goose abundances exhibited negative correlations with changes in interval duration (i.e., days between complete sedge meadow exposure and goose arrival in the study areas), but positive correlations with the normalized difference vegetation index (NDVI) of sedge meadow in late wintering seasons. Comparing to Eastern Tundra Bean Goose, Lesser White-fronted Geese and Greater White-fronted Geese were more sensitive to habitat changes. No significant correlations were observed between goose abundances and both mean water levels and sedge meadow areas. Results indicate that the variations in herbivorous goose abundances may be caused by changes in the NDVI of sedge meadows and the interval durations between sedge meadow exposure and goose arrival. The earlier flood recession can accelerate the exposure, growth, and withering of sedge meadows (low NDVI in late January), thereby creating unsuitable feeding conditions for the geese in the wintering seasons. These findings are important as efforts are made to protect these valuable species from the effects of human intervention, and in particular, the Three Gorges Dam project.

Keywords East Dongting Lake · Habitat change · Herbivorous geese · Flood recession · Yangtze River floodplain

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Introduction

The majority (about 80%) of Eastern China's Anatidae (total of individuals actually counted, 671,668), especially geese, overwinter in Yangtze River floodplain where they occur mostly at the Poyang, Dongting, and Anhui Lakes (Cao et al. 2008). The East Dongting Lake supports over 90% of the geese occurring in Dongting Lake (Cao et al. 2008; Wang et al. 2012), dominated by Eastern Tundra Bean Goose (maximum number, 42,164), Lesser White-fronted Goose (maximum number, 24,261), and Greater White-fronted Goose (maximum number, 12,275). The world population of these three species have experienced concerning decreasing trends (IUCN 2013). Both Eastern Tundra Bean Goose and Greater White-fronted Goose are

listed as least concern species (IUCN 2013), with the majority overwintering in East Dongting Lake, Poyang Lake, and Shengjin Lake (Cao et al. 2008, 2010). The Greater White-fronted Geese populations have declined dramatically within China, from 140,000 in late 1980s (65–86.7% of the estimated flyway population 150,000–200,000; Cao et al. 2008) to 33,000 in mid-2000s (16.5–22%) and to 18,000 presently (9–12%; Cao et al. 2008; Zhao et al. 2012), while Eastern Tundra Bean Geese populations have fluctuated around 70,000 (87.5–100% of the estimated flyway population 70,000–80,000) in the mid-2000s (Cao et al. 2008). The Lesser White-fronted Goose is listed as a vulnerable species (IUCN 2013) and their populations experienced concerning annual variations in China from 11,000 (55% of the estimated flyway population 20,000; Cao et al. 2008) to 17,000 individuals (87.5%) in the past decade (Wang et al. 2012).

Recently, extreme changes in climate (floods and drought), as well as human activities (such as the large-scale construction of dams), have dramatically changed hydrological regimes and physical habitats in the East Dongting Lake (Xie and Chen 2008; Sun et al. 2012; Xie et al. 2015). Sedge meadows that dominated by *Carex* spp. community (Li et al. 2010), the preferred food resource of herbivorous geese overwintering in the East Dongting Lake (Cao et al. 2008), would inevitably be affected by the Three Gorges Dam project (TGD). The TGD reserves water during the winter, which may expose the sedge meadows too early or too late for optimal feeding (Guan et al. 2014). Such dramatic changes in habitat may result in a lack of suitable wintering sites for herbivorous geese, which will affect their population and distributions in the East Dongting Lake (Wang et al. 2012, 2013b; Yuan et al. 2014).

Finding sufficient food resources at wintering sites is a major challenge for migratory birds (Vafidis et al. 2014), and hydrological regime, climate, and in particular, food availability are crucial for waterbird populations and distributions (Xie and Chen 2008; Sun et al. 2012; Xie et al. 2015). According to the competitive exclusion hypothesis, dominant and early-arriving migrants may secure higher-quality habitats, while subordinate or late-arriving individuals may be competitively excluded and need to settle in secondary habitats (Salewski and Jones 2006). Another, although not mutually exclusive, explanation is that migrants are "eurytopic" (i.e., adaptable) and have less restrictive habitat requirements during the non-breeding season, allowing them to use a wider range of overwintering habitats than ecologically similar but more specialized species (Leisler 1992; Salewski et al. 2003).

In the East Dongting Lake, three herbivorous geese, i.e., Eastern Tundra Bean Goose, Lesser White-fronted Goose, and Greater White-fronted Goose, are dominant species in the overwintering season, even though they all arrive at the same overwintering site in early November (November 1 was recognized as the arrival time each year in this study). Three herbivorous geese extensively exploited sedge meadows, where they showed considerable overlap in spatial distribution (Zhao et al. 2015). According to the competitive exclusion hypothesis, competition may exist among these three species. However, short-leaved sedge meadows are the main food resource for the short-billed Lesser White-fronted Goose, while long-leaved meadows are preferred by the long-billed Eastern Tundra Bean Goose and Greater White-fronted Goose but are not available for too long (Zhao et al. 2010; Cong et al. 2012; Zhao et al. 2012). In addition to the sedge meadows, other graminoids in the *Carex*-dominated habitats could be also exploited by Eastern Tundra Bean Geese (Zhao et al. 2010). Since the three species consume a different diet, they have less competition for food and, consequently, can secure higher-quality habitats.

