Assessing the Suitability of Habitat for Wintering Siberian Cranes (Leucogeranus leucogeranus) at Different Water Levels in Poyang Lake Area, China

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Assessing the suitability of habitat for wintering Siberian cranes *(Leucogeranus leucogeranus)* at different water levels in Poyang lake area, China

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ABSTRACT

Poyang lake area (1000–3246 km^2) is the most important wintering ground for the globally critically endangered Siberian crane (*Leucogeranus leucogeranus*). More than 98% of the Siberian crane population overwinters in Poyang lake area. Remote-sensing and the spatial analysis tools of geographic information system (GIS) technology were used to assess the suitability of the habitat for wintering Siberian cranes in Poyang lake area at different water levels. The results demonstrated that as the water level increased within the range of 7.93–12.16 m, the area of unsuitable habitat increased gradually, but the areas of good, fair and poor habitat decreased. When the water level reached 12.16 m, good habitat for Siberian cranes covered an area of only 3005 ha, which is only 0.93% of the area of the total lake area. When human disturbance factors including vehicles, fishing and construction activities were added to the analysis of the current distribution of Siberian crane habitat, the results again indicated that the area of good habitat decreased with an increase in water level within the range of 7.93–12.16 m. Additionally, the areas of good habitat occurred primarily in the region of two national nature reserves, which are the Poyang Lake National Nature Reserve and the Nanjishan National Nature Reserve. Our study provides important data and an important theoretical basis for water level management and nature reserve construction in Poyang lake area.

INTRODUCTION

In the past few decades, wetlands have been damaged extensively by land reclamation and development, which seriously threaten the survival of waterbirds (Liang *et al.* 2004, Mistry *et al.* 2008, MacKinnon *et al.* 2012). Assessments of habitat suitability for endangered waterbirds that are threatened by habitat loss are needed for their conservation (Ali *et al.* 2010, Cao *et al.* 2010, Ma *et al.* 2010). There are currently insufficient field survey data for ecological analysis and planning. A combination of remote-sensing and geographic information system (GIS) technology has supported considerable progress in wildlife habitat assessment research (Ali *et al.* 2010, Nagendra *et al.* 2012, Imam and Kushwaha 2013). Remote-sensing technology can help to identify and distinguish species' habitats and thus to predict their spatial distributions. The technology also helps to analyze habitat changes that are caused directly by natural processes or by human activities (Kerr and Ostrovsky 2003, Bradley *et al.* 2012). Satellite-based remote sensing applications in ornithology has been used increasingly for assisting in habitat evaluation, habitat modelling and other conservation and management objectives effectively (Gottschalk *et al.* 2005).

Habitat suitability assessment guides the development of conservation measures to protect rare and endangered species (Ouyang *et al.* 2001). Several models have been developed in studies of habitat suitability assessment, such as maximum entropy models (MaxEnt) (Kumar and Stohlgren 2009), ecological niche factor analysis (ENFA) (Zhao *et al.* 2012), the generalised linear model (GLM) (Brotons *et al.* 2004) and the genetic algorithm for rule-set production (GARP) (Tsoar *et al.* 2007). These models construct habitat suitability assessments by classifying and overlaying environmental data at sites at which the species is present or absent (McDermid *et al.* 2009, Melin *et al.* 2013, Wang *et al.* 2012). Prediction accuracy has improved and assessment scales have increased with improvements in remote-sensing resolution, image interpretation and classification methods (Cao *et al.* 2010, Dong *et al.* 2013).

The Siberian crane (*Leucogeranus leucogeranus*) is a globally critically endangered species (IUCN Red List 2013). At a global scale, this species can be divided into three populations. The largest is the eastern population that breeds in northeastern Siberia. This eastern population accounts for more than 98% of the global population and overwinters primarily in Poyang Lake of the Yangtze River Basin in China (Li *et al.* 2012). A recent survey recorded 3800–4000 Siberian cranes in the wintering population at Poyang lake area. The largest recorded wintering population was 4577, which occurred in 2011 (Li *et al.* 2012). Most of the Siberian cranes in Poyang lake area are distributed in Bang Lake, Sha Lake and Dahu Lake, which are all located in national nature reserves (Li *et al.* 2012, Shan *et al.* 2012).

Food resources are among the most important factors that affect habitat selection by waterfowl (MacArthur *et al.* 1962). Poyang lake area has become the largest wintering grounds for Siberian cranes because it provides a large amount of food, specifically *Vallisneria* spp. As the water level decreases and exposes the lake bottom, the submerged plants, which are *Vallisneria* and *Potamogeton*, gradually become available at a foraging depth that is suitable for Siberian cranes (<30 cm) (Meine and Archibald 1996, Burnham 2007, Barzen *et al.* 2009). The tubers of these submerged plants therefore become the most important late-winter food source for Siberian cranes (Sun and Huang 2010). However, extreme variation in water levels is a major limiting factor for the development of aquatic plants (Zhang *et al.* 2012). For example, the severe flooding that occurred in the Yangtze River basin in 1998 has had a large impact on the aquatic vegetation of Poyang Lake. The flooding altered the vegetation community structure of the lake and caused the productivity of the submerged vegetation to decline dramatically (Cui *et al.* 2000). The flooding decreased underwater light penetration in Poyang Lake and greatly reduced the biomass of *Vallisneria* in the following year. This forced the wintering Siberian cranes to forage for the tender roots of *Potentilla limprichtii* and *Amana edulis*, which grow primarily in sedge areas (Barzen *et al.* 2011, Li *et al.* 2012, Jia *et al.* 2013).

Water depth is the most important factor that affects the foraging of wintering Siberian cranes because of the cranes' distinct morphology (Isola *et al.* 2000, Ma *et al.* 2010). Very high water prevents the cranes from foraging for underwater tubers, and very low water levels cause the surface of the mudflat substrate to dry, which also prevents normal foraging (Wu *et al.* 2013). The dry season has begun earlier and has lasted longer in Poyang Lake in recent decades, which leads to very low winter water levels. This causes long exposure and drought-induced deaths of major Siberian crane food sources, including *Vallisneria* and *Potamogeton*, over a wide area (Hu *et al.* 2010, Guo *et al.* 2012, Zhang *et al.* 2012).

A previous study has shown that approximately 60% of all Siberian cranes occur within the Poyang Lake National Nature Reserve (Shan *et al.* 2012, Xu *et al.* 2014). However, because of limited space and food resources, some cranes overwinter outside of the nature reserves. Therefore, factors such as development, construction and other forms of human disturbance outside of the national nature reserves have become factors that threaten the cranes (Crosby 2003, Pimm *et al.* 2006). In order to strengthen the management of Poyang Lake and provide the Siberian crane a better living condition, we predicted suitable crane habitat at different water levels supported by remote sensing and GIS technology. The study focused on assessing potential suitable crane habitats under different water level scenarios and analyzing the use of currently suitable habitats by Siberian cranes.

MATERIALS AND METHODS

Study area

Poyang lake area is located in the northern part of Jiangxi Province and on the southern end of the lower portion of the Yangtze River. Its geographical location is 28°22'–29°45'N and 115°47'–116°45'E. Poyang Lake is an exorheic shallow water lake that is affected by incoming water runoff from the "Five Rivers" (Gan River, Fu River, Xiu River, Rao River and Xin River) and the Yangtze River (Fig. 1). During the dry season, the water level decreases to expose the lake bottom, and the water surface area might decrease to less than 1000 km^2 (Shankman and Liang 2003). During the wet season, the water level increases considerably, floating plants and submerged plants die and the maximum water surface can grows to 3246 km^2 (Shankman and Liang 2003, Hu *et al.* 2007). According to the previous field survey, the Siberian crane were recorded at nearly all the small lakes within this maximum 3246 km^2 water surface area, so the area within this maximum 3246 km^2 was set as the study area in this paper (Shan *et al.* 2012). Changes in the water level and area of Poyang lake result in a dynamic shift between the various types of natural wetlands and changes in the propor-

Table 1. Remote-sensed images and water levels of Poyang lake area.

No.	Image type	Image time	Water level (m)
1	Landsat 5 TM	2009-01-11	7.93
2	Landsat 7 ETM	2006-11-11	9.00
3	Landsat 7 ETM	2004-03-10	10.02
4	Landsat 7 ETM	2004-11-21	11.07
5	Landsat 7 ETM	2003-02-20	12.16

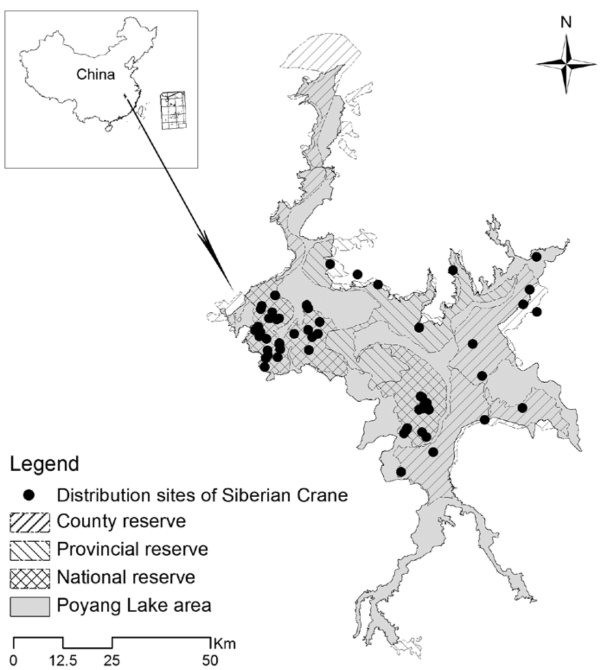

Fig. 1. Geographical location of Poyang lake area and the distribution of national, provincial and county nature reserves and Siberian Crane.

tions of land and water in the landscape (Hu *et al.* 2007). In particular, land-water transitional zones appear as marshland fronts or disk-like depressions (Dronova *et al.* 2011, Yésou *et al.* 2011). Land-water transitional zones that have moderate water depths provide the best habitat for wintering migratory birds. Poyang lake area is rich in ecological resources and contains diverse vegetation (Liu *et al.* 2011).