Previous studies indicated that Eastern Tundra Bean Geese and Greater White-fronted Geese overwintered in the East Dongting Lake, the Poyang Lake, and the Shengjin Lake in the Yangtze River floodplain; however, over 90% of Lesser White-fronted Geese overwintered in the East Dongting Lake. Their major food resource was sedge meadows, though Eastern Tundra Bean Geese, and Lesser White-fronted Geese could also feed on other graminoids (Zhao et al. 2015), *Eleocharis migoana* and *Alopecurus aequalis* (Cong et al. 2012; Wang et al. 2013a) separately when food availability declined. Consequently, the response of three herbivorous goose populations to wintering habitat changes could be different. However, few researches have been conducted to evaluate these effects in the East Dongting Lake. Therefore, it is important to understand how and to what degree habitat changes influence the populations of three herbivorous geese in the East Dongting Lake.

This study analyzes the relationship between shifts in population of three herbivorous geese and the changes in their wintering habitats over the last decade using remote sensing and geographic information system (GIS). Our results support the development of wetland management strategies that will work with the Three Gorges Dam operations and ultimately protect three herbivorous geese in the middle Yangtze River floodplains.

Study area

Dongting Lake is the second largest freshwater lake in China, consisting of three parts: East, South, and West (Fig. 1). The substantial biodiversity of Dongting Lake has led to its recognition as one of the 200 global conservation priority eco-regions in the world (Olson and Dinerstein

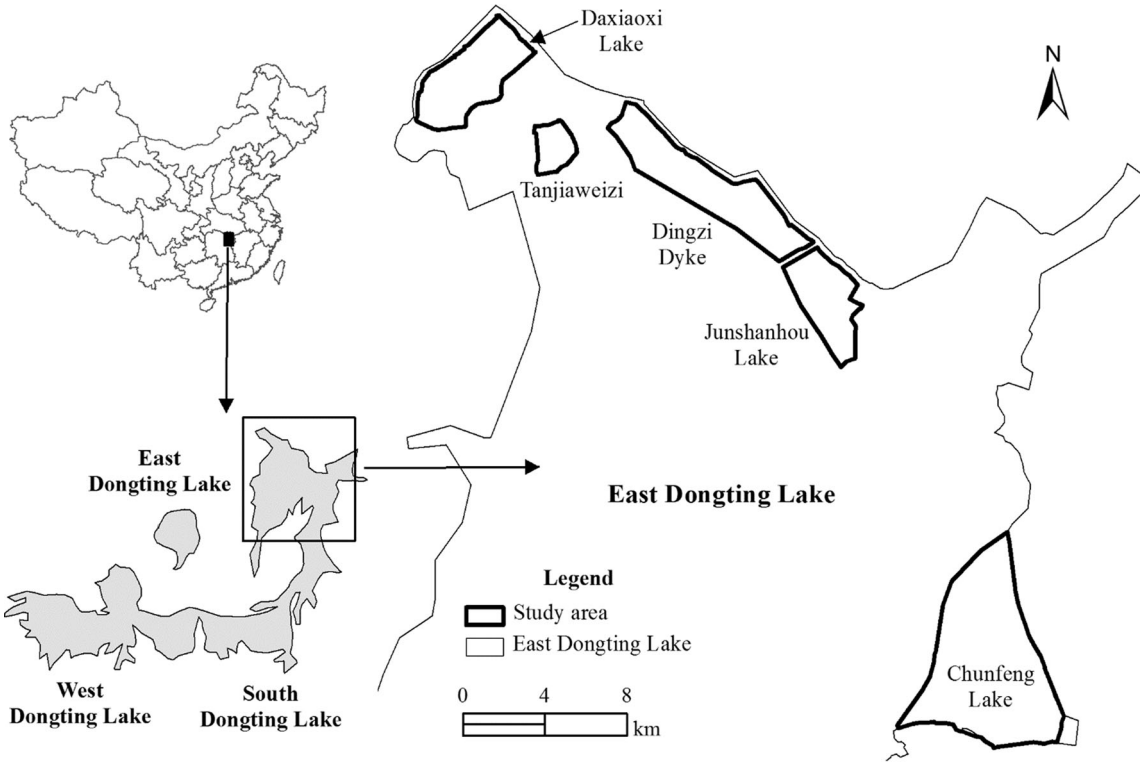

Fig. 1 Location of the study area (East Dongting Lake)

1998). More specifically, 14 orders, 50 families, and 335 species of birds have been recorded in the East Dongting Lake over the last few decades. Moreover, the East Dongting Lake is a Ramsar site in the middle and lower reaches of the Yangtze River floodplain in China. The East Dongting Lake National Nature Reserve (112°43′–113°14′E, 29°0′–29°38′N) (Fig. 1), covering an area of approximately 1900 km^2, is the major wintering site for Eastern Tundra Bean Geese, Lesser White-fronted Geese and Greater White-fronted Geese. We chose five regions, including Daxiaoxi Lake, Chunfeng Lake, Dingzi Dyke, Junshanhou Lake, and Tuanzhou Beach, to be our study area because the majority of these three goose species overwinter there (Wang et al. 2012).

The major categories of wetland in the study area include sedge meadows (dominated by *Carex* spp. community), marshes, and shallow freshwater lakes (Li et al. 2010). Sedge meadows are the main foraging habitats for three herbivorous geese (Cong et al. 2012; Wang et al. 2013a; Zhao et al. 2015). The annual fluctuation in water level in this region is approximately 12–14 m (as recorded at the Chenglingji Hydrological Gauging Station), with the maxima in August and minima typically in January or February. Falling water levels in late September or early October expose the sedge meadows and allow them to rapidly grow, providing the major food source for three herbivorous geese when they arrive at the study area.

Human-related activities in the East Dongting Lake include fishing, reed harvesting, and grazing (mostly goats and buffalo), except in Daxiaoxi Lake, which has closed management during the wintering season. Hunting is illegal and strictly controlled.

Methods

Herbivorous goose surveys and analysis

Three herbivorous goose survey data during 2002/2003–2014/2015 were acquired from the management office of the East Dongting Lake Nature Reserve and previous studies (Barter et al. 2004, 2005; Wang et al. 2012). All surveys covered the five study areas (Fig. 1) and were carried out during a 2- to 3-day period in January. Each survey started 1 h after sunrise and lasted 4–5 h every day. Two to three investigators counted three herbivorous goose individuals using 10 × 42 binoculars and 20× to 60× spotting scopes by walking along fixed line transects. These protocols were used for all surveys during 2002/2003–2014/2015.

Similar to Armitage et al. (2007), SHDI was calculated to describe the diversity of herbivorous geese in East Dongting Lake as well as in five separate study area in the wintering seasons during 2002/2003–2014/2015, where SHDI $= -\sum (p_i)(\ln p_i)$ and p_i is the proportion of the

Table 1 Dates of satellite images

Date	Image type	Water level (m)	Date	Image type	Water level (m)
2002-3-19	Landsat 7 ETM+	23.75	2009-1-16	Landsat 5 TM	20.93
2002-10-13	Landsat 7 ETM+	24.69	2009-3-14	Landsat 5 TM	24.30
2003-1-17	Landsat 7 ETM+	22.01	2009-4-15	Landsat 5 TM	23.50
2003-5-25	Landsat 7 ETM+	29.73	2009-9-6	Landsat 5 TM	28.70
2003-10-16	Landsat 7 ETM+	26.63	2013-7-31	Landsat 8 OLI	29.25
2006-6-10	Landsat 5 TM	27.25	2013-9-17	Landsat 8 OLI	25.47
2006-8-20	Landsat 5 TM	23.91	2013-10-3	Landsat 8 OLI	27.62
2006-9-21	Landsat 5 TM	23.69	2013-12-22	Landsat 8 OLI	21.37
2006-11-1	Landsat 5 TM	23.79	2014-1-23	Landsat 8 OLI	21.12
2006-12-19	Landsat 5 TM	21.08	2015-3-31	Landsat 8 OLI	22.87
2007-2-5	Landsat 5 TM	20.58	2015-4-16	Landsat 8 OLI	24.40
2008-3-11	Landsat 5 TM	20.67	2014-12-19	GoogleEarth	21.50
2008-4-28	Landsat 5 TM	25.40			

geese that belong to the *i*th species (Krebs 1994). We analyzed changes in the abundance (total individuals) of three herbivorous geese in the overall study area (the East Dongting Lake), as well as in each separate study area in the wintering seasons during 2002/2003–2014/2015. Five study areas, however, may not be used equally by three herbivorous geese. Therefore, we compared the populations of three herbivorous geese among the five study areas via one-way ANOVA. Post hoc tests (Games–Howell multiple comparison) were then used to test differences among five study areas. We then analyzed temporal changes in the abundance of three herbivorous geese in the East Dongting Lake during 2002/2003–2014/2015.

Habitat variable extracting and analysis

Four habitat variables, i.e., water level, sedge meadow area, NDVI of the sedge meadows, and interval duration between complete sedge meadow exposure and three herbivorous geese arrival, were used to assess the influence of habitat change on three herbivorous goose abundances during 2002/2003–2014/2015. The water level at 8:00 AM at Chenglingji Hydrological Gauging Station during 2002/2003–2014/2015 was used to represent the water level of East Dongting Lake, as has been done in previous hydrological studies of that part of the lake (Chang et al. 2010; Sun et al. 2012; Xie et al. 2015).

Previous research indicated that *Carex*-dominated sedge meadows were the main foraging habitat for three herbivorous geese (Cong et al. 2012; Wang et al. 2013a; Zhao et al. 2015). Thus, areas and NDVI of *Carex* sedge meadows were used to represent the food availability of three herbivorous geese. The NDVI of sedge meadows were extracted from the Terra MODIS images. The dataset used in this study was MODIS 16-day composite NDVI time series data products (MOD13Q1) during 2002/2003–2014/2015 provided by Earth resources observation systems (EROS) data center, the United States Geological Survey (USGS), with the spatial resolution 250 m. The periods of data acquisition were from January 16–31 or February 1–16 according to the dates of the goose survey in each wintering season. The interval duration between complete sedge meadow exposure (when the water level was 25.4 m) and goose arrival near November 1 was calculated for each wintering season. This value may significantly affect food availability (NDVI and area of sedge meadow) and thereby the abundance and distribution of three herbivorous geese in the East Dongting Lake as well as other study areas. The sedge meadow and water habitats were extracted using 25 satellite images, i.e., twelve Landsat TM images, five Landsat ETM+ images, seven Landsat 8 OLI images, and one GoogleEarth image (Table 1). The satellite images were chosen and processed based on the framework by Xie et al. (2015).