Data sources and processing

The remote-sensing data were obtained from the geospatial data platform (www.gscloud.cn) (Table 1). Water level data were provided by the Water Resources Department of Jiangxi Province (all water levels were measured at the Wusong elevation at the Xingzi Hydrology Station). Our depiction of the distribution of nature reserves was based on the work of Chen and Jessel (2011) (Fig. 1).

Series of five remote sensing images were selected between 2003 and 2009. Each annual series of images covered the winter season that began in October and ended in March of the following year. This period corresponds to the wintering of Siberian cranes in Poyang lake area. An analysis of variation in the water level of Poyang lake area during the winters of 1989 through 2008 indicated that the average yearly minimum winter water level was 8.05 m and the average annual water level was 13.38 m (Xia *et al.* 2010). According to Qi *et al.* (2013), when the water level remained at 14 m between October and April of the following year, the areas of good waterfowl habitats and feeding grounds were significantly reduced. Winter water levels below 12 m are most suitable for foraging by wintering waterbirds (Qi *et al.* 2013). Xia *et al.* (2010) and Hu *et al.* (2014) both indicated that habitat area of wintering birds decreased rapidly and became very little over 12 m and if the water level exceeds 14 m, the habitat area would be difficult to maintain the normal demand of birds. Therefore, five remote-sensing images of 30 m spatial resolution with about one meter water level height difference ranged between 7.93 and 12.16 m were chosen for the habitat analysis in our study. Our study incorporated data from Landsat TM images that were obtained after 2003, because the monthly (except March) average water level in Poyang lake area decreased after the opening of the Three Gorges Dam in 2003. These decreases resulted in premature wetland exposure, which might have had a negative impact on wintering waterfowl (Jia 2013).

Before interpretation, a field survey was carried out in Poyang lake area in early spring. We went to the places which were easier to reach and throughout the whole Poyang lake area. The information of land use was recorded for each point. And a total of 296 sampling sites were recorded. 200 points were used to help interpretation as training data and the other 96 points were used to validate the classification results. The software package ENVI 4.8 and Arcgis10.0 (ESRI, Redlands, CA, USA) were used to preprocess and classify the satellite image data. From the image data, the information of food distribution and suitable habitat distribution were generated with the help of field survey. The pre-processing steps included primarily geometric correction, which is based on 1:50000 digital line graphics, radiation calibration and image cropping. The vector file of Poyang lake area was used for image cropping. The method of supervised classification was used to interpret the images, and a confusion matrix was used to estimate accuracy. Firstly, a supervised classification with the maximum likelihood method was used in the land cover classification, and then interactive visual interpretation methods based on the field survey results was implemented to get the most precise land cover data of this study. The likelihood maximum method achieved the best results, with a weighting accuracy of 85%, when a variety of supervised classification methods are compared.

The habitat requirements of the cranes and the actual land cover types of Poyang lake area were used to classify the area as permanent deep-water lake wetlands (including deep-water lakes, rivers, canals, ponds), seasonal shallow lake wetlands, seasonal mudflats, meadow wetlands, settlements (including woodlands), farmlands (including rain-fed lands and paddy fields) and roads. Vegetation types were classified as submerged plant formations, emerged plant formations, sedge plant formations, weed formations and woodlands (Sun and Huang 2010).

These interpretations and definitions were saved in TIFF formats with 30 m grid size in ArcGIS 10.0. Thus the maps of landscape types and maps of vegetation types were produced. Raster calculator of GIS spatial analysis tools were used to analyze the two types of images by overlaying them at each water level. The same method was then used to add the disturbance factors to the potential suitable habitat maps. This allowed us to depict currently available Siberian crane habitat.

Habitat suitability assessment

Assessment of the suitability of wintering Siberian crane habitat in Poyang lake area included analysis of the habitat requirements of wintering Siberian cranes by reviewing large amounts of literatures, establishment of evaluation criteria for each factor and collection of data that were based on these evaluation criteria, prediction of the distribution of potential habitat for wintering Siberian cranes and, assessment of the use of currently suitable Siberian crane habitat in combination with human disturbance factors (Ouyang *et al.* 2001). Finally, we use the distribution sites of Siberian cranes in 2010–2014 to testify the assessment result (Fig. 1).

Factor selection and evaluation criteria

The factors that affected the quality of wintering Siberian crane habitat were categorized as habitat factors, food factors and human disturbance factors (Table 2 and Table 3). Each factor was graded on a scale of 0 to 3, which represents unsuitable, poor, fair, and good, respectively, on the basis of the habitat requirements and food preferences of Siberian cranes.