Given that the sedge meadow habitats were relatively stable during the study period (2002/2003–2014/2015), a high-resolution GoogleEarth image (acquired on December 19, 2014, resolution of 0.52 m) was used to extract the sedge meadow habitats in a low water level (21.50 m). These habitats were then used as base images to extract sedge meadow areas from other Landsat images. A supervised method was used for sedge meadow and water habitats classification. The spectral classes were merged to three representative classes (sedge meadow, water, and others) as defined in the classification scheme used as a training set for the supervised classification. The sedge meadow habitat classifications extracted from Landsat images (30-m resolution) were rectified by comparing them to the sedge meadow habitat classification extracted from the GoogleEarth image. Classification accuracy was evaluated using a standard error matrix (confusion matrix) (Dadaser-Celik et al. 2008) that reported overall classification accuracies and kappa chance correction statistics

were prepared for each image to determine the accuracy of the classifications. We then analyzed temporal changes in the habitats (water level, mean water level, interval duration between complete sedge meadow exposure and goose arrival, and area and NDVI of sedge meadow) during 2002/2003–2014/2015.

Relationship between three herbivorous goose abundance and habitat changes

D'Agostino–Pearson omnibus tests (D'Agostino et al. 1990) were used to analyze whether the abundance of three herbivorous geese and characteristics of their habitats (mean water level, interval duration between complete sedge meadow exposure and goose arrival, and the NDVI of sedge meadows) were normally distributed. Results of these tests indicated that all variables passed normality tests (all $p > 0.05$). Regression analyses were then used to examine the correlation between the abundance of three herbivorous geese and water level, interval duration between sedge meadow exposure and goose arrival, and the area and NDVI of sedge meadows in the entire study area (East Dongting Lake). Normality tests were performed using GraphPad Prism version 6.0 for Windows. One-way ANOVA and all regression analyses were performed using the Software Package for Social Statistics (IBM SPSS Statistics Version 21.0).

Results

Herbivorous geese distribution patterns

The population of three herbivorous geese exhibited dramatically variations during 2002/2003–2014/2015. Specifically, the population of Eastern Tundra Bean Geese was 20530.63 ± 4434.21 (mean ± standard error), with a maximum value (42,164 individuals) in the winter of 2014/2015 and a minimum value (7837 individuals) in the winter of 2011/2012. The population of Lesser White-fronted Geese was 12959.58 ± 1656.41, with a maximum value (24,261 individuals) in the winter of 2010/2011 and a minimum value (1620 individuals) in the winter of 2006/2007. The population of Greater White-fronted Geese was 5593.88 ± 1628.91, with a maximum value (12,275 individuals) in the winter of 2003/2004 and a minimum value (895 individuals) in the winter of 2012/2013.

Significant differences in species diversity (SHDI) of three herbivorous geese were observed in East Dongting Lake and five study areas ($F = 5.11$, $p < 0.001$; Fig. 2). The least significant difference obtained during post hoc comparisons indicated higher species diversity in East Dongting Lake, Daxiaoxi Lake and Chunfeng Lake than in Tuanzhou Beach (all $p < 0.05$; Fig. 2). The abundances of total geese and three

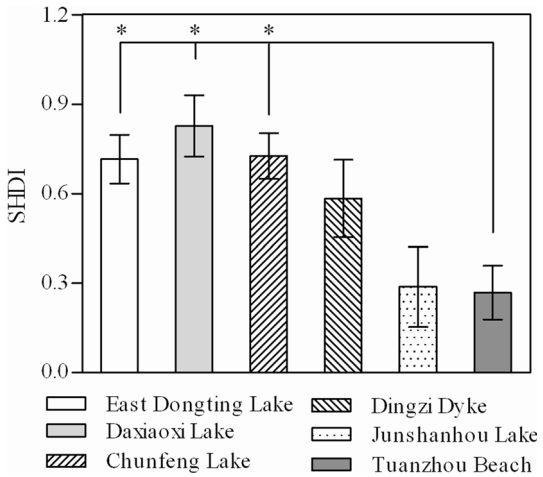

Fig. 2 Species diversity (SHDI) of three herbivorous geese in the East Dongting Lake and five study areas during 2002/2003–2014/2015. *Error bars* represent standard error (SE). *Asterisk* denotes $p < 0.05$

species of herbivorous geese exhibited significant differences in five study areas (total geese, $F = 7.61$, $p < 0.001$; Eastern Tundra Bean Geese, $F = 5.82$, $p < 0.001$; Lesser White-fronted Geese, $F = 11.21$, $p < 0.001$; Greater White-fronted Geese, $F = 3.32$, $p < 0.001$; Fig. 3).

The abundances of three herbivorous geese exhibited obvious variations during 2002/2003–2014/2015, and however, abundance data of Eastern Tundra Bean Geese and Greater White-fronted Geese were not available for three winters (2002/2003, 2007/2008, and 2009/2010), because their abundances were not counted during these winters (Fig. 3). Specifically, the abundances of the total geese and Eastern Tundra Bean Geese approximately exhibited the same trends during the study period, decreasing from 2003/2004 to 2008/2009, increased in 2010/2011, decreased after 2010/2011, and remained low abundances during 2011/2012–2013/2014, but increased in 2014/2015. The abundance of Lesser White-fronted Geese decreased during 2003/2004–2006/2007, increased during 2006/2007–2011/2012 (with a slight decline in the winter of 2009/2010), and subsequently decreased after 2011/2012, but remained relatively stable during 2012/2013–2014/2015. The abundance of Greater White-fronted Geese decreased during 2003/2004–2008/2009, increased in 2010/2011, decreased after 2010/2011, and remained low abundance during 2012/2013–2014/2015.

Changes in wintering habitats of three herbivorous geese

After accuracy assessment of the individual classifications (sedge meadow, mudflat, and water habitats) with a standard error matrix (confusion matrix) (Dadaser-Celik et al.

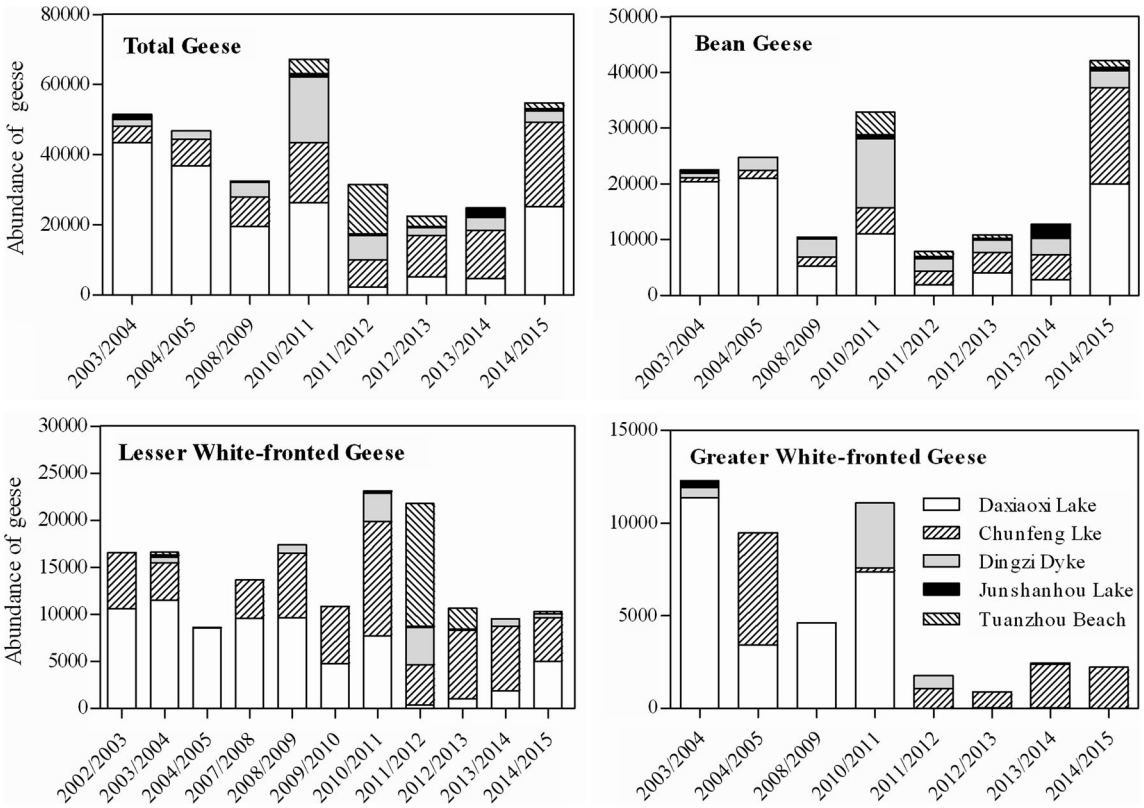

Fig. 3 Abundance of total geese and three herbivorous geese in five study areas during 2002/2003–2014/2015

2008), the overall accuracies of all classifications (2002–2015, using reference data from the images) were greater than 90%, whereas the kappa statistic values for the same classifications were greater than 0.9.

The areas of exposed sedge meadow were relatively stable in all study areas when the water levels were less than 25.4 m (and 24.4 m in Chunfeng Lake and Dingzi Dyke), but when the water level surpassed 25.4 m, the areas of sedge meadow decreased during 2002/2003–2014/2015 (Fig. 4). In order to sustain the maximum area of sedge meadow for three herbivorous geese in all study areas, the maximum level of water needs to be less than 25.4 m in winter, and this was the case during the wintering seasons of 2002/2003–2014/2015.