(1) Habitat factors. Shallow lakes that have water that is less than 30 cm deep are the favored foraging habitat of Siberian cranes and are also the most important habitat variable for the Siberian crane population. The cranes also forage on mudflats and in wetland meadows

Table 2. Criteria for suitability assessments that are based on food and habitat factors.

Factors	Good (3)	Fair (2)	Poor (1)	Unsuitable (0)
Food factors	Submerged plant formations	Sedge plant formations	Emerged plant formations	Weed plant formation and woodlands
Habitat factors	Lake area (distance from lake edge is <500 m)	Lake area (distance from lake edge is 500–1000 m) and seasonal mudflats	Lake area (distance from lake edge is 1000–1500 m) and meadow wetland	Lake area (distance from lake edge is >1500 m) and permanent deep-water lakes

Table 3. Average numbers and occurrence rate of each disturbance factors in areas with different levels of protection. n – number of observation sites. The number inside round parentheses after factor means the weight of each factor.

Variable	Factor	National reserve (n=14)	Provincial reserve (n=9)	County reserve (n=5)	Unprotected area (n=7)
Average numbers	Fishing boat (or yacht) (0.20)	0.26	0.56	1.67	1.14
	Vehicle(0.15)	8.60	6.22	10.00	5.71
	People(0.15)	6.5	6.22	15.67	18.81
	Cattle(0.10)	14.90	19.00	10.33	16.81
Occurrence rate	Fishing net(0.20)	0.45	0.74	0.67	0.71
	Construction(0.20)	0.36	0.52	0.53	0.76
Synthesis score		3.97	4.13	5.46	5.88

(Sauey 1985, Meine and Archibald 1996, Burnham 2007. Barzen *et al.* 2009, Sun and Huang 2010). When water levels fluctuate abnormally, as they did in 2011, the extreme summer water level caused the yield of *Vallisneria* to be insufficient for the cranes. Many of the Siberian cranes foraged instead on *Potentilla limprichtii* and *Amana edulis* tubers that occurred in grass islands (Barzen *et al.* 2011, Li *et al.* 2012, Jia *et al.* 2013).

According to our observation and interview, the Siberian cranes' foraging sites are distributed primarily in an area that is within approximately 500 m from the edge of lake (Meine and Archibald 1996, Burnham 2007, Barzen *et al.* 2009). Since the bottom of Poyang lake area is relatively flat, thus we hypothesized that the available region where the water depth is less than 30cm is within the 500 m from the edge of lake. This "edge" means current water surface edge. However, slight fluctuations in the water surface due to wind action, or small differences in bottom topography may increase or decrease the area that is suitable for foraging. Therefore, shallow waters within 500 m of the edge of the lake were defined as good habitats, areas that were 500–1000 m from the edge of the lake were defined as fair habitats, areas that were 1000–1500 m from the edge of the lake were defined as poor habitats, and areas that were more than 1500 m from the edge of the lake were defined as unsuitable habitats (Table 2). We made these assumptions to define suitable water depth because there were no good-quality lakebed topographic maps of Poyang lake area. However, there are many small lakes, whose maximum diameter is less than 3000 m, in Poyang lake area. The water levels of these small lakes are affected by many different factors, and the lakes may be too small to contain all of the habitat grades that are based on the lake-edge distance measures that are defined above, i.e., they may be too small to have any poor or unsuitable habitats. Therefore, to avoid biasing the analysis, these small lakes were not considered separately. If the diameter was less than 1000 m, the whole lake was good suitable habitat. If the diameter was more than 1000 m, they would be calculated by GIS using a same set of rules and procedures as big lakes. The order of calculation was good habitat (within 500 m), fair habitat (500–1000 m), poor habitat (1000–1500 m) and in the end unsuitable habitat (>1500 m).

(2) Food factors. *Vallisneria* is the preferred food of Siberian cranes. However, when *Vallisneria* is extremely scarce, the cranes also consume *Potentilla limprichtii* and *Amana edulis*, which grow in sedge plant formations (Jia *et al.* 2013). In the early stages of the wintering period, the water level is high and the cranes feed primarily on tender sedge formation roots. In the middle stages of the wintering period, water level decreases and the cranes forage primarily in areas with emergent plants and also begin to use feeding grounds that have small amounts of submerged plant formations. Finally, in the late stages of the wintering period, areas with submerged plants become the main feeding areas for the cranes because they have large amounts of these preferred foods (e.g., *Vallisneria* spp.) (Sun and Huang 2010).

(3) Human disturbance factors. The total amount and number of occurrence of humans, vehicles, cattle, fishing boats, fishing nets, construction activities at each sampling site were used as evaluation factors for determining the degree of protection status or degree of disturbance of the area (Table 3). Since during our 30 min observation every time, the "fishing net" and "construction" are rather immobile and it's hard to describe them in number. Therefore, we took different scoring criteria for different factors. For the disturbance factors, vehicle, people, cattle and fishing boat (or yacht), we can record the numbers of these factors, and we used the average number (number of observe sites divided by the total number of the factor recorded) to value the disturbance level of the four types of areas with different protective levels. For the disturbance factors, construction and fishing net, we cannot record their numbers, and we used the occurrence rate (number of observe sites divided by the occurrence number of the factor in these sites, if seven of the 14 sites had the fishing net, then the occurrence rate was 7/14=0.5) to value the disturbance level of the four types of areas with different protective levels.

Then we artificially divided Poyang lake area into 4 parts according its degree of protection: national nature reserves, provincial nature reserves, county nature reserves and nonprotected areas. Our survey was carried out in above four parts. The number of sampling sites in each part was determined by the relative area ratio between each other. We surveyed 35 sites in total and each given site was surveyed 3 times in different period to ensure that every site could be surveyed in the morning, noon, and afternoon. And each time lasted 30 minutes. The observation was conducted from 8:00 am to 5:00 pm both on workday and weekend. Observation sites were selected beside shallow lakes where Siberian crane has been observed before. These shallow lakes are lakes only appeared in the dry season, which is shaped along with Poyang lake splitting into some small lakes when water level dropped. The site is a circle with 1 km fixed radius, and the circle is just at the place where cranes stayed according to the field survey. The distance between two adjacent sampling sites was at least 2 km.

Different weights were put to the different disturbance factors according to the experts. Then the final score of factors came out. Higher scores indicate the greater degree of disturbance to cranes. The result of disturbance survey indicated that the national nature reserve showed the least human disturbance impacts. The county nature reserve and unprotected area showed a similar degree of influence which was strongest. The impact of provincial nature reserve was relatively moderate. According to the disturbance degree, we assigned value "3" to the least human disturbance part, "2" to the provincial nature reserve and "1" to the county nature reserve and nonprotected area. Then the layer of different types of disturbance area was prepared in GIS. When assessing the currently available habitat, we overlaid the disturbance layer and the potential suitable habitat. Raster calculator was used to generate the currently available habitat.

(4) <u>Survey data of Siberian cranes</u>. From 2010 to 2014, we carried out the field survey of Siberian cranes distribution in the winter season (October to next March). The investigation was carried out on the high visibility days. If encountered the bad weather, it would be postponed until the weather change good. On the investigation day, synchronization investigations were performed in different locations at the same time. GPS, Long lens, single-tube telescope and binoculars were used to observe the cranes. We recorded the time, location and population numbers of the cranes.

RESULTS

Distribution and areas of potential suitable habitats

At a water level of 7.93 m, good potential Siberian crane habitats were widely distributed in the two national nature reserves and the main body of Poyang lake area and in the provincial nature reserves in Duchang and the county nature reserves in Baishazhou. Unsuitable habitats were scattered in farmlands, villages, roads and the deep areas of the lake. We can see that most area cranes using were within this suitable habitat and this area is larger than the zone that the cranes are using according to the distribution data of cranes (Fig. 1). At a water level of 9.00 m, the water in the Baishazhou and Duchang nature reserves becomes too deep for foraging, and these areas therefore become unsuitable. When the water level is between 10.02 m and 11.07 m, good habitat was concentrated in the two national nature reserves. Finally, when the water level reached 12.16 m, both good and fair habitats were greatly reduced and were distributed in only a few small areas along the shores of such lakes as Bang Lake, Sha Lake, Dahu Lake, Xi Lake and Chengjia Lake (Fig. 2).

As water level increases from 7.93 m to 12.16 m, the area of unsuitable habitats increases and the area of good and fair habitats gradually decrease. The areas of poor habitats change the least within this range of water levels. At a level of 7.93 m, the area of unsuitable habitats was 86,175 ha, which was smallest among the unsuitable areas at different water levels. The areas of fair and poor habitats at this water level were 86,554 ha and 112,548 ha, respectively, which were the largest of the four grades. At a water level of 12.16 m, the area of good, fair, and poor habitat suitability decreased significantly and the area of unsuitable habitat increased to its maximum. At this water level, there were only 3005 ha of good potential habitat (Fig. 3).