Water levels were under 25.4 m (the level required for complete sedge meadow exposure, Fig. 4) in all wintering seasons (November 1 to March 15) during 2002/2003–2014/2015, with the exceptions of 2002/2003 (25.56–25.91 m during November 2–6), 2008/2009 (25.56–29.75 m during November 5–28), and 2014/2015 (25.56–26.93 m during November 1–14). The mean water levels varied from 20.77–22.94 m in the wintering seasons during 2002/2003–2014/2015 (Fig. 5a). The interval duration between complete sedge meadow exposure (at a water level of 25.4 m) and three herbivorous geese arrival (November 1) varied from −2 to 80 days during 2002/2003–2014/2015,

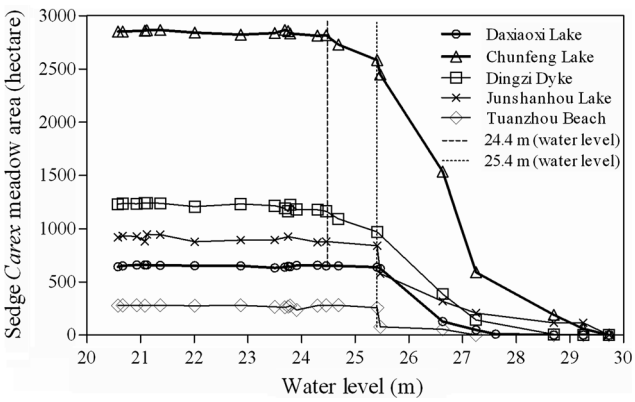

Fig. 4 Changes in the areas of sedge meadows in response to water level fluctuations in the five study areas

with a maximum interval (80 days) in the winter of 2006/2007 and a minimum interval (−2 days, when the water level was 25.4 m on November 3) in the winter of 2005/2006 (Fig. 5a). The NDVI of sedge meadows exhibited drastic variation in late (January 16–31) wintering seasons during 2002/2003–2014/2015. Spurious data existed in January 16–31, 2008 (Fig. 5b), which was caused by snow-covered sedge meadows. Such data were removed from the analysis of the relationship between the NDVI of sedge meadows and the abundances of three herbivorous geese.

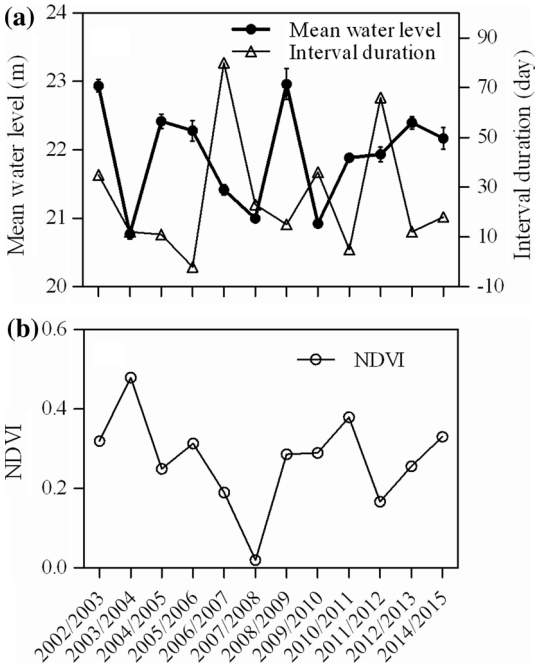

Fig. 5 Changes in (mean) water level, NDVI of sedge meadow, and interval duration between complete sedge meadow exposure and goose arrival during 2002/2003–2014/2015. The water level at Chenglingji Hydrological Gauging Station (at 8:00 AM) is used to represent the water level of East Dongting Lake. Spurious NDVI data in the winter of 2007/2008 (January 16–31, 2008) are caused by heavy snow (snow-covered sedge meadows)

Relationship between three herbivorous goose abundances and habitat changes

While the areas of sedge meadow tended to be stable, there were dramatic changes in the abundances of three herbivorous geese in the East Dongting Lake during the wintering seasons of 2002/2003–2014/2015 (Figs. 3, 5), and thus, regression analysis was not performed to evaluate the correlation between sedge meadow area and variation in abundances of three herbivorous geese. Significant correlations also were not observed between the changes in mean water levels and the abundances of three herbivorous geese in the wintering seasons of 2002/2003–2014/2015 (all $R^2 < 0.005$, all $F < 0.03$, all $p > 0.8$).

In the East Dongting Lake, the changes in the abundances of three herbivorous geese, especially Lesser White-fronted Geese, exhibited negative correlations with the changes in the interval duration between complete sedge meadow exposure and goose arrival (Eastern Tundra Bean Geese, $F_{1,6} = 1.61$, $p = 0.25$; Greater White-fronted Geese, $F_{1,6} = 1.93$, $p = 0.21$; Lesser White-fronted Geese, $F_{1,10} = 8.136$, $p = 0.016 < 0.05$; Fig. 6a), however, positive correlations with the changes in the NDVI of sedge meadows in late wintering seasons (Eastern Tundra Bean Geese, $F_{1,6} = 1.26$, $p = 0.31$; Greater White-fronted Geese, $F_{1,6} = 5.04$, $p = 0.07$; Lesser White-fronted Geese, $F_{1,9} = 6.82$, $p = 0.028 < 0.05$; Fig. 6b).

Discussion

The present study, which evaluated 11 (8 for Eastern Tundra Bean Geese and Greater White-fronted Geese) wintering seasons during 2002/2003–2014/2015 in East Dongting Lake, revealed a variation in the abundances of three herbivorous geese (Fig. 3) and their corresponding habitats (NDVI and the interval duration between complete sedge meadow exposure and goose arrival, Fig. 5). Several environmental factors may have contributed to these changes in goose abundances. As shown in our study, one probable cause is the change in wintering habitats in the East Dongting Lake, as indicated by the positive or negative relationships between the abundances of three herbivorous geese and their habitats (NDVI and the interval durations between complete sedge meadow exposure and goose arrival, Fig. 6).

Our results show that the abundances of three herbivorous geese were negatively correlated with the interval durations between complete sedge meadow exposure and goose arrival (Fig. 6a). Longer interval durations may have led to a lower number of geese in the wintering seasons of 2011/2012 (66 days; Lesser White-fronted Geese, 9158 individuals; Eastern Tundra Bean Geese, 7837 individuals; Greater White-fronted Geese, 1780 individuals). In the East Dongting Lake, sedge meadow (dominated by *Carex*) has two growing seasons during the year: from late September after the water recedes to January, and March to May, when the water submerges the meadow. A longer interval duration between sedge meadow exposure and goose arrival may lead to earlier growth and thereby earlier withering of sedge meadow in the first growing season (Guan et al. 2014). Long-leaved *Carex* is a relatively inefficient forage for the short-billed Lesser White-fronted Goose (Durant et al. 2004), as also inferred by the low abundance of Lesser White-fronted Geese foraging in natural wetlands (9158 individuals) but high abundance in wheat croplands in 2011/2012. Long-leaved *Carex* can be used by long-billed Eastern Tundra Bean Geese and Greater White-fronted Geese (Zhao et al. 2010), and however, withered *Carex* is unsuitable forage and made them looking for a more suitable prey source. A probable evidence is that the abundances of Eastern Tundra Bean Geese and Greater White-fronted Geese decreased in the East Dongting Lake in 2011/2012 (Fig. 3), but increased in the Shengjin Lake during the same period (Zhao et al. 2015). More powerful evidence might be revealed by satellite telemetry in our future study. In contrast, too short of an interval duration may also be unsuitable for the geese,

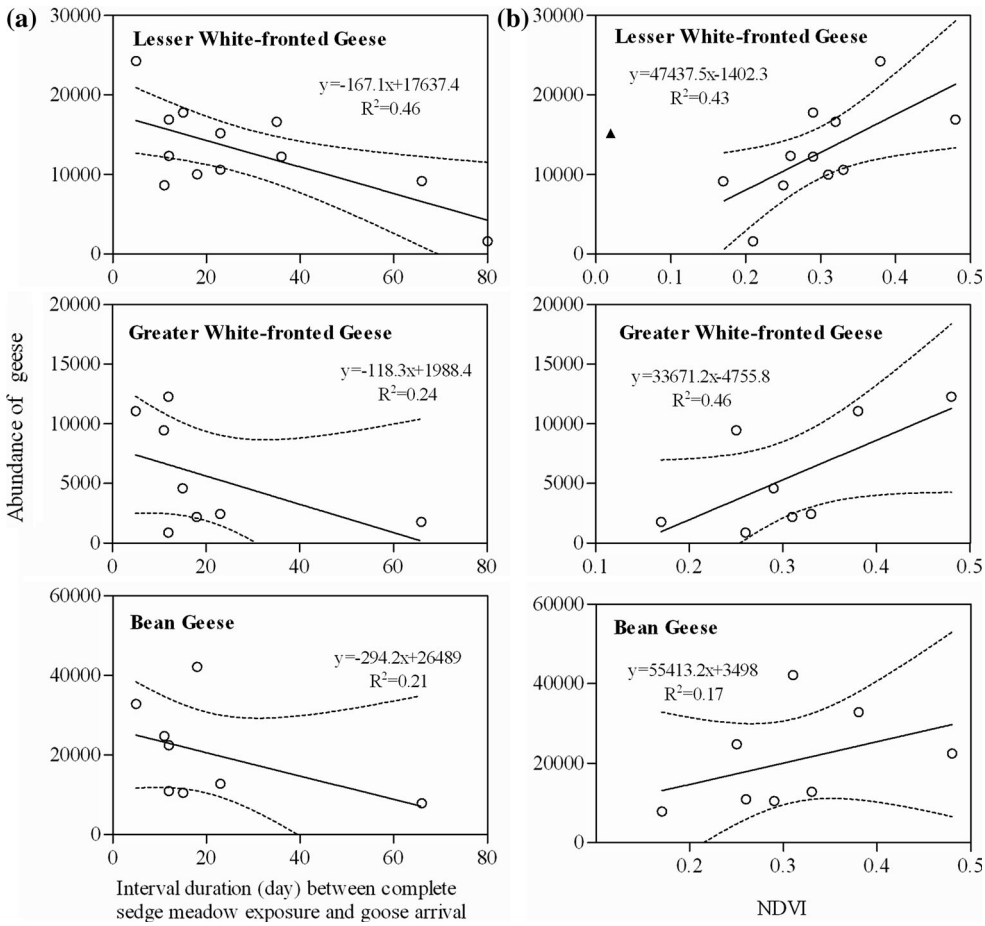

Fig. 6 General linear regression of the abundance of three herbivorous geese and interval duration between complete sedge meadow exposure and goose arrival **a** as well as the NDVI of sedge meadows **b** in the East Dongting Lake (the entire study area) during 2002/2003–2014/2015. Each symbol (*circle*/*triangle*) represents the abundance of geese in a single year. General linear regression is represented by a *solid line*, and the *upper* and *lower limits* of the 95% confidence intervals are shown with *dotted lines*. Spurious NDVI data (represented with *filled triangle*) are excluded from the general linear regression, which are caused by heavy snow (January 2008; snow–covered sedge meadows)