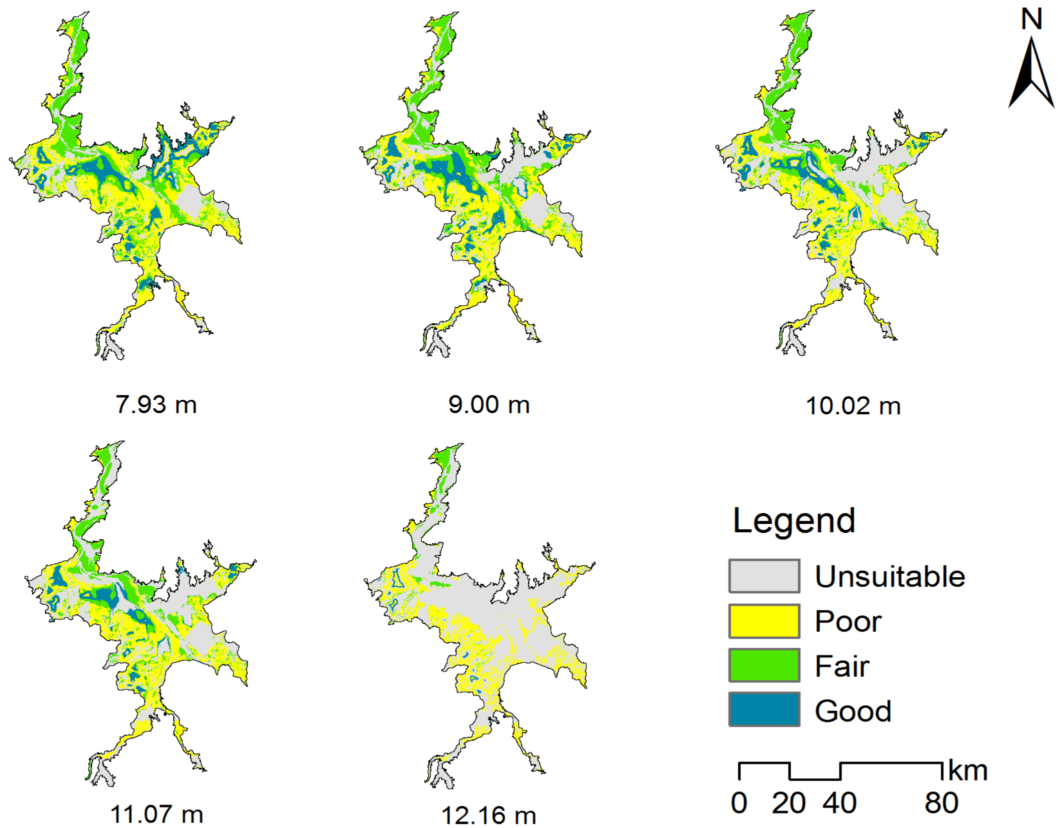

Fig. 2. Distribution of potential suitable habitat for wintering Siberian cranes in Poyang lake area at different water levels.

Status of the currently available habitats

Because of the impact of human activities, the area of the currently available Siberian crane habitat was actually smaller than the total area of potential suitable habitat and was concentrated in the two national nature reserves (Fig. 4). At a water level of 7.93 m, the habitats that are currently graded as good were distributed primarily in the two national nature reserves, and habitats that are graded as fair are located in the provincial nature reserve in Duchang and the county nature reserve in Baishazhou. This currently suitable habitat is consistent with the distribution of cranes. As water level gradually increases, the good and fair habitats are gradually transformed into poor habitats (Fig. 4). At a water level of 7.93 m, the potential habitat area was 39,272 ha, which is 12.10% of the total area of Poyang Lake. However, the currently available habitat area is reduced because of human activities. Approximately 9435 ha of the area of potential habitat are not suitable for survival at a level of 7.93 m. At 12.16 m, the currently available habitat area was 2971 ha, which is only 0.92% of the total area of Poyang Lake (Table 4).

DISCUSSION

Factor selection

Hydrological characteristics have been recognized as main driving forces in wetland. Because the normal growth of vegetation is the key factor to keep the wetland function well, several studies about how the water level fluctuation impacts the vegetation were conducted in recent years (Hudon 1997, Van Geest *et al.* 2005, Sah *et al.* 2014). Water level in winter was treated in this study as the only environmental factor that affects Siberian cranes. This is considered by food accessibility of the Siberian crane due to the winter water level directly depend the water depth which in turn impact the forage behaviour due to its distinct morphology. However, the summer water level is quite vital to the habitat of the crane as well for its important effects on the biomass of vegetation, especially the aquatic species *Vallisneria* spp. The long-lasting high water level in summer might reduce the yield of the tuber of *Vallisneria* spp. since the period from March to April is the tuber producing stage of the species (Jia *et al.* 2013). Our study is conducted under the assumption that under the normal circumstances and what we concern more is whether the water depth can meet the demands of the cranes since its distinct morphology. Actually, during the wintering season (November to the following March), variations in other environmental factors, such as temperature, precipitation and available food resources, should also be considered and discussed. Nevertheless, water level is one of the most important factors (Burnham 2007, Barzen *et al.* 2009), and it influences the distribution and structure of vegetation communities, which in turn may influence the feeding locations of birds (Zhang *et al.* 2012). As well known, the earlier fall of water level in Poyang lake area in winter season was becoming an increasingly major concern in recent years, which was attributed to the Three Gorges Project (Guo *et al.* 2012). However, according to Hu *et al.* (2014), a high water level have a more negative impact than low water level in dry season and if water level in the shallow lakes can be managed scientifically, wintering migratory birds will not have significant adverse impact, when dry season water level of Poyang lake area is low.

Because human activity plays an increasingly important role in the survival of wildlife, consideration of human disturbance in habitat assessment studies is essential (Wang *et al.* 2012). Many studies have used distance from villages, presence of farmland and presence of roads as disturbance factors. However, our observations suggest that these factors do not actually harm or seriously disturb Siberian cranes because the cranes are usually found in lakes that are surrounded by extensive areas of marshland, which act as barriers to the presence of most people (except fishermen). We therefore chose three different types of factors as interference factors. The first category included vehicles, people and cattle, and reflected the overall level of interference. The second category included construction, which might reflect the management and attention of the regional government. The third category included fishing boats and pleasure boats and fishing nets, and reflects the impact of fishing activities on Siberian cranes.