as indicated by the low abundance of Lesser White-fronted Geese in 2005/2006 (–2 days, 4400 individuals), and however, the abundances of Eastern Tundra Bean Geese and Greater White-fronted Geese were not counted in the same period. In this case, the low numbers of Lesser White-fronted Geese could be attributed to the late flood recession, especially the late high water level, which was also indicated by Guan et al. (2014). Late flood recession delayed the exposure and growth of sedge meadow and resulted in retained water, small areas of sedge meadow, and a shortage of food in the early wintering seasons (Guan et al. 2014). Climate change (drought) and especially the Three Gorges Dam operation may cause flood recession too early (before early November), or too late (after November 1 when three herbivorous geese arrive at the East Dongting Lake), and both circumstances are unsuitable for three herbivorous geese and may lead to a decline in their abundance in the wintering seasons.

The East Dongting Lake is the main wintering site for three herbivorous geese (Cao et al. 2008, 2010; Wang et al. 2012). Previous studies have indicated that the sedge meadows are crucial foraging habitats for three herbivorous geese (Zhao et al. 2010; Cong et al. 2012; Wang et al. 2013a; Zhao et al. 2015). In present study, changes in the abundance of three herbivorous geese, especially Lesser White-fronted Geese, exhibited positive linear correlations with the changes in the NDVI of sedge meadows in the East Dongting Lake (Fig. 6). The earlier flood recession accelerated the exposure and growth of sedge meadows, which resulted in earlier withering of sedge meadows (low value of NDVI) in late January in the wintering seasons (Fig. 5b). The withered sedge meadows (low value of NDVI) led to the shortage of suitable food resources for three herbivorous geese. In this case, a high value of NDVI in late January is likely more suitable for three herbivorous geese, especially Lesser White-fronted Geese in East Dongting Lake (Fig. 6).

However, the responses of the abundances of three herbivorous geese to wintering habitat changes were different. Specifically, comparing to Eastern Tundra Bean Goose, Lesser White-fronted Geese and Greater White-fronted Geese were more sensitive to their habitat changes (Fig. 6). Two probable reasons might contribute to such dramatic phenomenon. Over 90% of the Eastern population of Lesser White-fronted Geese overwinters in the East Dongting Lake (Cao et al. 2008; Wang et al. 2012).

Therefore, their highly concentrated population in the East Dongting Lake may make this species particularly vulnerable to wintering habitat changes in the East Dongting Lake. Previous studies indicated that Eastern Tundra Bean Goose and Greater White-fronted Geese overwinter in Yangtze River floodplain where they occur mostly at the Poyang, Dongting, and Shengjin Lakes (Cao et al. 2008; Zhao et al. 2010, 2015). Greater White-fronted Geese highly dependent on sedge meadows, and however, Eastern Tundra Bean Goose could also exploit other graminoids in the *Carex*-dominated habitats (Zhao et al. 2015). Comparing to Eastern Tundra Bean Goose, highly dependence on a limited variety of food made the abundance of Greater White-fronted Geese more sensitive to their habitat changes in the East Dongting Lake (Fig. 6). When food availability sharply decreased (e.g., longer interval duration of 66 days and thereby the lower NDVI of 0.17 in the winter of 2011/2012, Fig. 5), Greater White-fronted Geese might shift to other wintering site, such as Shengjin Lake (Zhao et al. 2015).

The relatively stable areas of sedge meadow along with the significant fluctuation in the abundances of three herbivorous geese (Fig. 3) and un-significant correlations between the changes in three herbivorous goose abundances and mean water levels during the wintering seasons of 2002/2003–2014/2015 indicate that changes in the areas of sedge meadow and mean water levels are not the likely causes of the variation in three herbivorous goose abundances in the East Dongting Lake in our study period. But both sedge meadow areas and water levels affected the NDVI in the study area. Sedge meadow areas were sensitive to water levels and would be submerged with water levels greater than 25.4 m (Fig. 4). Overall, the mean water levels were under 25.4 m (and varied from 20.77 to 22.94 m) throughout the wintering seasons of 2002/2003–2014/2015, with the exception of November in 2002/2003, 2008/2009, and 2014/2015. Higher water levels (greater than 25.4 m) led to a decline in sedge meadow areas, which resulted in a severe risk of food shortage. Consequently, water levels should ideally be less than 25.4 m in the wintering seasons.

Other variables, though not analyzed in this study, might also influence the abundances and distributions of three herbivorous geese. Importantly, previous studies have suggested that human disturbance accounts for changes in waterbird populations (Yuan et al. 2014). Fishing, reed harvesting, and grazing (mostly goats and buffalo) occur throughout the East Dongting Lake, except at Daxiaoxi Lake (where there is closed management) in wintering seasons. Therefore, human disturbance is an important consideration when evaluating goose populations and distributions and is an area for future investigation.

Our results indicate that the abundances of three herbivorous geese were significantly affected by changes in their wintering habitats, including the NDVI of sedge meadows and the interval duration between complete sedge meadow exposure and goose arrival in the East Dongting Lake. We suggest that the following conservation measures be quickly implemented as part of the Three Gorges Dam operations. Flood recession should not occur before early November and water levels should be less than 25.4 m, which would ensure complete sedge meadow exposure. In addition, harmful human disturbance of these valuable areas must be avoided and closed management of particularly sensitive habitats should be considered.

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