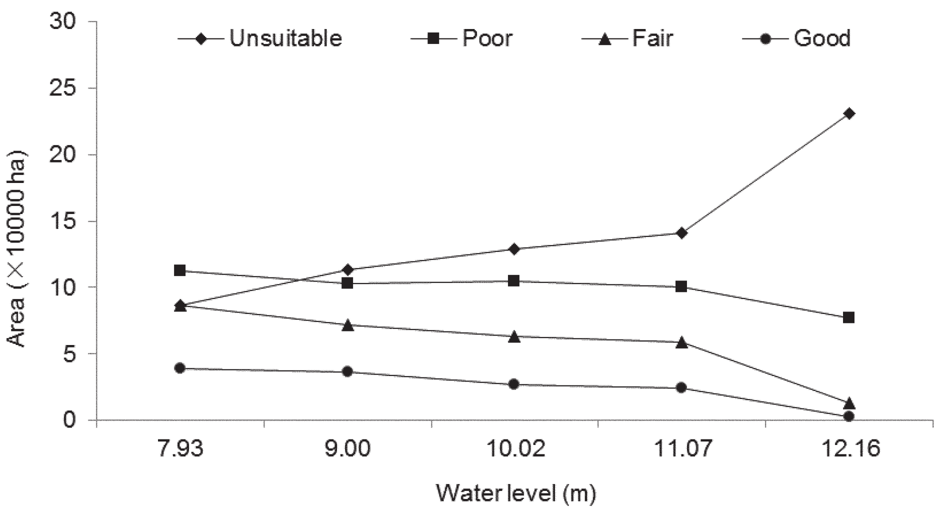

Fig. 3. Areas of potential suitable habitat for wintering Siberian cranes in Poyang lake area at different water levels.

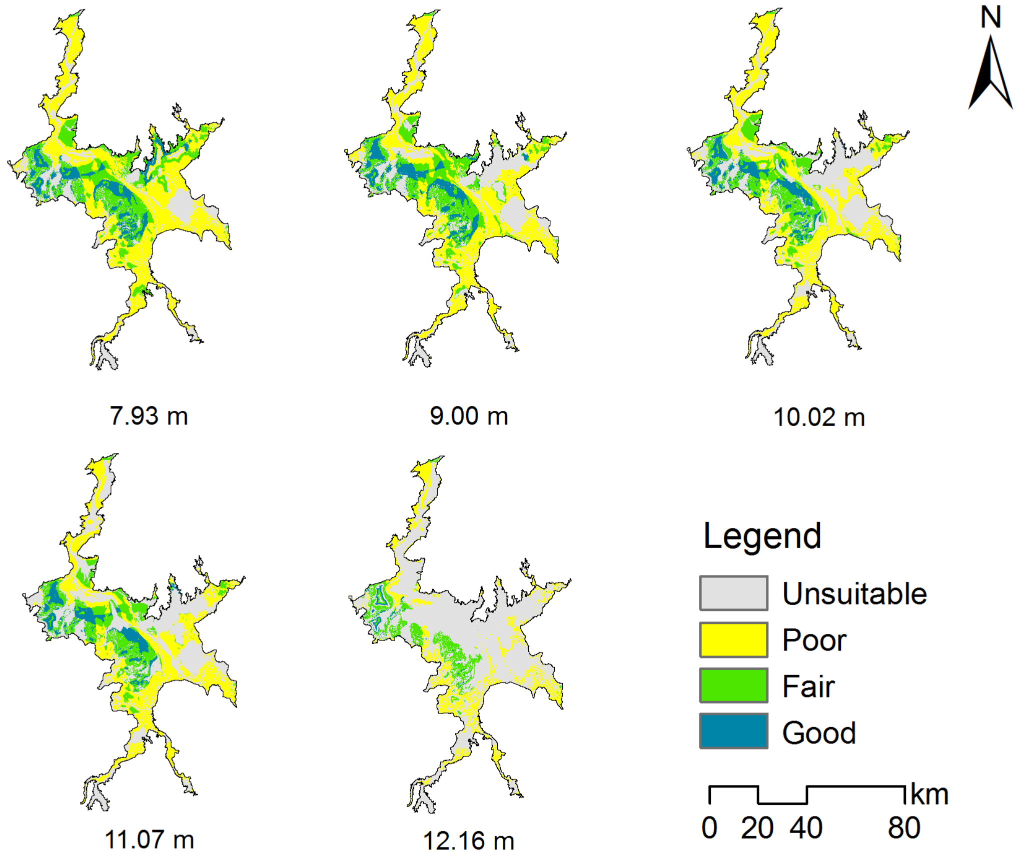

Fig. 4. Distribution of the currently available habitat for wintering Siberian cranes in Poyang lake area at different water levels.

Assessing potential suitable and currently available Siberian crane habitats

Recent studies of Siberian crane habitat have focused primarily on stopover sites and wintering habitats, and these studies were conducted at only one or a few lakes (Li *et al.* 2012, Hu 2012, Shan *et al.* 2012, Kong *et al.* 2013, Wu *et al.* 2013). However, Poyang lake area has many small lakes and Siberian crane foraging sites. Studies that are based on only a single lake or a few lakes could not adequately predict or analyze Siberian cranes habitats in the entire Poyang lake area. Based on a literature review and a field survey of factors that affect wintering Siberian cranes in Poyang lake area, our study quantitatively predicted and analyzed the potential habitats of wintering Siberian cranes in response to different water levels in the area. We also analyzed current use of the habitats.

The water depths used in this study were not based on current water depth measurements because of the poor quality and low resolution of the existing topographic map of the Poyang lake bottom and of existing Digital Elevation Model (DEM) data. The remote-sensing technology-based method of determining water depths by means of interpreting spectral characteristics is used mostly in deep-water research because interpretation accuracy is poor for water that is shallower than 30 cm (Wang and Xiong 2008, Qi *et al.* 2010). We therefore developed and adopted manually set standards for expressing water depth that were based on the flat terrain of the Poyang lake bottom, observations of Siberian crane behavior during the field survey process of cranes population.

In our study, the habitat of Siberian cranes at different water levels were depicted by means of remote sensing images that corresponded to different water levels during the

Table 4. Extent of the potential suitable and currently available habitats for Siberian cranes at different water levels and different degrees of human disturbance. Area indicates the area of good habitat. Ratio is the proportion of good habitat relative to the total area of the Poyang lake area. Unused Habitat indicates the difference between the potential suitable and currently available habitat areas.

Water level (m)	Potential suitable habitat		Currently available habitat		Unused habitat
	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)	Area (ha)
7.93	39,272	12.1	29,837	9.2	9435
9.00	36,247	11.2	27,286	8.4	8961
10.02	27,307	8.4	24,240	7.5	3066
11.07	23,957	7.4	22,575	7.0	1383
12.16	3005	0.9	2971	0.9	34

same season in different years. Although the accuracy of the remote-sensing method has been to some degree limited because of the unavoidable residual in the process of interpretation, the error effect that is caused by remote sensing is small in this paper. The accuracy of the weighting precision of the remote-sensing interpretation was found to exceed 85% when it was validated by the field survey data from 96 sample sites. Since we use the estimation algorithm to calculate water depth and Poyang Lake bottom can't be absolutely flat, there must be some discrepancies between deep and shallow water. However, as can be seen from the cranes' distribution sites, the assessment and prediction was close to the reality. And because sedge and emerged plant formations usually grow together within the same communities, small discrepancies exist as well. Fortunately, these two types of plants are not the main food of Siberian cranes except in extreme weather, the discrepancies did not affect the outcome of suitable habitat. The distribution of submerged plants was interpreted by the maps of a 2009 field survey of the distribution of vegetation for the reason that the submerged plants are invisible on the winter images. And the maps were provided by Jiangxi Poyang Lake National Nature Reserve.

Implications for Siberian crane habitat conservation and management

An ecosystem approach of water level management of Poyang Lake is needed to maintain the water level fluctuation at the right moment should be used to protect the suitable habitat of wintering cranes in Poyang lake area, especially for the flood and drought years. This is very meaningful and helpful to the conservation of birds in Poyang lake area. A study by Wang *et al.* (2013) put an emphasis on the impact after the building of Three Gorges Dam, and they suggested the optimal water level for all kinds of waterbirds. Our study is aimed at the globally critically endangered species, the Siberian crane, and we predicted and simulated the potential available habitat of the species so as to provide an important advice to administrative department. Also, Siberian cranes prefer to overwinter in the two national nature reserves in Poyang lake area, and there is relatively less human disturbance within these reserves than areas that are outside of the national reserves (Shan *et al.* 2012). We suggest that the Duchang provincial reserve, which has suitable potential natural habitat, but only a few Siberian cranes visit should be upgraded to a national nature reserve. A nature reserve should be established in the main lake area, in which much potential habitat is nonprotected.

CONCLUSIONS

The distribution of potential overwintering Siberian crane habitats in Poyang lake area at different water levels was predicted and assessed in our study using field survey, GIS and remote-sensing data. The study found that at water levels ranging from 7.93 m to 12.16 m, the potential and available overwintering Siberian cranes' habitats in Poyang lake area tended to decrease as the water level increased. The Poyang Lake and Nanjishan national nature reserves provided the majority of habitats current used by the Siberian cranes. At 7.93 m, the Siberian cranes were widely distributed in habitats within the national nature reserves, provincial nature reserves and county nature reserves. When human factors were considered, the good habitats in the county and provincial nature reserves and nonprotected areas became fair or poor grade, and fair habitats became poor grade habitats. And the suitable habitat and the location of cranes showed the similar distribution pattern.

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